

**Faculty of Science and Engineering
Centre for Marine Science and Technology**

**Southern Right Whale (*Eubalaena australis*) Population
Demographics in Southern Australia**

Claire Marie Charlton

**This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University**

September 2017

Declaration of authorship

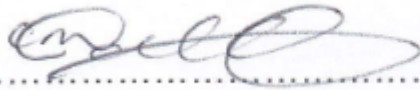
I, **Claire Charlton**, declare that to the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Animal Ethics:

The research presented and reported in this thesis was conducted in compliance with the National Health and Medical Research Council Australian code for the care and use of animals for scientific purposes 8th edition (2013). The proposed research study received animal ethics approval from the Curtin University Animal Ethics Committee for observational and passive research, Approval Number #. AEC_2013_27 and 28.

Signature:

A handwritten signature in blue ink, appearing to read 'C. Charlton', is written over a dotted line.

Date: 7 September 2017

Dedication

This thesis is dedicated to

the Yalata Anangu and Mirning people who share their land with us and Dr. Steve Burnell for giving me the opportunity to continue and extend the southern right whale research he started at Head of Bight in 1991.

Abstract

Southern right whales (SRWs) *Eubalaena australis*, are listed as Least Concern under the International Union for Conservation of Nature (IUCN) Red List and in Australia they are listed as endangered under the Commonwealth Environment Protection Biodiversity and Conservation (EPBC) Act 1999. SRWs were reduced to near extinction globally from commercial whaling in the 19th century. Signs of the return of SRWs to Southern Hemisphere winter calving grounds were recorded in the late 1960's, but Soviet Pelagic Southern Hemisphere catches at that time slowed their recovery for several years. SRWs have a circumpolar distribution between 16° and 65° S. Four genetically distinct populations occupy the southern coastlines of Argentina, South Africa, Australia and New Zealand during the Austral winter where they calve, mate and rest. SRW numbers are increasing in Australia. However current abundance of the Australian population is approximately 2,500 and they are divided into two sub-populations (the 'western' with ~2,200 whales and the 'eastern' with ~ 300 individuals). The two sub-populations are estimated to be less than 20% of their pre-whaling abundance of approximately 15,000.

The long-term recovery objective in the Commonwealth SRW Conservation Management Plan is to minimise anthropogenic threats to allow the conservation status of the SRW to improve so that it can be removed from the threatened species list under the EPBC Act. A key interim recovery objective is to demonstrate that the number of SRWs occurring off south-west Australia is increasing at or near the maximum biological rate. To fulfil these national research priorities, long-term research in the order of decades is required to assess the species' population biology and demographics. Population demographics including long-term trends in abundance, rate of increase, distribution, life history parameters and movements provide critical information for population recovery assessment and monitoring of changes to a population over time.

There are 13 known aggregations of SRWs in Australia with the Head of the Great Australian Bight (GAB), South Australia (SA) representing the major calving ground for the Australian population. Southern right whales at Head of Bight (HoB) are protected under the Marine Mammal Protection Zone (MMPZ) in the GAB Commonwealth Marine Reserve through seasonal exclusion of all human activities between May 1 and October 31. The GAB is a multi-use area and the management of interactions between threatened EPBC listed species such as the SRW, and human activities requires a baseline understanding of distribution, abundance and movements of the species. Understanding

the timing of arrival and departure of the whales along the Australian coastline and the coastal movements and connectivity between the areas is required for impact assessment and management of SRW population recovery.

The overall objective of this thesis was to assess the population demographics of SRWs at the two calving areas in the GAB, the primary aggregation area at HoB and the smaller established aggregation at Fowlers Bay (FB) (160km southeast of HoB). Specifically, the aims of this thesis were to assess the: inter- and intra-seasonal trends in abundance and distribution; life history parameters including age of sexual maturity and age at first parturition, date of calving; and, residency and site fidelity, for SRWs at HoB. This thesis also aimed to characterise SRW distribution, abundance, and residency of SRWs at FB. The coastal movements and connectivity of SRWs between FB and other calving areas in Australia and New Zealand were assessed.

To achieve the thesis aims, counts and photo identification mark recapture data were used from a combination of long term cliff-based surveys, aerial surveys and vessel surveys. Annual cliff based research was undertaken at HoB during 1991-2016 and provided an unbroken time series dataset on population trends across 26 years. The survey effort each year was variable across the 26-year study and the research was expanded to 3.5 months between 2014 and 2016 for this PhD research. Data from annual aerial surveys undertaken by J. Bannister of the Western Australian Museum (WAM) during 1993-2016 for the 'western' sub-population of SRWs in Australia contributed to results presented. Specifically, SRW count and photo ID data from FB between 1993 and 2016 were contributed, along with sighting histories of whales identified at HoB and FB for assessment of life histories, connectivity and movements. Vessel surveys were completed at FB on board the local tourism operator vessel (Fowlers Bay Whale Eco Tours) between July and September, 2014-2016.

This research improves the understanding of SRW population demographics in Australia. The rates of population increase estimated for HoB of 3.7% per annum (p.a.) for all individuals and 4.6% p.a. for females accompanied by a calf for years 1992-2016 are lower than prior estimates made for HoB (5.3% p.a. and 5.6% p.a., respectively) for the years 1992-2006. Results are also lower than the rate of increase for the overall 'western' sub-population of 5.55% p.a. for total individuals and 6.01% p.a. for females accompanied by a calf (1993-2016), although results are within the confidence intervals and show no significant difference. The growth rate of SRW at HoB relative to the overall western population appears to have declined slowly over time, possibly representing saturation of

the HoB aggregation. Current estimates show that the 'western' sub-population is increasing at or near the maximum biological rate for the species of 6-7% p.a. The estimated apparent mean calving interval was 3.3 years (SD=0.8, \pm 0.3, 95% CI); and mean age at first parturition 9.3 years (n=22, SD=2.1, \pm 0.9, 95% CI). The oldest known female was estimated to be in her mid-50s. Estimated life history parameters are comparable with previous studies on this population (1991-2007), and with research on other SRW populations in the Southern Hemisphere. Consistent with SRWs in other parts of their range in Australia, SRWs at HoB and FB were primarily distributed within 1 km of shore and within the 10 m depth contour between May and October. Inter and intra-seasonal variation in abundance was observed. SRWs generally arrived at HoB in late May and June; abundance peaked in July and August. Results show that a maximum of approximately a quarter of pregnant females that occupied HoB migrated to the study area by mid-June and over half of the breeding females remained at the site at the end of September. By late-October most females with calves had departed their winter ground. Group composition of SRWs at HoB and FB were primarily female and calf pairs, representing 70% of all sightings at HoB and 80% of all sightings at FB. Unaccompanied adults represented 30% of all sightings at HoB and 20% of sightings at FB.

The proportion of SRWs relative to the annual count for the overall 'western' sub-population decreased with time at HoB and increased with time at FB. The relative proportion of the overall 'western' sub-population that visited the Australian coastline each year that HoB represented ranged from a maximum of 48% in 1994 to a minimum of 21% in 2002. Increased immigration and emigration into and out of HoB was observed, but overall the population increased over the study period. Increased movement into and out of HoB in recent years is supported by the increase in new females accompanied by a calf that have not previously been sighted in the area or females with their first calf. Mark recapture resightings decreased from 85% during 1995-1999, to 52% during 2014-2016, with a mean of 70% resightings across all years. Residency periods also decreased over time with female and calf pairs mean residency of 71 days between 1992 and 1994 reducing to 40 days between 2014 and 2016.

These results suggested that the primary area occupied by SRWs at HoB may have reached a saturation capacity and that habitat dispersal can be expected with further population increase. Based on nearest neighbour distances of 150 m (Pirzl, 2008) between individuals or pairs and the area occupied by 95% of SRWs at HoB, the area could reach saturation capacity at 68 female and calf pairs. Maximum abundance ever recorded at HoB is 172 total individuals including 81 female and calf pairs, recorded in

mid-August 2016. Results from helicopter aerial surveys completed in 2013-2014 showed that a maximum of 17% of sightings in the HoB area were recorded outside of the cliff based study area, during mid-July near the seasonal peak in abundance, perhaps indicating animals were beginning to disperse during high density periods.

The occurrence of SRWs monitored at FB since 2004 highlights the significance of the area as a calving and nursing ground. At FB, the rate of increase in abundance between 2004 and 2014 of 38.8% p.a. (SE=29.7), although highly variable, exceeded the maximum plausible rate of increase for the species. Within and between seasonal movements were recorded between FB and eight different locations, most commonly between FB and HoB. No movements were recorded between FB and the south-east of Australia. A single across year movement was recorded between FB and Auckland Islands 3,400 km away. First time breeders to FB and a possible remnant population were represented by 40% of calving females identified at FB. Site fidelity was low at FB for calving females (21%) compared with HoB (70%). Shifts in selected calving habitats were recorded for 45% of calving females, most commonly from HoB to FB. Increased abundance at FB correlated with high abundance of female and calf pairs at HoB and as alluded above likely represents a dispersal from adjacent habitat at HoB that may have reached a saturation capacity. Increased abundance at FB in years of high abundance of SRW in Australia may also be attributed to individuals calving early and selecting the nearest suitable habitat for nursing. Whilst there is movement of individuals recorded between FB and six other areas in south-western Australia and NZ, the increase in abundance in the last decade is predominantly related to emigration from HoB. This study highlights the importance of established and emerging aggregation areas along the Australian coastline as the population continues to grow, and the potential importance of coastal migratory corridors connecting these aggregation areas.

The improved understanding of population demographics provided by this research will inform the assessment of recovery targets and management goals for SRW. Life history parameters and changes to the population over time will be used to inform marine park management, management of activities inside and outside of the marine reserve and future monitoring planning. Recovery planning for the endangered SRW would benefit from an Australia-wide assessment with detailed mark recapture analysis of estimated abundance and connectivity across the SRW range in Australia. As the 'western' sub-population continues to grow in Australia and disperses along the coastline, an increase in interactions between SRWs and human activities can be expected. Conservation and management of potential threats from increased human interactions with whales and

understanding SRW population growth are critical for the recovery and protection of endangered SRW in Australia.

Acknowledgements

Many people and organisations supported the work carried out for this thesis and I sincerely thank all who contributed.

I thank Curtin University, Centre for Marine Science and Technology and my PhD supervisors Robert McCauley and Chandra Salgado Kent for providing support, guidance and review of my Thesis. Thank you to my primary PhD supervisor Rob McCauley for going the extra mile to provide support with field research and analysis, and for providing motivation, support and mentoring. I am thankful to Robert Brownell Jr. from NOAA California for his supervision, reviews, ideas and commitment to helping me to network with the marine mammal scientists around the world. Bob's commitment of travelling to South Australia to visit the field site and dedication to his co-supervision role by meeting me in Japan and California, and providing reviews and input on such a fast turnaround, when also juggling many high priority work tasks, is a tribute to his professionalism and credibility. I am most grateful to Steve Burnell for giving me the opportunity to be involved and run the long-term southern right whale research at Head of Bight (HoB). Steve has provided guidance and contribution of all the data from the long-term research study at HoB. The integrity and longevity of the southern right whale research at HoB is attributed to the people that led the study before me, Steve Burnell who began this study in 1991 and Rebecca Pirzl who led the research for several years. I also owe a great debt of thanks to John Bannister of the Western Australian Museum for his collaboration, support and guidance over the years. It has been a pleasure to work with someone as esteemed and accomplished as John and I have always appreciated his honesty and support. Thanks also to Cath Kemper of the South Australian Museum for her support of the long-term research at HoB since it began and for the mentoring and collaboration provided. Cath leads by example with her passion and dedication to her work and to science more generally.

Research funding was provided by Murphy Energy and Santos Ltd. under a three-year PhD sponsorship with field funds and a PhD scholarship stipend (scholarship top-up). The support of Paul Carroll, Ted Kirkbride (Murphy), Samantha Jarvis and Tom Baddeley (Santos) was crucial to the sponsorship and has allowed a strong link between industry operators and Curtin University. Scholarships for PhD Student Claire Charlton were granted through Commonwealth Australian Postgraduate Award (APA) and Curtin University Postgraduate Scholarship (CUPS). The research was completed under a South

Australia (SA) Department of Environment Water and Natural Resources Scientific Permit to complete research in South Australia (M26508-3, M26508-4 and M26508-5) and animal ethics approval through Curtin University for observational and passive research (AEC_2013_27 and 28).

Research funding and in-kind support was provided from the Australian Antarctic Division, Marine Mammal Centre and the Department of Environment, Water and Natural Resources (DEWNR) in South Australia and the Alinytjara Wilurara Natural Resources Management Board. Many thanks to the Yalata Aboriginal Community and Aboriginal Lands Trust for ongoing support, access to the Yalata Aboriginal Lands and use of the White Wells accommodation facility. Terry and Claire Hardy from the HoB Whale Interpretive Centre provided invaluable support and day to day assistance in the field at HoB - thank you. Our team is grateful to the staff and locals of the Eyre Peninsula and in particular Alessandro Madonna of Yalata Land Management, Robbie Sleep of DEWNR and Dirk Holman- Manager of the Great Australian Bight Commonwealth Marine Reserve, for looking out for us and supporting the research. We are thankful to Rod and Simone Keogh from the Fowlers Bay Eco Whale Tours for their support, generosity and contribution towards the research at Fowlers Bay. Rod and Simone provided the research team with accommodation and vessel use and assisted with equipment and logistics. They included us in their team at the Fowlers Bay Eco Whale Tourism operation and shared their passion and knowledge of the whales in Fowlers Bay. The research at Fowlers Bay could not have gone ahead without their contribution.

The availability of existing southern right whale datasets was fundamental to the research. I am grateful to Steve Burnell and Eubalaena Pty. Ltd. for sharing 26 years of survey and photo-ID data from HoB, and to John Bannister for providing 23 years of count and photo-ID data from annual aerial surveys completed through the Western Australian Museum. Thank you to Pin Needham and Cath Kemper for providing data from HoB during the 1980s and early 1990s. Thank you to Mandy Watson from the Department of Environment in Victoria for contributing images from the south east of Australia around Warrnambool. Thank you to Alice Mackay from SARDI and Dirk Holman from DEWNR for providing aerial survey sighting data from 2014 and 2015 at HoB. Many thanks to Fredrik Christiansen and Fabian Vivier for contributing drone images to the research in 2016 and to Fredrik and Lars Beijder for building a collaboration for UAV work at HoB.

Technical support was provided by Mal Perry from CMST who always went the extra mile to help, was extremely organised and punctual and was a delight to work with. GIS support

was provided by Annie Charlton who helped generate maps and provided advice on figure display. Thank you to Doug Butterworth, Anabela Brandão and Andrea Ross-Gillespie for their collaboration and support with modelling the life history parameters using their very complex models developed specifically for southern right whales.

This project would not have been possible without the dedication and commitment from many volunteers. A special thank you to Sacha Guggenheimer who volunteered on the project in 2013, was a research assistant in 2014 and who was a force of energy, enthusiasm and creativity at exactly the right time. Sacha encouraged me to undertake my PhD and to expand the southern right whale research in the Great Australian Bight. Sacha dedicated many months to providing field and office support. She contributed creativity and established the study's social media profile, logo, branding and website and was responsible for merchandise. Sacha helped raise the public profile of the research and provided a unique perspective and contagious energy to this study. Thank you to Richard Twist for his commitment and passion towards the research during the 2014, 2015 and 2016 field seasons and for all his help and ideas outside of the field, including creating short films on the research. Thank you to Ana Costa for completing a six-week field internship in 2015 and particularly for her help with running the theodolite team and fine scale behaviour team at HoB. Thank you to Alice Morrison for completing a six-week internship in 2016 and for her ongoing support of the research. Sincere thanks to Paul Rogers for his encouragement, field support, friendship and advice over the years, regardless of time and space. Paul told me that to do a PhD you must be extremely passionate about the topic so that during the times when it is most difficult, the passion gets you through. He was right. Countless volunteer hours contributed to the field research for the long-term research at HoB. Other volunteers acknowledged for their support and assistance during this PhD research (2014-2017) include: Stacey Chillcott, Sophie Hicks, Penni Howard, Karyn Ward, Annie Charlton, Hana Cox, Jaimie Mainwaring, Guy McCauley, Hera Segara, Tomoyo Segawa, Steve Hart, Jessica Leask, Luke Clark, Erin Ryan, Stephanie Watts and Sarah Price Twist. Thank you also to Stacey Chillcott and Green Collar Productions for completing a 2-minute film clip of the research. I am grateful to have shared this research and experience with many inspiring and wonderful people.

I would like to sincerely thank my family and friends for their support and encouragement. Thank you to my mum Penni Howard for always encouraging me to follow my dreams, taking me to HoB in 2003 and encouraging me to pursue my passion for working with marine mammals. She also reviewed my thesis in its entirety and assisted with formatting. To my dad, Gerry Charlton thank you for sharing your love for nature and passion for the

environment. A heartfelt thank you to my partner Steve Hart who gave me encouragement, support and patience during the write up phase of my thesis, and who helped in the field in 2015 and 2016 and made every endeavour to assist and support me.

Finally, my most sincere thanks and gratitude to Rhianne Ward who has contributed to the research as her own and has been instrumental, from planning and executing field research to reviewing and contributing to scientific publications and my PhD thesis. Rhianne committed four months a year from 2014 to 2016 to the field research, whilst also completing her own PhD on acoustics, and in 2017 has taken on the project lead role. From the bottom of my heart, thank you Rhianne for your dedication, friendship and intellect.

The last ten years working on the Yalata Aboriginal Lands in the Great Australian Bight has taught me an appreciation for nature, marine life and the remote far west of South Australia, a place that very few people are lucky enough to understand. The raw, isolated Nullarbor Plain and the harsh and dynamic Great Australian Bight is a place like nowhere else. Once that red dirt gets under your skin and the reflection of the Milky Way on twin rocks imprints in your heart, it will hold you captive forever. I am truly grateful and thankful for the opportunity to have contributed to the conservation of southern right whales in the Great Australian Bight and Australia.

Abbreviations

AMMC	Australian Marine Mammal Centre
APPEA	Health Safety and Environment
CAGR	Compound Annual Growth rate
CI	Confidence Interval
CMST	Centre for Marine Science and Technology
DEWNR	Department of Environment, Water and Natural Resources
DSEWPac	Department of Sustainability, Environment, Water, People and Community (now Department of Environment)
EPBC Act 1999	Environment Protection Biodiversity and Conservation Act 1999
FB	Fowlers Bay
GAB	Great Australian Bight
GIS	Geographic Information System
HoB	Head of Bight
HSE	Health, Safety and Environment
ID	Identification
IUCN	International Union for Conservation of Nature
IWC	International whaling Commission
MMPZ	Marine Mammal Protection Zone
nm	Nautical miles
NOAA	National Oceanic and Atmospheric Administration
NZ	New Zealand
p.a.	Per annum
SA	South Australia
SARDI	South Australian Research and Development Institute
SEA	South East Australia
SD	Standard deviation
SRW	Southern right whale
WA	Western Australia
WAM	Western Australian Museum

Publications and Reports

This thesis has produced the following reports and papers prepared for peer-review:

- I. **Charlton C.M.**, S.N. Guggenheimer, S.R. Burnell. May 2014a. Long-term Southern Right Whale Population Monitoring at Head of Bight, South Australia (1991-2013). *Final report to the Department of Environment, Australian Antarctic Division- Australian Marine Mammal Centre.*
- II. **Charlton C.**, S. Guggenheimer., S. Burnell. S., J. Bannister. May 2014b. Southern right whale abundance at Fowler Bay and connectivity to adjacent calving ground, Head of Bight, South Australia. *Final report to Commonwealth Government, Australian Antarctic Division, Australian Marine Mammal Centre.*
- III. **Charlton C.M.** May 2016. 2014 and 2015 Field report for southern right whale population biology research at Fowlers bay and Head of Bight, South Australia. *Report to Curtin University Centre for Marine Science and Technology.*
- IV. Ward, R., **C. Charlton.**, S Guggenheimer. July 2013. Characterising southern right whale acoustics at Fowlers Bay 2013 field report. *Report to Curtin University Centre for Marine Science and Technology*
- V. **Charlton C.**, R. Ward., 2015 Resights of Satellite Tagged Southern Right Whales at Head of Bight using Photo Identification. *Report to Curtin University Centre for Marine Science and Technology.*
- VI. **Charlton C.M.**, R.McCauley., R. Ward, R.L. Brownell., S. Burnell. 2017. Southern right whale life histories at Head of Bight, South Australia. *Journal of Cetacean Management (In prep).*
- VII. **Charlton C.M.**, R.McCauley., R. Ward, C.Salgado Kent., R.L. Brownell., S. Burnell. 2017. Southern right whale distribution and abundance at major aggregation ground at Head of Bight in the Commonwealth Great Australian Bight Marine Reserve. *Marine Mammal Science (In prep)*
- VIII. **Charlton C.M.**, R.McCauley., R. Ward, R.L. Brownell., J. Bannister. 2017. Southern right whales return to historical aggregation area at Fowlers Bay, South Australia. *Marine Mammal Science; Journal of Cetacean Management (in prep)*

Conferences and seminars

Conferences: Information compiled from this research has been presented at the following conferences and seminars.

- I. 2014, December. *International Society for Marine Mammal Biennial Conference*, Otago, New Zealand. **C Charlton**: “Right whale” workshop.
- II. 2014, September. *Australian Petroleum Production and Exploration Association (APPEA) Health Safety and Environment (HSE)*, Perth, **C Charlton**: “Great Australian Bight Right Whale Study: How baseline studies promote sustainable operations in oil and gas”.
- III. 2014, November. *International Marine Mammal Protected Areas Conference*, Adelaide: **C Charlton**: “Citizen Science southern right whale research in the Great Australian Bight”.
- IV. 2015, April 28. *Santos Energy sustainability seminar*, Santos office, Esplanade, Perth, Western Australia **C Charlton** – Long term southern right whale research in the Great Australian Bight, South Australia
- V. 2016, May. Murphy Oil Seminar. Murphy office, St Georges Terrace, Perth. Presentation to sponsors and broader group interested in the Great Australian Bight. **C. Charlton**: “Southern right whale research in the Great Australian Bight 1991-2016”.
- VI. 2017, March 28. Commonwealth Government Southern right whale workshop, Melbourne. **C. Charlton**: “Long term monitoring of southern right whales at Head of Bight, SA lessons learned for monitoring and key results”.
- VII. 2017, July *International Mammalogy Congress*, Perth, Western Australia. **C Charlton** Presentation on southern right whale population demographics in South Australia.
- VIII. 2017, October. *International Society for Marine Mammal Biennial Conference*, Halifax, Canada. **C Charlton**: Conference oral presentation accepted: “Southern right whale population demographics in South Australia, 1991-2017” pending

Media and Communication

The following media articles and communication tools were produced from the research completed during this PhD program:

- Project website: established June 2014. <https://www.gabrightwhales.com>
- Project Facebook: established July 2014. Great Australian Bight Right Whale Study <https://www.facebook.com/GABRWS/>
- Project Instagram: established July 2014. @southernrightwhales <https://www.instagram.com/southernrightwhales/>
- Project video: By Richard Twist. September 2014 https://www.facebook.com/GABRWS/videos/336151729883922/?autoplay_reason=gatekeeper&video_container_type=0&app_id=2392950137
- Project logo: designed and created by Tom Hulse and Sacha Guggenheimer, May, 2014
- Papersea Quarterly Magazine: The return of the Nullarbor Giants. 4 December, 2014. <http://www.papersea.com.au>
- Tidal Magazine, Learning their language. November 2014. <http://www.tidalmagazine.org/#!/LEARNING-THEIR-LANGUAGE/came/56ca5ca80cf2c75daa89a50a>
- Green Collar Productions, Great Australian Bight Right Whale Study. 30 March 2015. <https://vimeo.com/123696459>
- The Times, Returned visitors: photos. 03 September 2015. <http://www.victorharbortimes.com.au/story/3324791/returned-visitors-photos/>
- ABC News, Drop in number of southern right whales spotted in Great Australian Bight surprises scientists. 22 August 2015. <http://www.abc.net.au/news/2015-08-22/drop-in-southern-right-whale-numbers-surprises-scientists/6716866?section=sa>
- Sunday Mail (SA), Southern right whales head to Great Australian Bight. 10 July 2016. <http://www.news.com.au/technology/science/animals/southern-right-whales-head-to-great-australian-bight/news-story/8f06dd7eb6ce1e07869bb4a78b95aac7>

- West Coast Sentinel, Record numbers at the Bight. 16 August 2016.
<http://www.westcoastsentinel.com.au/story/4101405/record-numbers-at-the-bight/>
- ABC News, Whales on increase in Great Australian Bight as BP oil drilling looms. 23 August 2016. <http://www.abc.net.au/news/2016-08-23/whales-on-increase-in-the-bight-as-oil-drilling-looms/7776474?section=business>
- ABC News West Coast SA, Record-high number of southern right whales spotted in Great Australian Bight encouraging. 23 August 2016.
<http://www.abc.net.au/news/2016-08-23/record-high-number-of-southern-right-whales-spotted/7776916>
- Crinkling News, Whale of a time: 45 baby whales and two albinos. September, 2016. <http://www.crinklingnews.com.au/2016-07/whale-time-45-baby-whales-two-albinos/>
- The Australian, Southern right whales are all right - back from the brink. 15 July, 2017. <http://www.theaustralian.com.au/news/health-science/southern-right-whales-are-all-right-back-from-brink/news-story/52f74b701868a0ae5f9f2dab5f836835>



Statement of candidate contributions

This thesis is presented as a series of five manuscripts in journal format, in addition to a general introduction and general discussion.

These papers were primarily developed from my own ideas and approaches, with the support and guidance from my supervisors and collaborators.

Dr Robert McCauley supported with writing of code in MATLAB toolbox for processing data and development of figures. Rob assisted in the field with calibrating elevation platform heights using a theodolite. Dr Stephen Burnell and colleagues collected 17 years of data at Head of Bight between 1991 and 2007, before I started working on the project in 2008. I participated in data collection in 2008 and have led the field program at Head of Bight since 2009. Based on historical methods used for the long-term study, I designed and executed the extended survey period at Head of Bight between June and September from 2014 to 2016. John Bannister of the Western Australian Museum provided aerial survey data from surveys undertaken between 1993 and 2016 of the 'western' sub-population of SRW.

I set up relationships and undertook research at Fowlers Bay with the Fowlers Bay Whale Eco Tours, assisted by Rod and Simone Keogh. Sacha Guggenheimer and Rhianne Ward completed vessel based surveys at Fowlers Bay during intensive periods while I ran the research program at Head of Bight in 2014, 2015 and 2016. Other contributors to fieldwork and logistics are included in the acknowledgements. Dr Robert Brownell provided expertise in great whales, guidance and reviews of all papers. Dr Chandra Salgado Kent assisted with analysis completed in R Statistical package and she reviewed the thesis.

I wrote all chapters with feedback from supervisors and collaborators.

Claire Charlton

(PhD Candidate)

 07/09/2017.

Dr Robert McCauley

(Primary Supervisor)

 7-Sep-2017.

Contents

1	Introduction	9
1.1	Objectives	15
1.2	Layout of thesis	16
2	Seasonal trends in the distribution and abundance of Southern right whales (<i>Eubalaena australis</i>) at the Head of the Great Australian Bight Commonwealth Marine Reserve, South Australia	17
2.1	Abstract	17
2.2	Introduction	18
2.3	Methods	20
2.3.1	Study area	20
2.3.2	Data collection	21
2.3.3	Analysis	24
2.4	Results	26
2.4.1	Study period	26
2.4.2	Visual detection range	27
2.4.3	Distribution	29
2.4.4	Abundance	33
2.4.5	Peak abundance period	34
2.5	Discussion	35
3	Long term trends in abundance and life history parameters of Southern right whales (<i>Eubalaena australis</i>) at Head of Bight, South Australia (1991-2016).....	39
3.1	Abstract	39
3.2	Introduction	40
3.3	Methods	42
3.3.1	Study area	42
3.3.2	Study period	42
3.3.3	Counts	43
3.3.4	Photo identification	44
3.3.5	Data Analysis	45
3.3.6	Life histories	45
3.3.7	Longevity	47
3.4	Results	47
3.4.1	Trends in long-term abundance	47
3.4.2	Proportion of SRW at Head of Bight relative to the 'western' population	52
3.4.3	Life history parameters	53
3.4.4	New calving females not previously sighted at Head of Bight	54
3.4.5	Apparent mean calving interval	54
3.4.6	Shifts in calving intervals	57
3.4.7	Age at first parturition	57
3.4.8	Longevity	58
3.5	Discussion	58
3.5.1	Long term trends in abundance	59
3.5.2	New calving females not previously sighted at HoB	60
3.5.3	Mean observed calving interval	61

	3.5.4	Age at first parturition.....	62
	3.5.5	Longevity	63
	3.5.6	Conclusion.....	63
4		Residency site fidelity and date of calving of Southern right whales (<i>Eubalaena australis</i>) at the Head of the Great Australian Bight, South Australia 1991-2016	65
	4.1	Abstract	65
	4.2	Introduction.....	66
	4.3	Methods	68
	4.3.1	Study site.....	68
	4.3.2	Data collection	69
	4.3.3	Data Analysis	70
	4.4	Results	72
	4.4.1	Residency.....	72
	4.4.2	Site fidelity	75
	4.4.3	Natal site fidelity	76
	4.4.4	Date of calving.....	77
	4.5	Discussion	79
	4.5.1	Residency.....	79
	4.5.2	Site fidelity	81
	4.5.3	Natal site fidelity	82
	4.5.4	Mean date of calving	83
5		Southern right whales (<i>Eubalaena australis</i>) return to a former wintering ground: Fowlers Bay, South Australia.....	85
	5.1	Abstract	85
	5.2	Introduction.....	86
	5.3	Methods	88
	5.3.1	Study Site	88
	5.3.2	Data collection	90
	5.3.3	Data analysis.....	93
	5.4	Results	95
	5.4.1	Long-term trend in abundance between 1993-2016 (WAM aerial counts).....	95
	5.4.2	Seasonal trends in abundance between 2014-2016 (Vessel surveys).....	97
	5.4.3	Residency.....	101
	5.4.4	Distribution	103
	5.5	Discussion	108
	5.5.1	Conclusion.....	112
6		Connectivity and movement of Southern right whales (<i>Eubalaena australis</i>) between Fowlers Bay, South Australia and other aggregation areas in Australia And New Zealand.....	113
	6.1	Abstract	113
	6.2	Introduction.....	114
	6.3	Methods	116
	6.3.1	Study site.....	116
	6.3.2	Data collection	117
	6.3.3	Cross matching exercise	119

6.3.4	Data Analysis	120
6.4	Results	121
6.4.1	Origin of calving females sighted at FB.....	123
6.4.2	Site fidelity and shifts in calving habitat of calving females .	124
6.4.3	Within and across season coastal movements of SRWs between FB and other aggregation areas.....	126
6.5	Discussion.....	129
6.5.1	Conclusion	132
7	General discussion	133
7.1.1	Conclusion	140

Table of Figures

Figure 1-1: Southern right whale distribution range in Australia. Source: DSEWPaC, 2012	12
Figure 1-2: Regional map of the Great Australian Bight, including southern right whale aggregation areas and study sites at Head of Bight and Fowlers Bay, South Australia, marine park boundaries and oil and gas permit lease areas in South Australia.....	14
Figure 2-1: Study area and Southern right whales shore-based observation stations southern right whales at Head of Bight in the eastern Great Australian Bight, South Australia. Observations sites on the cliffs are labelled west to east.....	21
Figure 2-2: Distributions of Southern right whale distance from 0 bathymetry contour (left) and depth (right), for sightings at Head of Bight recorded between June and September, 2014-2016.	28
Figure 2-3: Detection range with distance from observation station 16 to the south-east of the study site.....	28
Figure 2-4: All sightings of Southern right whales recorded within the Head of Bight study site in the Great Australian Bight, South Australia between 19 June and 28 September 2014 (A), between 18 June and 25 September 2015 (B) and between 16 June and 25 September 2016 (C), showing females accompanied by a calf in open circle, unaccompanied adults as X.	30
Figure 2-5: Kernel density plot of SRWs female and calf pairs (top) and unaccompanied adults (bottom) at Head of Bight study site, South Australia between June-September using pooled data collected between 2014 and 2016.....	31
Figure 2-6: Within season distribution of Southern right whales at the Head of Bight, South Australia using pooled data 2014-2016: A) June; B) July; C) August; D) September	32
Figure 2-7: Mean percentage of female and calf pairs observed at Head of Bight between June and October 1992-2016.....	33
Figure 2-8: Abundance of (a) the total southern right whales and (b) females accompanied by a calf sighted at the Head of Bight study area between 1992 and 2016 using a 14-day moving average with 12-day overlap (presented as proportion of overall sightings). The dotted lines represent the 95% confidence limits.	34
Figure 2-9: Mean peak abundance of southern right whales recorded within the HoB study area between May and October 1992-2016, using a 14-day moving average with 12-day overlap (top) with female and calf pairs in black and unaccompanied adults in red. The maximum daily relative abundance count recorded per year is presented below with black circles showing female and calf pairs and red circles showing unaccompanied adults.....	35
Figure 3-1: Boundaries of the study site and location of observation stations for Southern right whales at Head of Bight in the eastern Great Australian Bight, South Australia.....	42

Figure 3-2: Abundance (or maximum daily count in a season) of Southern right whale females accompanied by a calf, unaccompanied adults and unknown status at Head of Bight, South Australia 1992-2016.	48
Figure 3-3: Southern right whale abundance trends at Head of Bight, South Australia between 1992 and 2016.	49
Figure 3-4: Linear regression of the logarithm value for the maximum count per year of Southern right whales at Head of Bight, South Australia between 1992 and 2016 for A) 'all animals' and B) female and calf pairs.	50
Figure 3-5: Incremental growth rate using a logarithm regression analysis for southern right whales at Head of Bight, South Australia between 2006 and 2016, for female and calf pairs (black-CC) and total adults (red-TA), with 95% error bars.	51
Figure 3-6: Proportion of Western Australian sub-population of Southern right whales sighted at Head of Bight annually, 1993-2016, based on aerial survey annual counts, Cape Leeuwin WA – Ceduna SA, and maximum annual counts from cliff based surveys at Head of Bight, South Australia.	53
Figure 3-7: The proportion of southern right whale females with a calf not previously sighted at Head of Bight, South Australia compared with females that were known to have previously been identified at Head of Bight with a calf, 1996 to 2016.	54
Figure 3-8: Mean calving interval for southern right whales identified in photographs between 1996 and 2016 at Head of Bight, South Australia, displayed as a box plot with the mean displayed as black horizontal line, standard deviation as white box and range displayed as vertical tails or black dots.	56
Figure 3-9: Frequency distribution of intervals between observed calving of individually identified southern right whales at Head of Bight, South Australia between 1996 and 2016.	56
Figure 3-10: Frequency distribution of age at first parturition of Southern right whales of known age at Head of Bight, South Australia (n=23).	58
Figure 4-1: Boundaries of the study site and location of observation stations for southern right whales at Head of Bight in the central Great Australian Bight, South Australia.	68
Figure 4-2: Frequency distribution of number of calves produced at Head of Bight by known reproductive females (n= 459).	76
Figure 4-3: The proportion of southern right whale calves resighted at Head of Bight, South Australia, recorded between 1991 and 2016 with the year from birth starting at 1991 extending to 25 years after birth in 2016.	76
Figure 4-4: Stacked plot of number of southern right whale calves sighted at Head of Bight, South Australia in 2014, 2015 and 2016, between mid-June and reaching a maximum abundance by August 20.	79
Figure 5-1. Southern right whale aerial survey off southern Australia from 1993 to 2016. Dashed line represents approximate survey route but further offshore so that contour is visible (Source: Bannister, 2017).	89

Figure 5-2: Southern right whale vessel survey study area at Fowlers Bay, South Australia.....	89
Figure 5-3: Abundance of southern right whales at Fowlers Bay South Australia from Western Australian Museum aerial surveys 1993-2016 (fitted with loess smoother with 95% CI), a) total individuals (All), b) abundance of females accompanied by a calf (CCPairs), and c) abundance of unaccompanied adults.	96
Figure 5-4: Vessel tracks from surveys conducted between June and September, 2014-2016 on-board Fowlers Bay Eco Whale Tours vessels in Fowlers Bay, South Australia.....	98
Figure 5-5: Southern right whale maximum daily vessel based sightings of females accompanied by a calf of the year (cow), calves and unaccompanied adults at Fowlers Bay, South Australia between 4 July and 12 September 2014, 26 July and 29 August 2015, and 17 July and 18 September 2016.	100
Figure 5-6: Southern right whale sightings of female and calf pairs (open circles) and unaccompanied adults (x) recorded within the Fowlers Bay South Australia study site during vessel surveys between 4 July 2014 and 12 September 2014 (a); 26 July 2015 and 29 August 2015 (b); and 17 July 2016 and 18 September 2017 (c).	104
Figure 5-7: Kernel density distribution of southern right whales normalised for effort per km ² using sightings data collected during vessel surveys at Fowlers Bay, South Australia between 2014 and 2016 (top). Kernel density plot overlaid with vessel tracks to show effort (bottom).	105
Figure 5-8: Examples of the movement patterns of SRW females accompanied by a calf at Fowlers Bay, South Australia in 2015 and 2016; individual whale 'CC1' sighted 20 times between 26 July 2015– 28 August 2015 (top left); CC2 sighted 9 times between 26 July 2015 and 5 August 2015 (top right), and; CC3 sighted 13 times between 17 July 2016 and 22 August 2016- (bottom right). The sightings numbers are in chronological order and correspond to a date in the tables displayed at the bottom right of the figure. Multiple values represent more than one sighting in one day.	107
Figure 6-1: The location of Fowlers Bay, South Australia (source: Charlton 2017- Ch4).	117
Figure 6-2: Southern right whale abundance count data for total individuals recorded from annual aerial surveys undertaken at Head of Bight and Fowlers Bay aggregation areas, South Australia from 1993 to 2016 (top), and the abundance trend of southern right whales sighted at Fowlers Bay (y-axis) compared with maximum annual counts at Head of Bight (x-axis), fitted with a power curve and excluding zero values (bottom).	122
Figure 6-3: Origin (first sighting with a calf) of southern right whale calving females sighted at Fowlers Bay, South Australia 1986-2012 (n= 22).	124
Figure 6-4: Example of movements within and across season for southern right whales from Fowlers Bay, South Australia to other coastal aggregation areas on the southern coast of Australia and the Auckland Islands, New Zealand.	127

Table of Tables

Table 2-1: Southern right whale abundance and distributional study effort at the Head of Bight study area, South Australia between 1992 and 2016.	27
Table 3-1: The rate of increase calculated for ‘all animals’ and for females with a calf at HoB between 1992 and 2016 using Compound Annual Growth Rate (CAGR) and Linear Regression analysis. *Taken from Burnell (2008), ** taken from Bannister (2017).	51
Table 3-2: Number of photographed female Southern right whales with a calf (bolded bottom cell of each column), and number of those same individuals photographed with a calf in subsequent years (in the row corresponding to the bolded cell) at Head of Bight between 1991 and 2016.	55
Table 4-1: Southern right whale study periods at Head of Bight, South Australia, 1992-1994 and 2014-2016, mean residency periods for calving females and unaccompanied adults, maximum daily counts per year and photo identification success, and mean number of resights.	73
Table 4-2: Number of calving for reproductive females at Head of Bight, South Australia. 1992-2016.....	75
Table 4-3: Number of calves that have been resighted in year after birth at Head of Bight, 1991-2016 as a percentage.	78
Table 5-1: Vessel survey effort during 2014, 2015, and 2016 in Fowlers Bay, South Australia.....	97
Table 5-2: SRWs sighted at Fowlers Bay, South Australia in 2014, 2015 and 2016.	99
Table 5-3: Number of SRW photo-identified, number resighted, range in the number of times animals were resighted, days of site occupancy (range and mean) for 2014, 2015, and 2016 at Fowlers Bay, South Australia.	102
Table 6-1: Number of total individual southern right whales counted at Fowlers Bay, South Australia during annual aerial surveys undertaken through the Western Australian Museum between 1993 and 2016, the number of unique individuals successfully photo-ID’d during aerial surveys and vessel surveys combined, and the total number of photo-ID matches to existing photo-ID datasets. The number of total individuals’ photo-ID’d that were sighted outside of Fowlers Bay is also recorded.....	121
Table 6-2: Number of times each calving female has been sighted at Fowlers Bay with a calf of that year, along with the number of times they have been sighted with a calf of that year at locations on the southern Australian coast other than Fowlers Bay (n= 37). Two individuals sighted at Fowlers Bay and another location in the same year were excluded as it is not confirmed at which location the whale resided first. One calving female was sighted at Fowlers Bay as a calf but was never sighted with a calf of her own at Fowlers Bay was also excluded.	125

1 INTRODUCTION

Southern right whales (SRWs) *Eubalaena australis*, were reduced to near extinction globally from commercial whaling in the 19th (Dawbin, 1986) and 20th century (Tormosov *et al.*, 1998; IWC, 2013). An estimated 55,000 to 70,000 whales were present in the Southern Hemisphere in the late 1700s. By the 1920s there may have been fewer than 300 individuals remaining throughout the Southern Hemisphere (Tormosov *et al.*, 1998). The Australian population is thought to have been reduced from approximately 15,000 individuals (Bannister, 1990). Although SRWs became protected in 1935, there were signs of population increase but it was delayed until the 1960's and 1970's due in part to illegal pelagic catches by the Soviet Union (Tormosov *et al.*, 1998). As of 2009, global abundance estimates of SRWs were approximately 13,600 individuals (IWC, 2013).

SRWs are found in the Southern Hemisphere and have a circumpolar distribution between latitudes of 16°S and 65°S. They migrate from southern feeding grounds in Sub-Antarctic waters to temperate northern breeding grounds to breed, calve and rest during the austral winter. Genetically distinct populations exist in South Africa, Argentina, Australia and New Zealand (Patenaude *et al.*, 2007; Rosenbaum *et al.*, 2000). A further, population exists off Chile and Peru (Galletti *et al.*, 2014). Whilst SRWs are listed as least concern under the International Union for Conservation of Nature (IUCN) red list, in Australia they remain listed as endangered under the Commonwealth Environment Protection Biodiversity and Conservation (EPBC) Act 1999.

SRWs are baleen whales, feeding on large amounts of krill and other copepods to sustain their large body size. SRWs grow to a maximum length of approximately 17.5 m and weigh up to 80 tonnes, with males slightly smaller than females. SRWs can be recognised by the lack of a dorsal fin, rotund body shape and whitish callosities on their head. Callosities are patches of keratinised skin colonised by cyamids - small crustaceans that persist throughout life (Payne *et al.*, 1983). SRWs have two blowholes on the top of their heads and can be recognised by their v-shaped blow.

In Australian coastal waters, SRWs occur along the southern coastline of the mainland and Tasmania and generally extend as far north as Sydney (33°53'S, 151°13'E) on the east coast and Perth (31°55'S, 115°50'E) on the west coast (DSEWPac, 2012). There are occasional sightings further north, with the extremities of their range recorded at Hervey Bay (25°00'S, 152°50'E) and Exmouth (22°23'S, 114°07'E) (DSEWPac, 2012). For management purposes, the Australian population of SRWs is divided into two sub-populations or management units, one in the south-west and the other in the south-east of Australia (DSEWPac, 2012). Genetic studies suggest that the south-'eastern' sub-population of SRWs represents a remnant stock,

distinct from the 'western' sub-population based on significant differentiation in mitochondrial DNA haplotype frequencies and contrasting patterns of recovery (Baker *et al.*, 1999; Bannister, 2001; Carroll *et al.*, 2011, Jackson *et al.*, 2016). However, some limited movement between the two areas has been recorded (Burnell, 2001; Pirzl *et al.*, 2009).

The 'western' sub-population occurs predominantly between Cape Leeuwin, Western Australia (WA) and Ceduna, South Australia (SA). This sub-population comprises most of the Australian population and is estimated at around 2,200 individuals in 2016, increasing at an annual rate of approximately 5.5 % per annum (p.a.) (Bannister, 2017). The 'eastern' sub-population can be found along the south-'eastern' coast, including the region from Tasmania to Sydney, with key aggregation areas in Portland and Warrnambool in Victoria. The 'eastern' sub-population is estimated at less than 300 individuals and is showing no signs of increase (Bannister, 2017). A rate of around 6-7% p.a. is considered the maximum biological rate of increase for SRWs (IWC, 2013). The Australian Government's SRW Conservation Management Plan (2011-2021) has given high priority to understanding population dynamics and measuring population recovery of both Australian sub-populations (DSEWPaC, 2012).

Very little is known about the summer feeding grounds or the offshore distribution and migration pathways of SRWs. Current knowledge on the potential location of SRW feeding grounds and movement to and from coastal aggregation areas is based on historical whaling data (Townsend, 1935), *Discovery* marks (Tormosov *et al.*, 1998), photo-ID matches (Bannister *et al.*, 1997) and satellite tracks of SRWs from New Zealand (NZ) (Childerhouse *et al.*, 2010) and Tasmania to the South Pacific Ocean (DSEWPaC, 2012). It is generally thought that SRWs from Australian populations probably forage between about 40°S and 65°S, generally south of Australia (Bannister *et al.*, 1999). They mainly consume copepods between latitudes of approximately 41 - 44°S, in the region of the Sub-Tropical Front and they mainly feed on krill in higher latitudes south of 50°S (IWC 2013). SRWs are thought to be primarily surface skim feeders, completing shallow dives and skimming across the surface, filtering plankton through their baleen plates. Right whales also feed underwater and have been observed with mud on their rostrum in the North Atlantic and in Argentina (Vicky Rowntree *pers. comms.*). The migration pathways of SRWs are generally unknown. Southern right whales satellite tagged off New Zealand (NZ) (Childerhouse *et al.*, 2010), South Africa (Mate *et al.*, 2011) and Argentina (Zerbini *et al.*, 2015) showed that SRW distribution in the summer feeding months was associated with the Southern Tropical Convergence. A satellite tagging study conducted at HoB in 2014 by Mackay *et al.*, (2015) successfully obtained location data from three female SRWs accompanied by a calf. These data showed that two whales had a southern migration pathway directly south from HoB and the other travelled west from HoB parallel to the coast and into the Indian Ocean. Burnell (2001) hypothesised that SRWs show a general east to west movement along the southern Australian coastline

within the breeding season, based on observations of SRWs arriving and leaving calving grounds and from photo-ID matches of individuals between southeast and southwest Australia (Burnell, 2001; 2008). The movements of SRWs from HoB obtained by satellite tagging suggest movement of females with calves does occur directly south from HoB as well as to the west. Mean recorded swim speeds of SRWs are between 3 - 3.3 km/hr (Mate *et al.*, 2011; Mackay *et al.*, 2015).

Known and potential threats that may have individual or population level impacts to SRWs include: entanglement in fishing gear, vessel disturbance, orca and shark attacks, climate variability and change, noise interference, habitat modification and overharvesting of prey. Ship strike and elevated underwater noise from vessel traffic has had a significant impact on critically endangered North Atlantic right whales (*Eubalaena glacialis*) (Clarke *et al.*, 2009; Rice *et al.*, 2014). Currently, entanglement in fishing gear is the major cause of death in North Atlantic right whales. Right whales have a reference for nearshore shallow water habitat, making them susceptible to human interference.

In winter/spring adult females approach the coast to calve, mate and rest, where they distribute across thirteen primary aggregation areas along the southern coast of Australia (Figure 1-1) (Bannister, 2017; DSEWPaC, 2012). The largest established calving areas in Australia include Head of Bight (HoB) in SA, and Doubtful Island Bay and Israelite Bay in WA. Smaller but established aggregation areas regularly occupied by SRWs include Yokinup Bay in WA, Fowlers Bay in SA and the Warrnambool and Portland in Victoria. Emerging aggregation areas include Flinders Bay, Hassell Beach, Cheyne/Wray Bays, and Twilight Cove in WA, and sporadically occupied areas include Encounter Bay in SA (DSEWPaC, 2012). SRWs generally occupy shallow sheltered bays within 2 km of shore and within water depths of less than 10m.

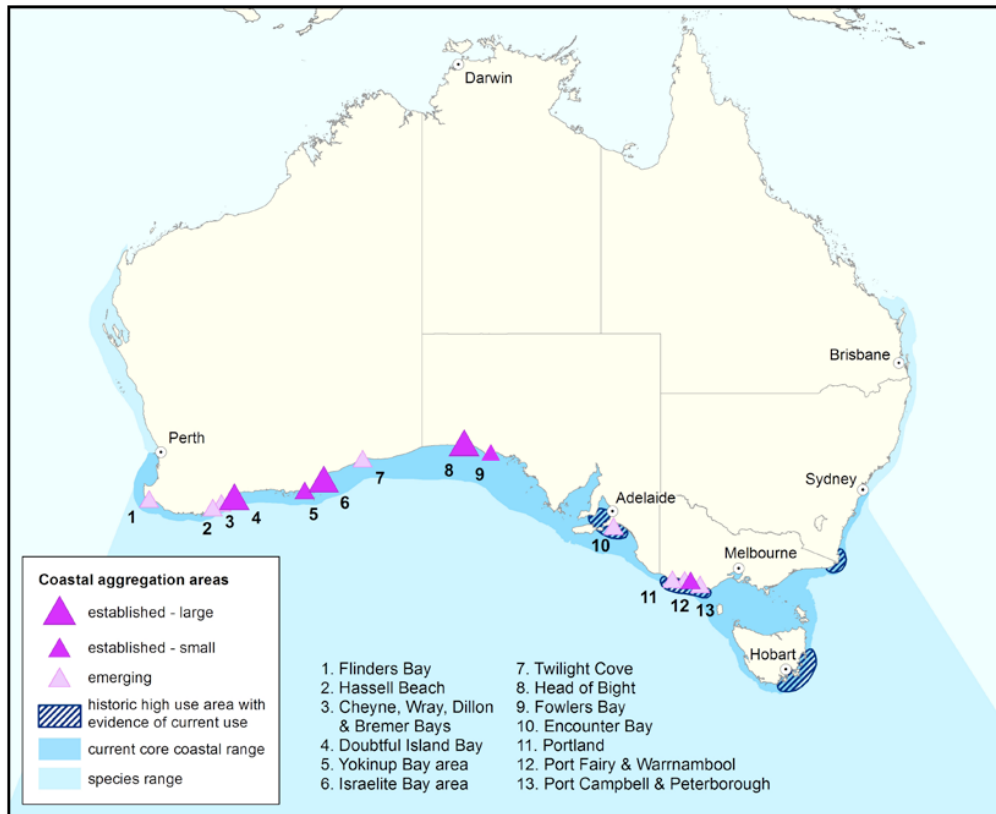


Figure 1-1: Southern right whale distribution range in Australia. Source: DSEWPaC, 2012

SRWs show strong philopatry to calving grounds (Burnell, 2001). However, movement of calving and non-calving adults has been recorded across broad distances both within and across seasons (Pirzl *et al.*, 2009). SRWs have a three-year calving cycle on average; causing cohort structured breeding cycles and variability in inter-annual calf production (Brandão *et al.*, 2011; Burnell, 2001; Best *et al.*, 2001; Cooke, 2001; Payne *et al.*, 1990). It is assumed that the year of calving is followed by a resting year with no migration (or migration to elsewhere), and then a mating year when animals migrate to areas alternate to their selected calving ground (Brandão *et al.*, 2011; Burnell, 2001; Cooke *et al.*, 2001). Female and calf pairs generally stay within the calving ground for 2–3 months (Burnell, 2001). Gestation is estimated to last 11-12 months and lactation for at least 7-8 months with weaning completed within 12 months (Best *et al.*, 2001; Burnell, 2001).

Two key long-term population monitoring studies have been undertaken in Australia to monitor the south-‘western’ sub-population of SRWs. Annual aerial surveys have been completed through the Western Australian Museum (WAM) since the mid-1970s (Bannister, 1999; 2001; 2011; 2016), and annual cliff based count and photo-ID surveys at the major aggregation ground at the HoB in the Great Australian Bight (GAB), SA since 1991 (Burnell

and Bryden, 1997; Burnell, 2001; Burnell, 2008; Charlton and Burnell, 2011; Charlton *et al.*, 2014). Long-term monitoring studies have assessed abundance and rate of increase in SRWs in the south-west of Australia and provided information on long term trends in abundance over time, population biology and life histories for species assessments (Bannister, 2017; Burnell, 2001). Whilst Bannister (2017) provides up to date abundance estimates and distribution and abundance information, life history parameters influencing population increase such as calving intervals and age of sexual maturity have not been published in peer reviewed literature since Burnell (2001). There is a need for updated analysis of life history parameters to inform recovery assessments.

Head of Bight, SA is the most important calving aggregation ground for the 'western' sub-population of SRWs in Australia. HoB is within the GAB Commonwealth Marine Reserve, which was established in 1995 to provide protection and a sanctuary to recovering SRWs (Figure 1-2). SRWs are protected within the GAB Marine Reserve at HoB with vessel closures between May 1 and October 31 in the Marine Mammal Protection Zone (MMPZ). The HoB aggregation remains one of the largest wintering aggregations in Australia. HoB was reported to represent up to 40% of the Australian population (Burnell, 2001). The geographic isolation, limited shoreline access and harsh weather conditions of the Southern Ocean served as natural protection for the whales from being hunted at HoB during the whaling era, though not at Fowlers Bay. Population recovery of SRWs at HoB was estimated at 5.5% p.a. over the years 1991-2006 (Burnell, 2008).

The wider GAB is a multi-use area for commercial fisheries, marine parks, tourism and offshore oil and gas activities (Figure 1-2). Ongoing and planned offshore oil and gas activities in the GAB include seismic exploration and exploratory drilling. Oil and Gas activities have been undertaken in the GAB basin since the 1970s, with the first two wells drilled in 1972. The last of the nine wells drilled to date was drilled in 2003. No oil discoveries have been made. Seismic exploration has occurred in the 'eastern' GAB over the last three decades, with the most recent campaigns operating from 2011-2015. Existing permit lease holders in the 'eastern' GAB include: Chevron, Statoil, Murphy Oil, Santos, Karoon Gas and Bight petroleum. The major players Statoil and Chevron are each scheduled to start a four-well exploration drilling programme in 2018/2019, pending environmental approval.

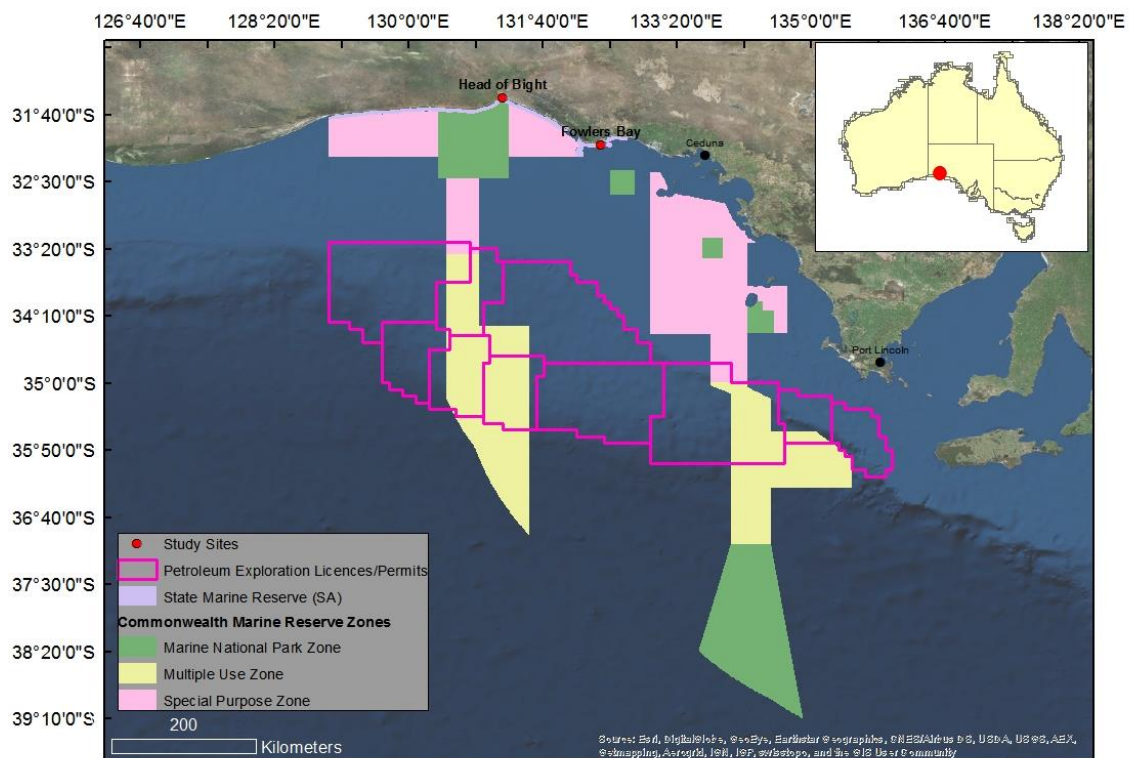


Figure 1-2: Regional map of the Great Australian Bight, including southern right whale aggregation areas and study sites at Head of Bight and Fowlers Bay, South Australia, marine park boundaries and oil and gas permit lease areas in South Australia.

Fowlers Bay (FB) in the GAB is a small established aggregation area for SRWs in the Nuyts Archipelago State Marine Park (Figure 1-2) approximately 160 km southeast of HoB. Increased sightings of SRWs at FB have occurred since the mid-2000s based on aerial survey data (Bannister, 2011) and anecdotal reports by tourism operators. Understanding of the characteristics of SRWs in established and emerging aggregation areas such as FB is required to facilitate recovery planning, including management of potential anthropogenic impacts and the setting of population recovery targets, with the aim to see the species delisted from endangered status in Australia.

The Australian Government's SRW Conservation Management Plan 2011-2021 has given high priority to understanding life history parameters and measuring population growth of both Australian sub-populations (DSEWPac, 2012). Life histories are an important indicator of population health and recovery potential. Therefore, analyses of long-term datasets that enable assessment of life histories and changes to these parameters over time are critical for conservation and management. For effective management of the marine park and management of human activities in the GAB, an understanding of the seasonal trends in distribution and abundance, timing of arrival and departure from the site and peak abundance periods is required.

1.1 Objectives

The aim of this research is to assess the population demographics of southern right whales in the Great Australian Bight, South Australia. Specifically, the objectives of each research chapter include:

1. Assess the within season trends in distribution and abundance of SRWs at HoB, using 3 years of cliff based research 2014-2016 (Chapter 2)
2. Assess the long-term trends in abundance and life history parameters of SRWs at the HoB over 26 years (1991-2016) (Chapter 3)
3. Assess the residence, site fidelity and date of calving of SRWs at the major calving area at HoB, SA (Chapter 4)
4. Quantify the long term and seasonal trends in abundance, distribution, residency and within season movement of SRWs at FB, SA (Chapter 5)
5. Assess the connectivity and movement of SRW between FB and other aggregation areas in Australian and NZ (Chapter 6).

1.2 Layout of thesis

This thesis contains five data chapters, each addressing one of the objectives detailed above. As the data chapters are in the format of scientific papers, each comes complete with its own Abstract, Introduction, Methods, Results and Discussion. Every effort has been made to provide a comprehensive yet non-repetitive literature review; however, it is inevitable that some overlap occurs given the preparation of chapters as 'papers'. The content of the data chapters is detailed below:

Chapter 2: Seasonal trends in the distribution and abundance of southern right whales (*Eubalaena australis*) at the Head of the Great Australian Bight Commonwealth Marine Reserve, South Australia

Chapter 3: Long term trends in abundance and life history parameters of southern right whales (*Eubalaena australis*) at Head of Bight, South Australia (1991-2016)

Chapter 4: Residency, site fidelity and date of calving of southern right whales (*Eubalaena australis*) at the major calving area at the Head of the Great Australian Bight, South Australia

Chapter 5: Southern right whales (*Eubalaena australis*) return to a former wintering ground: Fowlers Bay, South Australia

Chapter 6: Connectivity and movement of southern right whales (*Eubalaena australis*) between Fowlers Bay, South Australia and other aggregation areas in Australia and New Zealand

The thesis concludes with a general discussion intended to reflect on the significant findings from the project, and identifies limitations and future research directions.

2 Seasonal trends in the distribution and abundance of southern right whales (*Eubalaena australis*) at the Head of the Great Australian Bight Commonwealth Marine Reserve, South Australia (1991-2016)

Charlton C.M¹., R. Ward¹., R. McCauley¹., R. L. Brownell³., C. Salgado-Kent¹., S.R. Burnell³

¹Centre for Marine Science and Technology, Curtin University Western Australia

²NOAA Fisheries, Southwest Fisheries Science Center, Monterey, California, USA

³Eubalaena Pty. Ltd.

Key words: Southern right whale; marine reserve; monitoring; seasonality; abundance; distribution; conservation; management

2.1 Abstract

Seasonal trends in the distribution and abundance of Southern right whales (SRWs) *Eubalaena australis*, were assessed at Head of Bight, South Australia, using count data from annual cliff based surveys undertaken between June and October 1992-2016. SRWs were primarily distributed within a 15 km by 2 km area within the 10 m depth contour (with 95% of whale sightings made within a 10 km² area). The distribution of SRWs at Head of Bight varied within an individual season but was consistent between the years of this study. The composition of SRW sightings at HoB was 70% females accompanied by a calf and 30% unaccompanied adults. SRWs occupy the area between May and October and whilst there was some variation in the two-week peak abundance period, peak abundance was recorded between mid-July and end-August for both female-calf pairs and unaccompanied adults. A mean of 16% (range=8-28%, SD= 6.5, 95% CI=0.15) of calving females were present at the site in mid-June and a mean of 37% (range=13-61%, SD= 15.8, 95% CI=0.37) remained at the site at the end of September. Based on nearest neighbour distances of 150 m (Pirzl, 2008) the area occupied by 95% of SRW at Head of Bight could reach saturation capacity at 68 female and calf pairs. Results suggest that the primary aggregation area at Head of Bight may have reached saturation capacity and that habitat dispersal can be expected as the population increases. This study provides information on SRW seasonal trends in distribution and abundance, timing of arrival and departure from the site and peak abundance periods that can be applied to conservation and marine park management of this population.

2.2 Introduction

Southern right whales (SRWs) *Eubalaena australis*, were reduced to near extinction globally from commercial whaling in the 19th (Dawbin, 1986) and 20th century (Tormosov *et al.*, 1998; IWC, 2013). Although SRWs became protected in 1935, signs of population recovery were not evident until the 1970's in part due to illegal catches by the Soviet Union in the 1960s (Tormosov *et al.*, 1998). SRWs occupy Southern Hemisphere latitudes of 16°S to 65°S and migrate between high latitude feeding grounds where they presumably spend most of the austral summer and low latitude breeding grounds where they spend the austral winter (Bannister 1996). Genetically distinct populations exist in South Africa, Argentina and Brazil, Australia, New Zealand (Pateraud *et al.*, 2007; Rosenbaum *et al.*, 2000) and Chile- Peru (Galletti *et al.*, 2014). While, SRWs are listed as least concern on the International Union for Conservation of Nature (IUCN) Red List, they remain listed as endangered under the Australian Commonwealth Environment Protection Biodiversity and Conservation (EPBC) Act (1999).

The population of SRWs that occurs seasonally off the coast of Australia is divided into two sub-populations; 'western' and the 'eastern', based on genetic differentiation (Carroll *et al.*, 2011), photo-ID data (Burnell, 2001) and different increase rates and population sizes (Bannister, 2017). The Australian population is currently estimated to be approximately 2,500 animals, with approximately 2,200 individuals in the 'western' sub-population and approximately 257 individuals in the 'eastern' sub-population (Bannister, 2017). The 'western' sub-population occurs off southern Western Australia (WA) and South Australia (SA) and the 'eastern' sub-population occurs off Victoria, New South Wales (NSW) and Tasmania. The 'western' sub-population occurs predominantly between Cape Leeuwin, WA and Ceduna, SA and comprises most of SRWs in Australian waters. SRWs, including the 'western' and 'eastern' sub-populations are distributed across thirteen identified aggregation areas along the southern coast of Australia (Bannister, 2017; DSEWPaC, 2012) and are known to occupy shallow sandy bays that offer protection from south westerly weather, within 2 km from shore and 10 m water depth (Pirzl, 2008). The annual rate of increase of 'all animals' in the 'western' population between 1991 and 2016 was estimated to be approximately 5.55% (95% CI, 3.78, 7.36) per annum (p.a.) and 6.01% (95% CI, 3.49, 8.59) p.a. for females accompanied by a calf (Bannister, 2017). The 'eastern' sub-population, found along the south-eastern coast, including Tasmania and rarely further north than Sydney, is showing no signs of increase (Bannister, 2017).

Head of Bight (HoB), SA is a major aggregation area for SRWs in Australia that is within the Great Australian Bight (GAB) Commonwealth Marine Reserve, which was established in 1995 to provide protection and sanctuary to recovering SRWs. Over the past two decades, as much as 48% of the 'western' population of SRWs has been estimated to use the HoB

aggregation area, but in more recent years it has decreased to around 25% (Charlton, 2017 - Chapter 3). Based on cliff-based surveys of SRWs conducted at Head of Bight annually during 1991-2016, maximum annual counts of between 18 (1992) and 81 (2016) female and calf pairs were recorded (Burnell and Bryden, 1997; Burnell, 2001; Charlton, 2017- Chapter 3). A maximum of 172 SRWs were recorded on a single day at HoB in 2016, including 81 females accompanied by a calf (Charlton, 2017- Chapter 3). There is high inter-annual variability in long-term abundance trends due to the average three-year calving cycles that SRWs have throughout the Southern Hemisphere (Payne, 1984; Payne *et al.*, 1990; Bannister *et al.*, 1999; Best *et al.*, 2001; Burnell, 2001; Cooke *et al.*, 2003; Charlton, 2017 - Chapter 3).

Two long term monitoring programs have operated for the 'western' sub-population of SRWs, including annual aerial surveys between Cape Leeuwin, WA and Ceduna, SA undertaken during 1993 - current (Bannister, 2001; Bannister, 2017), and cliff based surveys at HoB undertaken during 1991-current (Burnell, 2001). While broad inter-annual trends are understood (Bannister, 2017; Burnell, 2001), current knowledge on within season trends in the distribution and abundance of SRWs at HoB remains limited (Burnell and Bryden, 1997; Burnell, 2001). It is known that SRWs occupy the Australian coast between May and October. However, how they are distributed and move between aggregation areas during their breeding season remains unclear. In addition, the timing of arrival and departure of whales and the peak abundance period in coastal aggregation areas is required to inform future planning and management. Thus, this study assesses the intra-seasonal trends in distribution and abundance of SRWs, peak abundance periods at HoB using 26 years of cliff based research. Assessment of inter-seasonal trends in the distribution and abundance will inform management on the effectiveness of sanctuary zones, such as the GAB Commonwealth Marine Reserve established to manage potential human impacts. The resulting information will also inform management outside protected areas and restricted access periods through improved understanding of the timing of arrival and departure and periods of peak abundance of whales within the marine park. The likelihood of the aggregation area reaching saturation capacity due to density resource (space) pressures is assessed using nearest neighbour estimates for female and calf pairs at HoB (Pirzl, 2008). As this key aggregation area reaches maximum capacity this could be expected to lead to increased dispersal and coastal movements, which has implications for habitat protection and the future management of the Australian population.

2.3 Methods

2.3.1 Study area

The study area at the Head of the Great Australian Bight (31° 29' S, 131° 08' E) is in the broader region of the Great Australian Bight (GAB) and is located on the far west coast of SA, 300 km west of Ceduna and 200 km east of the WA border. The wider GAB is a multi-use area for commercial fisheries, marine parks, tourism and oil and gas activities offshore. Ongoing and planned oil and gas activities in the GAB include seismic exploration and exploratory drilling. Current oil and gas lease areas granted in the GAB cover approximately 115,000 km² (~750 km x ~150 km) and are located approximately 200 km offshore from the coastal aggregation area at HoB, on the continental shelf. HoB is within the Marine Mammal Protection Zone (MMPZ) of the GAB Commonwealth Marine Reserve that covers State and Commonwealth waters. The study area is also within the Far West Coast State Marine Park that covers the state waters out to 3 nautical miles (nm). HoB is adjacent to Yalata Aboriginal Land on the Nullarbor Plain. The MMPZ of the GAB Commonwealth Marine Reserve was established in 1995 to provide a sanctuary for these whales (Figure 1-2). All vessels and general access are prohibited in the MMPZ of the GAB Marine Reserve between 1 May and 31 October each year (there is a complete no access zone- no fishing or recreational activities). The MMPZ area is approximately 9,000 km² in area (~100 km x ~90 km). The study area for this research is within the MMPZ and covers an area approximately 75 km² in size spanning approximately 15 km east to west along the coast and out to 8 km offshore (Figure 2-1).

Habitat characteristics of the study area at HoB include a shallow, gently sloping, sandy bay in the east leading at the 'western' end of the study site to the 33-53 m high Bunda Cliffs which provide some shelter from the dominating south westerly wind and swell. Along these cliffs, water depths drop to around 20 m within approximately 300 m of shore. Whales are often sighted directly below these cliffs within 50 m of shore (Figure 2-1).

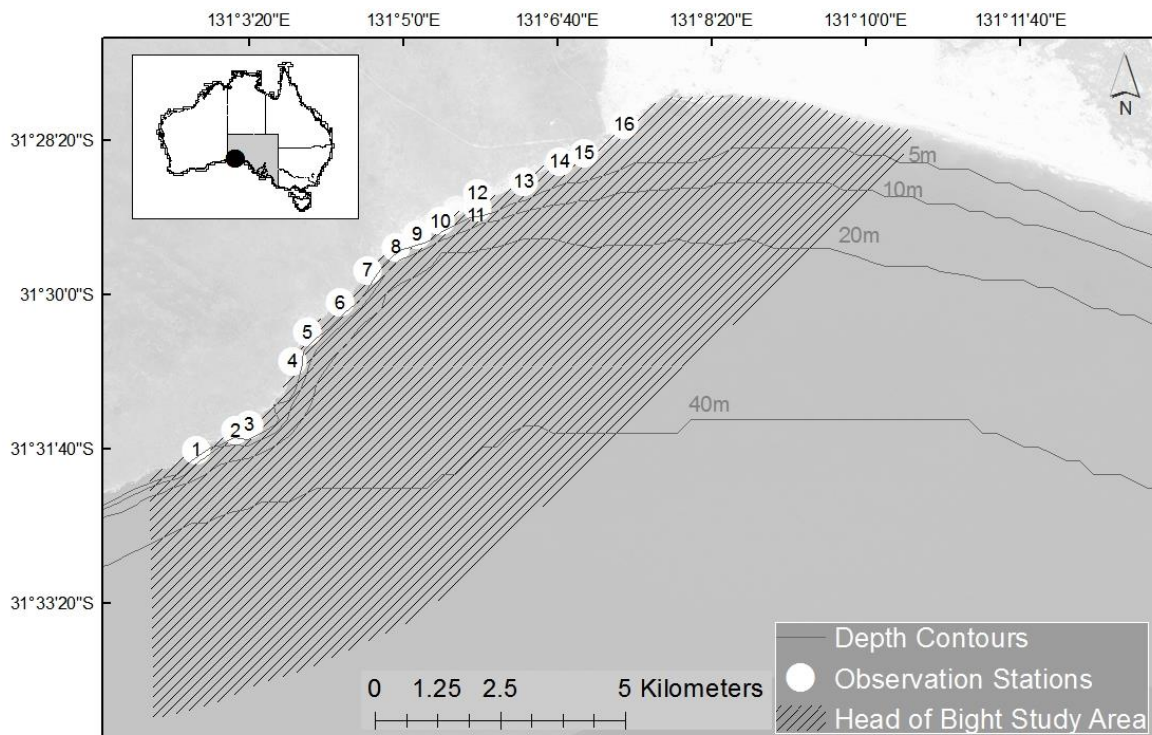


Figure 2-1: Study area and Southern right whales shore-based observation stations southern right whales at Head of Bight in the eastern Great Australian Bight, South Australia. Observations sites on the cliffs are labelled west to east.

2.3.2 Data collection

The study methods are consistent with the population census and photo-identification (ID) study completed annually at HoB between 1991 and 2015 described in Burnell and Bryden (1997), Burnell (2001) and Charlton *et al.*, 2014. Seasonal trends in abundance were assessed for SRWs at HoB using daily counts over 25 of the 26 years since the study began in 1991. Count data from 1991 were excluded because in that year the number of groups was recorded rather than number of individual whales, and therefore the data are not consistent with the rest of the dataset. Daily counts provide a snap shot of whale numbers and location on a given day. While the maximum value of the daily counts within a year was indicative of numbers using the site at on any one day during that season, they are likely an underestimate of the true maximum number of individual whales visiting the site since whales are known to immigrate and emigrate, to and from the site over the course of a season.

The within seasonal trends in distribution of SRWs at the HoB study area were assessed using three years (2014-2016) when quantitative data on whale locations were recorded. Prior to 2014, the spatial distribution of whales was recorded at a coarse resolution and is not comparable to the distribution data collected from 2014 onwards.

SRWs within the study area were surveyed from 16 land based observation stations (Figure 1) along a stretch of approximately 15 km of coastline. Observation stations on Bunda Cliffs ranged in height from 53 m towards the west to 33 m towards the east of the study area, and

were between 300 and 1000 metres apart. Observation stations were selected based on safety and topographic features to ensure full visual coverage of the study site (i.e. if the contour of the cliff line obstructed observer view, then the observation stations were closer together to allow unobstructed observations of whales along the 15 km stretch of coastline). During each daily survey, surveys from each station were conducted beginning at the 'western'-most station and ending at the 'eastern'-most station. The time spent travelling between stations ranged from 2 to 6 minutes.

Observations at each station consisted of systematic scans using 10x50 Bushnell binoculars and the naked eye at an angle of approximately 180° east to west and as far as the eye could see offshore to the south from the horizon down to the cliffs. To avoid duplicate sampling between adjacent stations, only individuals in front or to the west of observation stations were recorded. To further reduce the risk of duplicate sightings, the location of sighted whales at each station was mapped in real time based on measurements of distance and angle to whale, individuals were identified using photo-ID, and the location and ID was cross checked with sightings at a similar location at the next adjacent station. All surveys were completed in Beaufort Sea States of 3 or less and wind speeds less than 18 knots to reduce bias in counts due to weather conditions. Environmental conditions including wind speed and direction in knots, cloud cover in percentage, sea state using the Beaufort scale and swell height were recorded qualitatively at the start and end of each census. Glare was not recorded as observations were timed to avoid glare. Daily cliff-based survey effort ranged from 2.9 hours to 4.9 hours (mean=3.6 hours). Start times were roughly 08:30 and end times ranged between 12:30 and 16:00. Observations were timed to avoid glare in the early morning and sea breeze in the afternoon. Effort reported here excludes travel times between vantage points.

Most animals, particularly females accompanied by a calf, were easily observed in the relatively clear and shallow waters within a few hundred metres of observation stations, even when they were below the surface of the water. Thus, the probability of whales being available to be sighted within this distance of the observation stations was assumed to be 1 (Burnell, 2001; Bannister, 2017). A minimum of 10 minutes was spent observing at each station based on the assumption that at ranges beyond 5 km (where the larger incident angles of observation make detections of animals below the surface of the water more difficult), SRWs were at the surface at some point during that period. The minimum 10-min survey period at each observation station improved the detection probability of animals at a distance from observation stations while ensuring that whale movements were visually tracked to avoid double counting. Female and calf pairs spend the majority of their time on the surface and a maximum of 8 -minute dive times in 22 minutes for calves was recorded by Thomas and Taber (1984). Surface behaviour is common for young calves and dive times

are generally less than a few minutes (Charlton *unpublished observations* 2017). The data are biased towards potentially having greater detection probability for females and calves than unaccompanied adults. However, the overlap in observation stations and methodology moving west to east, increases the likelihood of sighting most animals. Longer time periods were spent at a location if additional time was required to capture photo ID's. A maximum of 50 minutes was spent at a location. In this instance, a dedicated observer watched the position of the whales to ensure that no animals had moved into or out of the observation station range. If a whale moved out of the observation station range to the east, it was later counted. If it moved out of the observation station range to the west, there was no risk of double counting the individual so it was still marked at the location station where it was first sighted. Photo-ID was abandoned if there was a risk of jeopardising the accuracy of the count. Whale location and assessment of distribution in the study area is biased by the movement of whales into an area when longer than 10 minutes was spent at an observation station. The whales move around the area frequently so the bias is not considered a limiting factor for the assessment of distribution and abundance.

Observer bias was reduced by using two trained and experienced observers during surveys and minimising rotation of researchers across the duration of the long-term study. For each SRW sighting the following variables were recorded: date, time, observation station (1-16), group composition (number, age class, and group type which included female accompanied by a calf, unaccompanied adult or unknown status). Unknown status was recorded when the observer could not be sure if the individual had a calf or was unaccompanied. A group of whales was defined as one or more whales within 100 m of each other that were seen to be interacting or travelling together. Range and bearing of the whale to the observer was recorded using a Bushnell 1600 laser range finder and marine grade Bushnell 10x50 binoculars fitted with a compass. Compass readings were taken in the absence of any metal objects that could have interfered with the accuracy of the reading. In instances where the whale was outside the rangefinder detection range (typically greater than approximately 450 m), reticule binoculars fitted with a compass were used to measure increments below the horizon to the whale. Various handheld GPS units were used to log the position of each observation station, all using the WGS 84 chart datum (equivalent to GDA 90).

2.3.3 Analysis

Visual detection range

Visual detection range of whales was defined conservatively at the observation station with the lowest elevation. The visual detection range was estimated by calculating the range to each sighting over 2014-2016 using sightings to the south east ($< 150^\circ$) from station 16, the 'eastern' most observation station, and establishing the range at which 95% of the whales were detected. At observation site 16 the shore line forms a boundary of the study area and the elevated Bunda Cliffs turn into lower elevation sand dunes. Thus at 33 m this site has the lowest elevation of the study sites.

Distribution

Whale distribution was mapped using location data calculated from range and bearing of whale plus elevation of observer. The equivalent measure in degrees for vertical angles associated with binocular reticules was calibrated using the distances and heights of known targets. Whale ranges using the reticules or theodolite were calculated assuming a spherical earth and allowing for observer-eye elevation. Height above sea level and GPS location of the observer eye was calculated for each of the 16 observation stations by using a theodolite to determine the angle below the horizontal down to a feature at the water's edge (usually a rock) to which the range was established using the laser range finders. Geometry then gave the theodolite elevation. Whale positions were calculated using code developed at the Centre for Marine Science and Technology, Curtin University (CMST) using MATLAB (The MathWorks, Inc.). The mapping toolbox was used to plot the location of whales based on the range estimate and true compass heading (corrected for variation at the site). The error associated with tide was considered minimal given the tidal changes (< 1.5 metres) relative to the distance that whales were sighted (most within 1 km) and measurement errors. There was some error in the precision of sighting locations between 1° and 120° (horizontal angle) at observation station 16 caused by land blocking the horizon. In 2015 and 2016 the vertical angle of the horizon was estimated from which location data in this area were estimated to have an error in the range of 1-300 m. In 2014, locations were not collected between 1° and 120° at observation station 16. Count data were however collected and recorded in all locations.

Spatial data processing used purpose-built programs in MATLAB software to generate whale locations. Maps were generated in MATLAB using Australian Hydrographic Service charts under Seafarer GeoTIFF license No 2618SG (Curtin University). Spatial data were normalised for effort (time spent at each observation station) and displayed as Kernel Density distribution plots (whales/0.5km²) using ArcMap v10. All times were presented in Australian

Central Standard Time (UTC + 9.5 hours). Bathymetry was retrieved from the Geoscience Australia 0.00250 grid (Whiteway 2009).

An estimate of the portion of the study area used by 95% of whales was made. To define the offshore 95% limit firstly the minimum range of each whale to the zero-m depth contour was calculated, with the zero-depth contour digitised from Australian Chart 341. The zero-bathymetry contour derived from the Geoscience Australia bathymetry Atlas (Whiteway, 2009) was slightly incorrect according to the Australian Chart. The minimum ranges of each whale from the zero-m depth contour were sorted and the value which encompassed 95% of all values taken as the distance offshore for 95% of whales. To define the alongshore 95% bounds of whales, as the study area was aligned roughly east-west, the whale longitude values were sorted (smallest to largest) and the longitudes at which 0.025 and 0.975 of the total number of values found. This gave the 2.5% and 97.5% longitude bounds, which gave the alongshore bounds for 95% of whales. Using the offshore and alongshore 95% bounds in which whales were found gave the area used by most whales.

Abundance

Within seasonal trends in abundance between June and October (1992-2016) were analysed by plotting the abundance of female and calf pairs and unaccompanied adults and calculating the proportion of each group type that was present in the study area during each month surveyed. The variation in abundance of each group type (females accompanied by a calf, unaccompanied adult) was assessed to provide information on immigration and emigration into and out of the site. The timing of arrival and departure of whales to and from the site was assessed using daily counts and calculating the percentage of whales from each group type present at the site at the start and end of the study period.

Peak abundance

Inter-annual comparison of peak abundance periods was assessed using a 14-day period because that is the duration of the comparable study period consistently sampled throughout this 26-year study. To maintain comparability of inter-annual trends in abundance between years, the abundance study was always completed between August 15 and 30. Outside of that period, the study effort varied between years (1991-2016). There was a need to determine if the 14-day study period between August 15 and 30 was reflective of the peak abundance period. Therefore, a 14-day moving average with a 12-day overlap was selected for analysis of the peak abundance period. The maximum daily count for each year was normalised to a scale of 0-1. Estimates of 14-day peak abundance periods were calculated using 14-day sliding averages with 12-day overlaps using Julian Day as the time base. Changes to the mean peak abundance period were assessed. To account for variation in sampling effort across years a null value was given where there was a gap in sampling and

the peak value data were presented with sampling effort. Analysis excluded years when only a two-week survey was completed (2007-2013). Normalised peak abundance periods and maximum annual counts were presented on a scatterplot for each year, 1992-2006 and 2014-2016.

2.4 Results

2.4.1 Study period

Over the period 1992 – 2016, a total of 805 daily surveys were conducted at the HoB study area between the months of June and October. Effort was variable across the years but an average number of 35 surveys per year were conducted, with the number of surveys ranging from eight in 2013 to 112 in 1993 (Table 2-1Table 2-1). Surveys resulted in 42,725 whale sightings over the 25-year study period.

Table 2-1: Southern right whale abundance and distributional study effort at the Head of Bight study area, South Australia between 1992 and 2016.

Year	Survey days	Survey period
1992	60	25 Jun - 10 Oct
1993	112	18 Jun - 13 Oct
1994	88	19 Jun - 12 Oct
1995	46	27 Jun - 10 Oct
1996	41	7 Jul – 9 Oct
1997	41	7 Jul - 6 Oct
1998	22	30 Jun – 2 Oct
1999	30	2 Jul - 7 Oct
2000	32	3 Jul - 7 Oct
2001	33	3 Jul - 4 Oct
2002	32	13 Aug - 9 Oct
2003	36	1 Jul -7 Oct
2004	36	3 Jul -3 Oct
2005	33	4 Jul - 30 Sept
2006	26	5 Jul - 29 Sept
2007	15	16 Aug - 30 Aug
2008	12	13 Aug - 25 Aug
2009	12	21 Aug - 2 Aug
2010	9	24 Aug - 1 Sept
2011	13	15 Aug - 26 Aug
2012	9	14 Aug - 29 Aug
2013	8	18 Aug - 30 Aug
2014	41	19 Jun - 28 Sept
2015	41	18 Jun - 25 Sept
2016	33	16 Jun - 25 Sept

2.4.2 Visual detection range

The maximum detection range was approximately 10 km, however, 95% of all sightings offshore of the cliffs were recorded within 1 km, with a drop off after this point (Figure 2-2). Whales were distributed within the 20 m depth contour and most whales were sighted in less than 10 m. When considering only sightings recorded at observation station 16, the visual detection range for 95% of whales sighted extended to 4.5km (Figure 2-3).

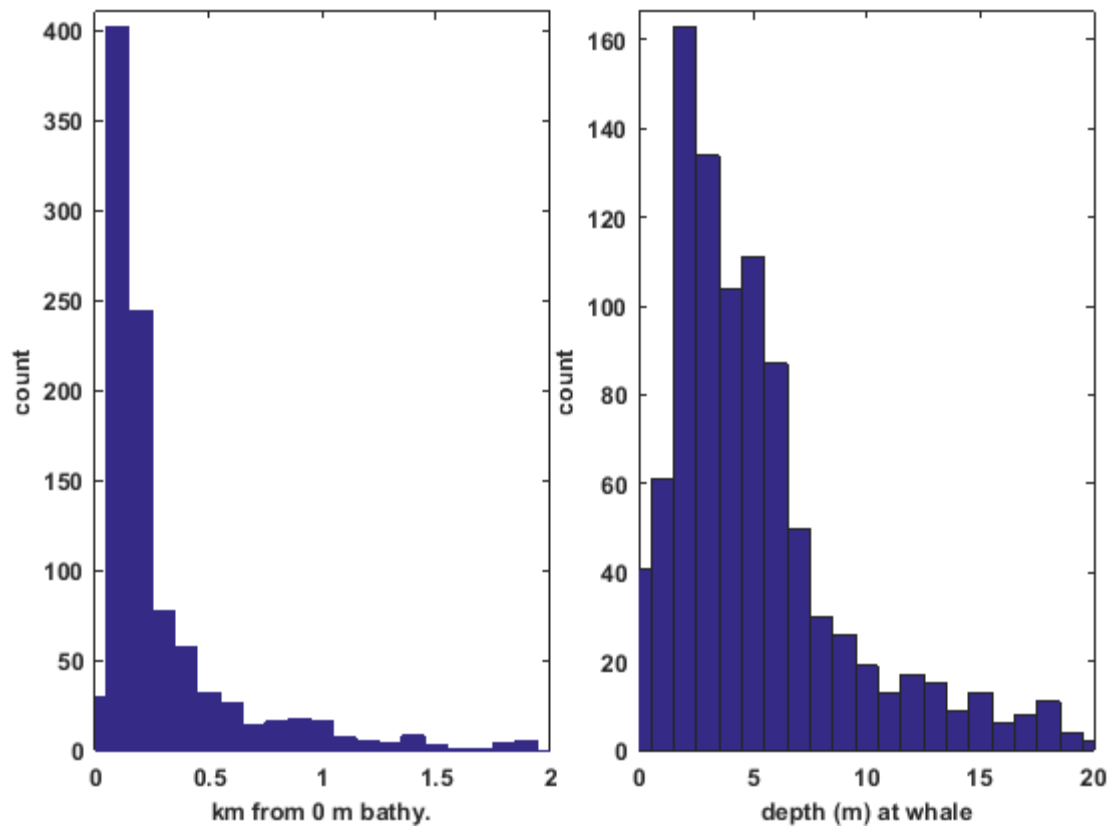


Figure 2-2: Distributions of Southern right whale distance from 0 bathymetry contour (left) and depth (right), for sightings at Head of Bight recorded between June and September, 2014-2016.

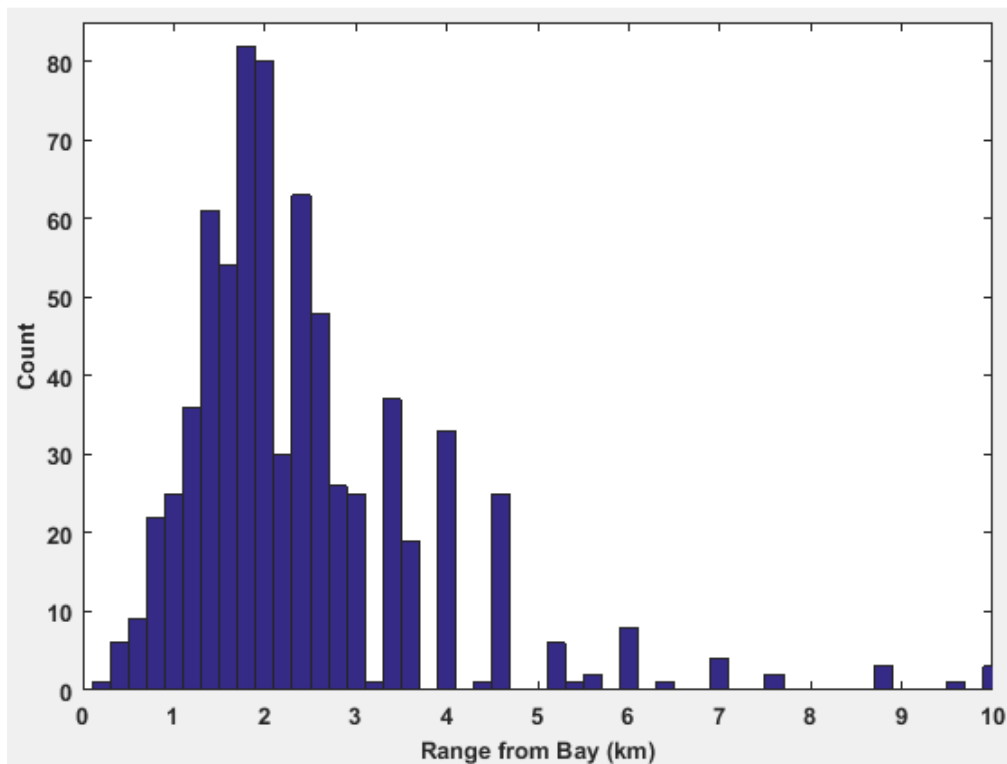


Figure 2-3: Detection range with distance from observation station 16 to the south-east of the study site.

2.4.3 Distribution

The distribution of SRWs sighted in the HoB study area was recorded for 1,621, 1,069 and 1,955 adults in 2014, 2015 and 2016, respectively. The mean group size of SRWs at HoB in 2014-2016 was 2.2 individuals (range 1-8; median 2). The mean group size for unaccompanied adults was 2.3 (range=1-7, SD=1.9, 95% CI=0.003) and 2.3, (range 2-8, SD=1.8, 95% CI=0.003) for females accompanied by a calf. The distribution of SRWs was similar between years (Figure 2-4). In 2014 whales were not sighted as close to shore at the 'eastern' most point as they were in 2015 and 2016 due to variation in the method, therefore the distribution in this area could not be compared. Within, the study area, SRWs were predominantly distributed along 15 km of the coast and within 2 km from shore (95% were within 1 km of shore) in water depths less than 20 m (Figure 2-4). Females accompanied by a calf were mostly distributed in the shallow sandy bay to the east primarily within 10m water depth. Sightings of unaccompanied adults were most frequently made along the cliff line in the centre and west of the study area primarily within 10-20m water depth (Figure 2-5).

Distribution of 95% of all SRW sightings recorded between 2014 and 2016 occurred within an area 10.16 km wide from east to west and within 1.04 km from shore. Based on calculated distances between mother and calf pairs (Pirzl 2008) a minimum preferred spacing distance between female and calf pairs of 150 m is assumed, in which case the area occupied by 95% of all whales sighted would reach capacity at 68 female and calf pairs, assuming a perfect packing density. If a minimum spatial requirement of 100 m is tolerated by SRWs at Head of Bight, the area occupied by 95% of whales sighted would reach capacity at 155 female and calf pairs, assuming a perfect packing density.

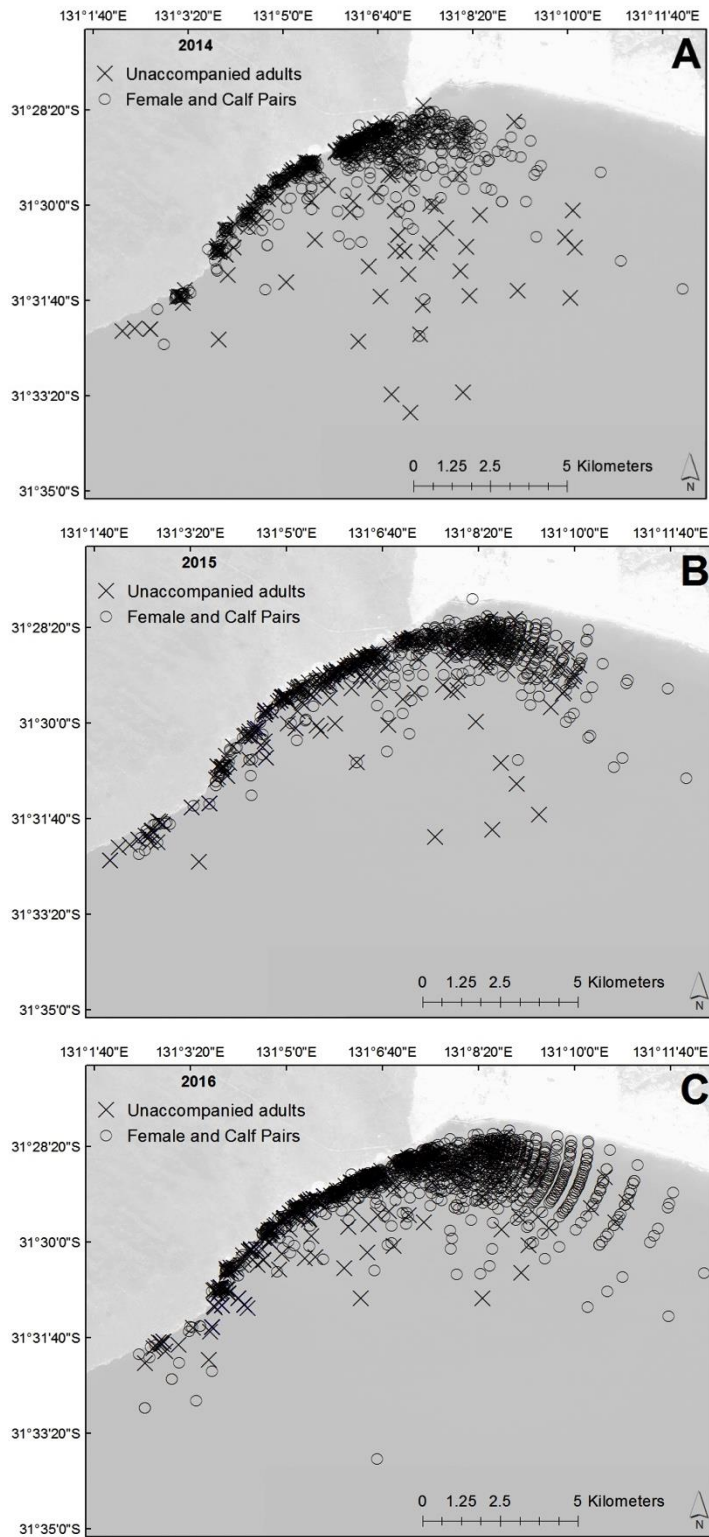


Figure 2-4: All sightings of Southern right whales recorded within the Head of Bight study site in the Great Australian Bight, South Australia between 19 June and 28 September 2014 (A), between 18 June and 25 September 2015 (B) and between 16 June and 25 September 2016 (C), showing females accompanied by a calf in open circle, unaccompanied adults as X.

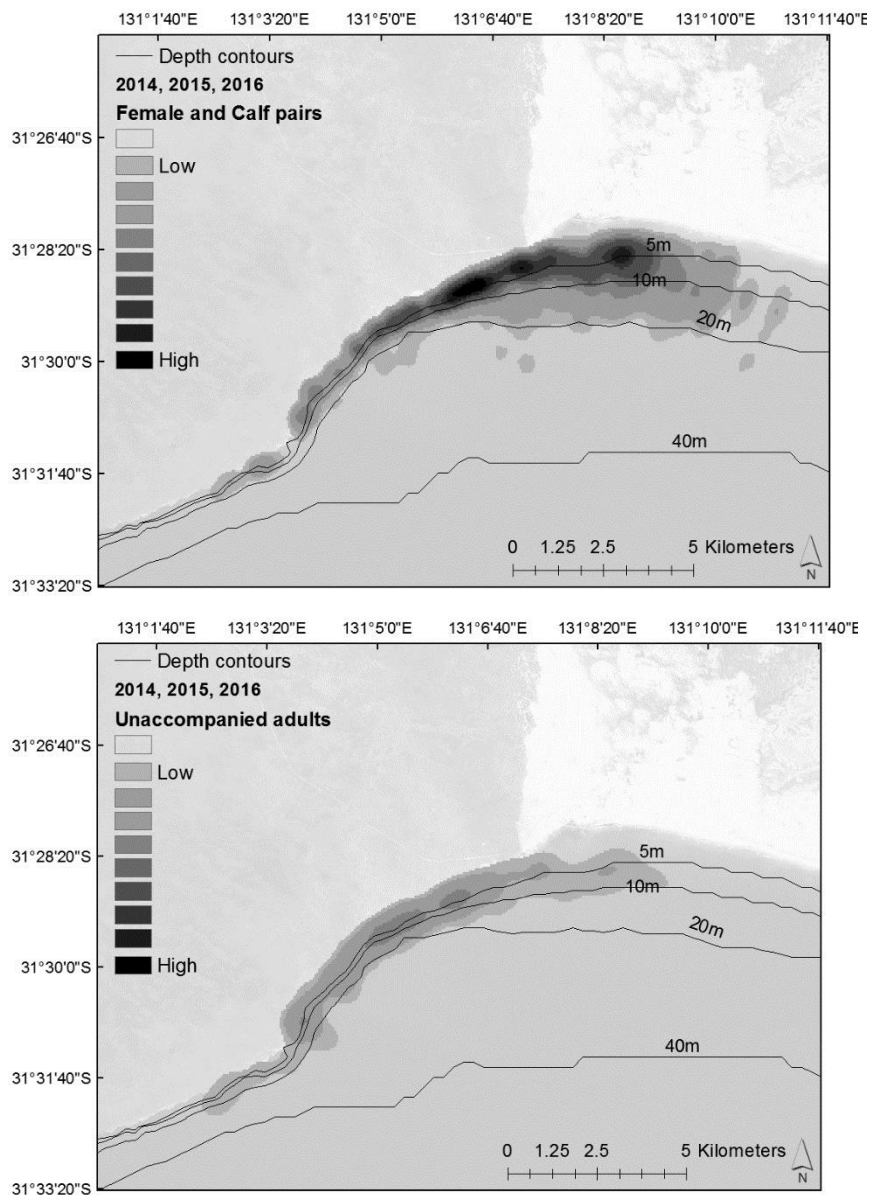


Figure 2-5: Kernel density plot of SRWs female and calf pairs (top) and unaccompanied adults (bottom) at Head of Bight study site, South Australia between June-September using pooled data collected between 2014 and 2016.

SRWs displayed within season variation in distribution at HoB (2014-2016). At the beginning of the season in June, when calves were very young or females were still pregnant, whales were commonly distributed in the shallow bay area in the east of the study area. As the season progressed, the distribution of female and calf pairs increasingly extended along the Bunda Cliffs to the west of the study area (Figure 2-6). Unaccompanied adults were predominantly distributed along the cliffs in the centre of the study area throughout the season.

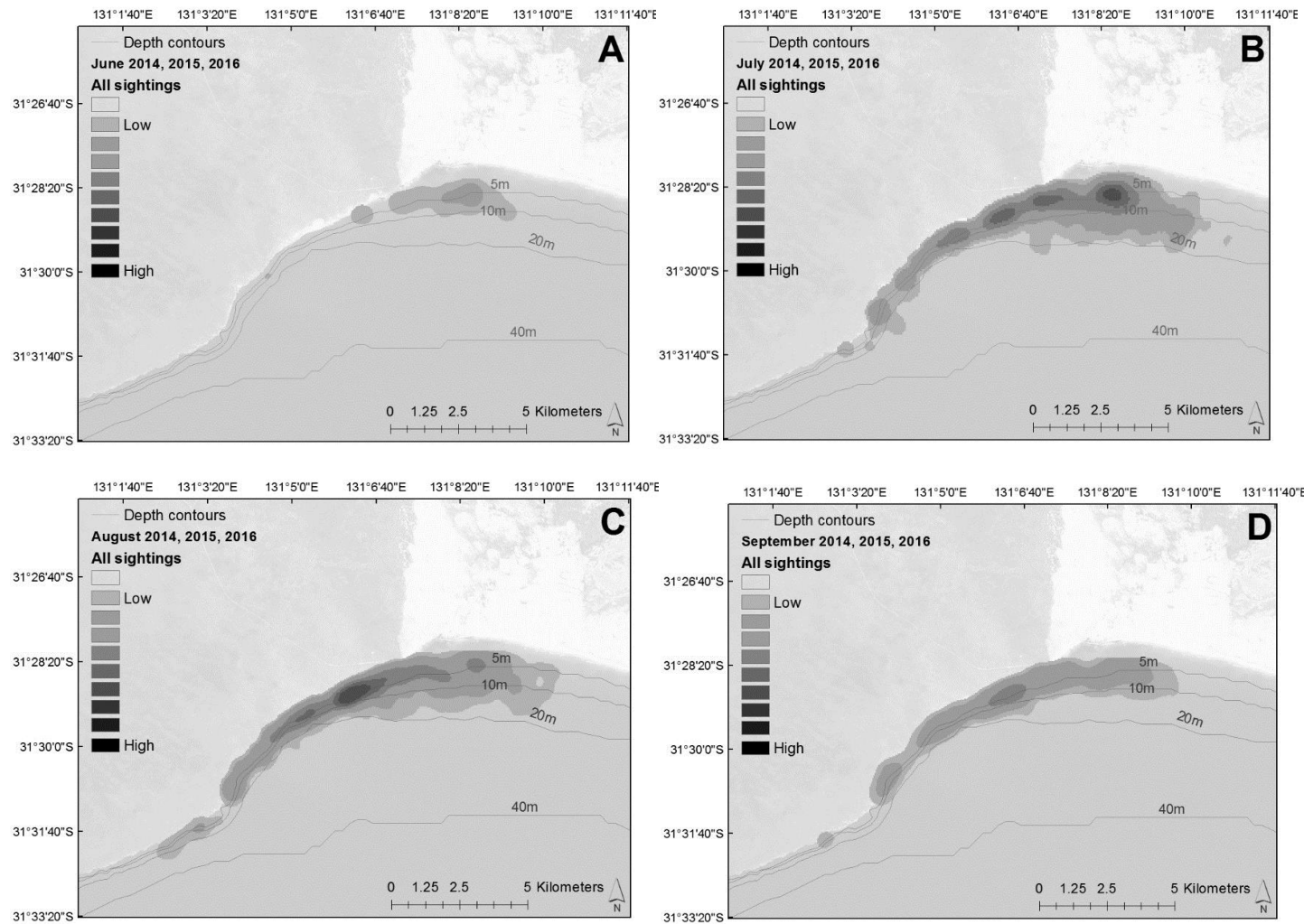


Figure 2-6: Within season distribution of Southern right whales at the Head of Bight, South Australia using pooled data 2014-2016: A) June; B) July; C) August; D) September

2.4.4 Abundance

A total of 794 counts resulted in a total of 24,806 SRW sightings at the HoB study area over the 25 years between 1992 and 2016. Sightings of female and calf pairs, unaccompanied adults and unknown status represent 67%, 27% and 6% of all sightings, respectively. SRWs displayed within season variation in abundance at the HoB study area (Figure 2-7). Whales arrive at the site in June and July, and reach their peak in August and then start to depart the site in September and October.

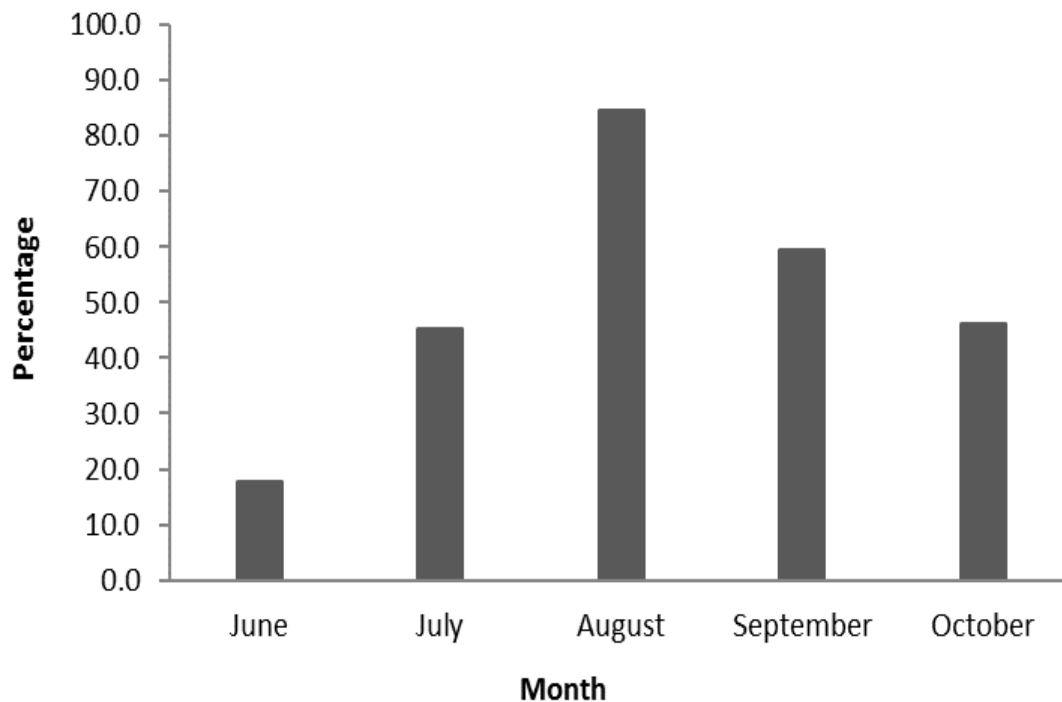


Figure 2-7: Mean percentage of female and calf pairs observed at Head of Bight between June and October 1992-2016

Female and calf pairs occupy the site between June and October. Based on the proportion of female and calves recorded within season, across the study period, a mean of 16% (range 8-28%, SD= 6.5, 95%CI=0.15) of the females that were sighted with calves during the season were present in the study area in mid-June, and a mean of 27% (range 13-61%, SD= 15.8, 95%CI=0.37) of females with calves remained in the area in late September (Figure 2-8).

Unaccompanied adults occupied the site in the greatest abundance between July and August, with few sightings before mid-June or in September. The percentage of unaccompanied adults sighted within the HoB study area throughout the season was 8% in June, 23% in July, 44% in August, 18% in September and 7% in October.

2.4.5 Peak abundance period

The peak abundance period of SRW at Head of Bight during 1992-2006 and 2014-2016 was between late July and mid-September, with peak abundance mostly occurring between mid to late August (Figure 2-8). The overall mean peak abundance period for a 14-day moving average with 12-day overlap occurs between August 3 to 17 for total individuals at HoB. The years 2007-2013 were excluded from this analysis because only the two-week period was surveyed between August 15 and 30. There was some inter-annual variability in the 14-day peak abundance period.

The overall mean 14-day peak abundance period occurs between July 20 to August 3 for females accompanied by calves at HoB. Inter-annual variation in peak abundance was recorded for female and calf pairs. The peak abundance period was recorded between early July and early September, with most variability occurring between 1992 and 2006 (Figure 2-9). Between 2014 and 2016 there was no significant difference in the 14-day peak abundance period, which was recorded in August.

The peak abundance period for unaccompanied adults was not significantly different across all years and was recorded between mid-August and early September, except for 1991 and 2016 (Figure 2-9). In 1991 the 14-day period of peak abundance was recorded between early and mid-September and in 2016 in late-July to early-August.

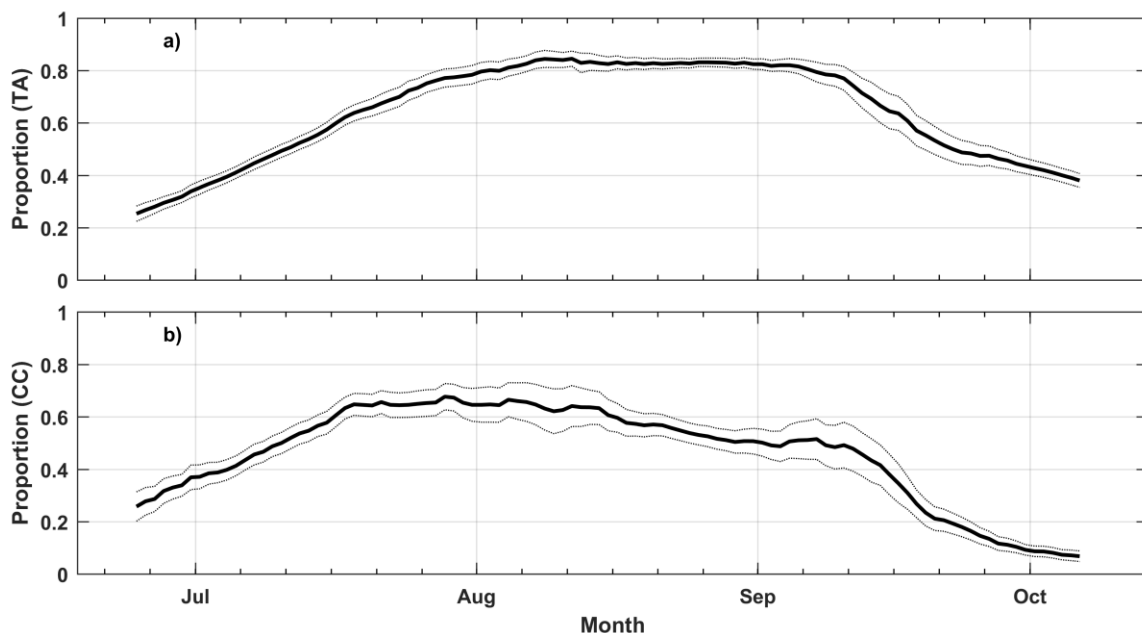


Figure 2-8: Abundance of (a) the total southern right whales and (b) females accompanied by a calf sighted at the Head of Bight study area between 1992 and 2016 using a 14-day moving average with 12-day overlap (presented as proportion of overall sightings). The dotted lines represent the 95% confidence limits.

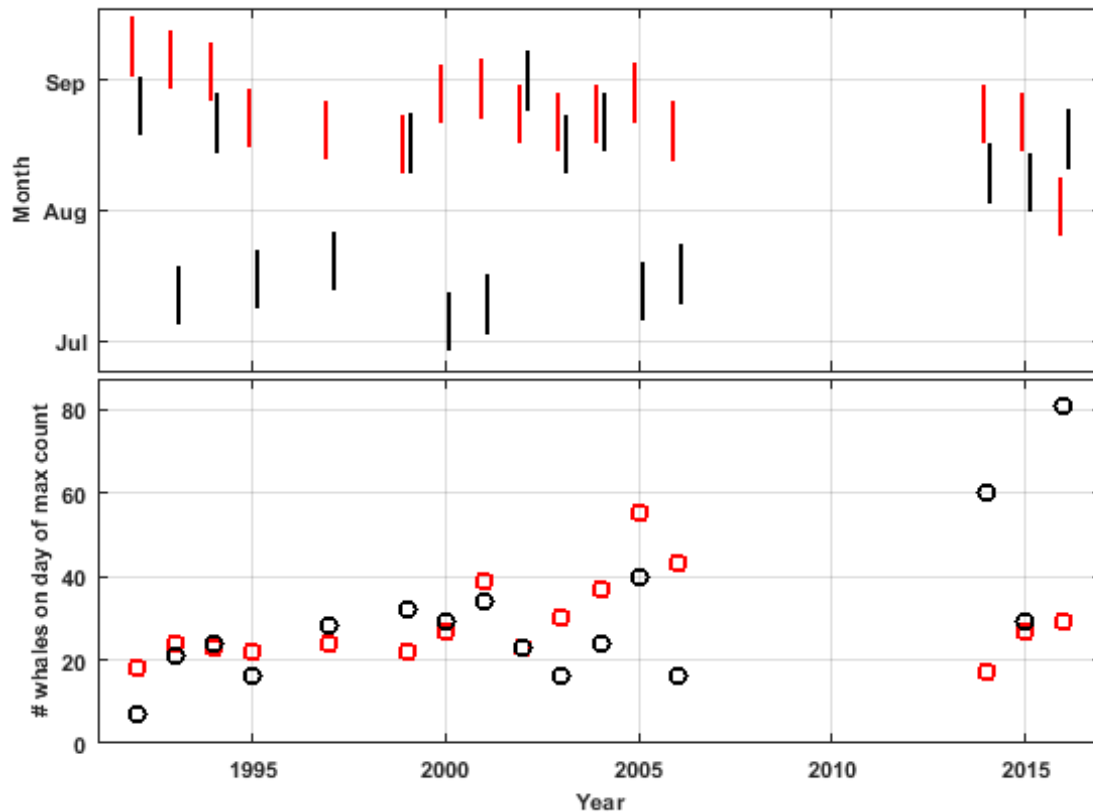


Figure 2-9: Mean peak abundance of southern right whales recorded within the HoB study area between May and October 1992-2016, using a 14-day moving average with 12-day overlap (top) with female and calf pairs in black and unaccompanied adults in red. The line represents a 14-day period. The maximum daily relative abundance count recorded per year is presented below with black circles showing female and calf pairs and red circles showing unaccompanied adults.

2.5 Discussion

Within and between season trends in distribution and abundance for SRWs at the major aggregation ground at HoB were investigated using 25 years (1992-2016) of count data collected during annual cliff based research. The distribution of SRWs at HoB showed variability within season and variation between seasons in the HoB study area, with variability within season more pronounced. Mother calf pairs were typically more densely distributed in the shallow sandy habitat in the east of the study site during June, becoming more widely distributed to the west along the deeper, cliff coast in July/August. Unaccompanied adults were more densely distributed towards the west of the study site. Consistent with findings from this study for the years 1991-1999 (Burnell and Bryden, 1997; Burnell, 2001), SRWs at HoB were distributed across the whole study area along approximately 15 km stretch of coast and within 2 km of shore at HoB.

Within season variability in abundance occurs at HoB as SRWs arrive in late-June to early-July, peaking in abundance during late-July to mid- August, and departing in late September

to early-October. Unaccompanied adults were more transient into and out of the site and their abundance was more variable than females accompanied by a calf. Within season variation indicates immigration and emigration of individuals into and out of the study site, particularly for unaccompanied adults.

Within season abundance varies for different populations of the species in the Southern Hemisphere. Peak periods of abundance were recorded earlier in the year for SRWs in Australia compared with Argentina, South Africa and Brazil. SRWs migrate to waters off Australia, South Africa, Argentina, Brazil, New Zealand and Chile during the austral winter, however the timing and duration of the 'calving' seasons can vary between locations. In South Africa, SRW's can be sighted all year round but with calves they are sighted between June and December, and peak numbers recorded in September (Best and Scott, 1993). At Peninsula Valdes, Argentina, the calving season is between May and December, with the maximum number of whales present from August to September (Crespo *et al.*, 2017; Rowntree *et al.*, 2001; Payne, 1984 & 1986). In Patagonia SRWs dispersed into a new area in San Matias Gulf, near Peninsula Valdes. Whales were observed from August to October with a peak in late August-early September (Arias *et al.* 2017). Off the coast of Chile, sightings of 'eastern' South Pacific SRWs were recorded between July and October with resident times of up to three months, and within season movements of up to 159 km (Galletti *et al.*, 2014). Similarly, in southern Brazil sightings occur from May to December, with most recorded between July and September (Camara and Palazzo, 1985; Simoes-Lopes *et al.*, 1992). An earlier peak in calving in Australia (late-July to early-August) may be attributed to the shorter distance travelled from feeding grounds. Triggers for arrival and departure to wintering aggregation areas also include weather and climate factors such as local storm events, air and water temperature influencing thermoregulation (Burnell and Bryden, 1997) and physical condition (Lockyer, 1981).

Results here provide information on timing of arrival and departure of SRWs to the HoB coastal aggregation area, which is required for species management in Australian waters and risk minimisation. Considering the proportion of the breeding population recorded at HoB from mid-June to late-September, and the maximum percentage of breeding females at HoB remaining at the end of the study period (61%), SRWs and their newborn calves may be sensitive to potential impacts in the broader GAB area between May and October or beyond. The number of breeding females present at the start of the season is an underestimate because pregnant females are not recorded as part of that season's breeding cohort until they are sighted with a calf. For example, of the five unaccompanied adults photo-identified between 16 and 19 June 2016, three were sighted later in the season with a calf.

There is some variability in the peak abundance period for female and calf pairs, ranging from mid-July to early September. There is less observed variation in the peak abundance period for unaccompanied adults, ranging from late July to early September. Although the study period August 15 to 30 is not always inclusive of the 14-day peak abundance period, the maximum daily count was always recorded during this period and it is considered the most representative period to sample female and calf pairs and unaccompanied adults.

Most females have calved by mid-August; therefore, for analysis purpose it is assumed that counts completed during August 15-30 include the majority of all breeding females that select the HoB study area as a calving/nursing habitat for that season (Burnell, 2001; Burnell and Bryden, 1997). To cover the peak abundance period for female and calf pairs as well as for unaccompanied adults, a six-week field study between mid-July and late-August is recommended. Future monitoring planning needs to take this into account whilst maintaining comparability with the long-term time-series. Females have been recorded the month after peak calving in South Africa (Best 1990) and Argentina (Rowntree *pers comms.*). Whilst mother calf pairs are sighted for the first time at HoB in September, these individuals are generally transiting through the area and not selecting HoB as a primary nursing ground.

Distribution and abundance reported here may have had biases associated with lower detectability with range in the 'eastern' end of the study area. However, aerial surveys conducted through the Western Australian Museum (Bannister, 2017) within the HoB study area following the coastline at a range of approximately 1 km indicate that the cliff-based surveys compare favourably. For example, in 2016, 66 females with calves and 11 unaccompanied adults were counted from the aircraft on one day. On the same day, the cliff-based team counted 66 females with calves and 10 unaccompanied adults.

A total of 95% of all SRW sightings recorded between 2014 and 2016 occurred within an area 10.16 km long from east to west and within 1.04 km from shore. Research suggests a minimum spatial distance of 150-200m between adults at Head of Bight (Pirzl, 2008). Based on a spacing distance of 150 m, the area occupied by 95% of female and calf pairs sighted would reach capacity at 68 female and calf pairs, assuming a perfect packing density. Given that a minimum spatial requirement of 100 m can be tolerated by SRWs at HoB, the area occupied by 95% of whales sighted would reach capacity at 155 female and calf pairs, assuming a perfect packing density. However, it is considered unlikely that whales would tolerate such crowding as habitat dispersal has been observed with much fewer whales. Results suggest that the primary habitat for SRW at Head of Bight may have already reached capacity with a maximum of 172 individuals including 81 female and calf pairs sighted on one day in 2017. Helicopter surveys completed by the South Australian Research and Development Institute (SARDI) in 2014 (Mackay *et al.*, 2015) of the broader region between the WA border in the

west and Fowlers Bay in the east showed that up to 17% of whale sightings occurred outside of the HoB cliff based study area. Density resource pressures i.e. space will cause SRWs to disperse outside of the desired habitat in the primary aggregation area at HoB. It can be expected that habitat dispersal outside of Head of Bight will occur with an increasing population.

While this study provided a clear indication of the consistency and timing of abundance of SRWs in the study area, daily counts provide a snap shot of SRWs distribution and abundance on a given day within the study area, and do not consider immigration and emigration of whales to and from HoB. Therefore, the maximum daily count is an underestimate of the true maximum number of individuals using the HoB aggregation area in a season. Photo-ID mark recapture shows that the number of individuals photographed in a season often exceeds the maximum daily count, implying immigration and emigration across a season (Burnell, 2001; Charlton, 2017- Chapter 2). Unaccompanied adults were more transient than females accompanied by a calf, displaying greater immigration and emigration from the site.

In summary, this study has improved our understanding of seasonal trends in distribution and abundance of SRWs at the major aggregation area, HoB using data over the period 1991-2016. Information on the timing of arrival and departure of whales to and from HoB highlights that May through to October are sensitive periods for SRW migration to and from the coast of Australia. Results show that whilst the MMPZ effectively provides protection for the whales at HoB, the movement of whales outside of this area has increased with population growth. The primary area occupied by SRW at HoB is likely to reach saturation capacity in years of abundance greater than 138 individuals and therefore dispersal into alternative habitat can be expected. It is important that recovery goals prioritise the management of SRW outside of the MMPZ, along the coastline and in small and emerging aggregation areas. Identification of the peak periods of abundance at HoB between mid-July and late-August will direct future monitoring planning. The historical study period (August 15-30) successfully covers the peak annual counts, however to ensure coverage of the full peak abundance period, surveys at HoB between mid-July and late August are recommended. This study provides a baseline for detecting changes in population size over time. Ideally, future monitoring and research should consider the full distribution of SRWs in Australia and connectivity between coastal aggregation grounds, to ensure protection of the population and continued recovery of the species.

3 Long term trends in abundance and life history parameters of southern right whales (*Eubalaena australis*) at Head of Bight, South Australia (1991-2016)

Charlton C.M¹., R. McCauley¹., R. Ward¹., R. L. Brownell ³., J. Bannister., S.R. Burnell³

¹Centre for Marine Science and Technology, Curtin University Western Australia

²NOAA Fisheries, Southwest Fisheries Science Center, Monterey, California, USA

³Eubalaena Pty. Ltd.

Key words: Southern right whale; South Australia; life history; demographics; photo identification; abundance; rate of increase; biological parameters.

3.1 Abstract

Long term trends in abundance and life history parameters for southern right whales (SRWs), *Eubalaena australis* at Head of Bight (HoB), South Australia were estimated using 26 years of photo identification mark recapture and 25 years of count data. The long-term cliff based SRW count and photo identification study was completed annually between 1991 and 2016. The estimated mean rate of increase in SRW at HoB was 3.17% (SD= ± 95% CI) per annum (1992-2016). The corresponding mean rate of increase for females accompanied by a calf was 4.6% (SD= ± 95% CI). Owing to cohort structure and pulses in calf production, the annual maximum abundance recorded was highly variable across years (\bar{X} =39, SD=17.8). The photo identification database includes 1,186 non-calf individuals, of which 459 are reproductive females with 471 inter-annual calving intervals. SRW sighted at HoB represent 0.21-0.48 of Australian 'western' sub-population in Australia. Mean photo identification success of 92% was recorded for females with a calf and mark recapture resights were recorded for 70% of those females. The estimated apparent mean calving interval was 3.3 years (SD=0.8, ± 0.3, 95% CI); and mean age at first parturition 9.3 years (n=22, SD=2.1, ± 0.9, 95% CI). Results from cross matching completed to date between the HoB and the rest of the 'western' sub-population provided an additional 207 calving events from 267 individuals. The combined data resulted in the same mean calving interval recorded for only HoB of 3.3 years. The data provide information on life history parameters for recovery assessments, species conservation management and global comparative studies.

3.2 Introduction

Southern right whales (SRWs), *Eubalaena australis* are listed as of least concern under the International Union for Conservation of Nature (IUCN) Red List, as endangered under the Australian Commonwealth Environment Protection Biodiversity and Conservation (EPBC) Act (1999). SRW were depleted to near extinction by commercial whaling in the 19th century (Dawbin, 1986) with further depletion in the mid-20th century (Tormosov *et al.*, 1998; IWC, 2013). Although SRWs became protected internationally from commercial whaling in 1935, illegal catches by the Soviet Union prevented continued increase in their abundance until the 1970's (Tormosov *et al.*, 1998). The global population estimate of SRWs recorded in 2009 was 13,600 individuals (IWC, 2013). SRWs are found in Southern Hemisphere latitudes between 16° S to 65° S, with genetically distinct populations in Australia, New Zealand (NZ), South Africa, Argentina and Chile-Peru (Portway *et al.*, 1998, Baker *et al.*, 1999, Patenaude *et al.*, 2007, IWC, 2013; Galletti *et al.*, 2014). SRWs migrate to northern aggregation grounds to breed, calve and rest during the austral winter.

Since overexploitation by commercial whaling, the endangered SRW was not rediscovered off Australia until anecdotal reports were made of a small number of whales during 1955–1968 (Bannister, 1986). Although the Australian population is now increasing, there is a marked difference in population size and rate of recovery between the 'western' sub-population, found in south-Western Australia (Western Australia [WA] and South Australia [SA]) and the 'eastern' sub-population found in south-'eastern' Australia (Victoria, New South Wales and Tasmania) (Bannister, 2017). Evidence of genetic differentiation has led to the proposed delineation of distinct south-'western' and south-'eastern' Australian management units (Carroll *et al.*, 2011, Carroll *et al.*, 2015, Jackson *et al.*, 2016). The 'western' sub-population occurs predominantly between Cape Leeuwin, WA and Ceduna, SA and comprises most SRWs in Australia. The current abundance estimate for the 'western' sub-population is around 2,200 individuals and the annual rate of increase is approximately 5.55% (95% CI 3.78, 7.36) per annum (p.a.) for all animals and 6.01% (95% CI 3.49, 8.59) p.a. for females with a calf, based on aerial surveys undertaken between 1993 and 2015 (Bannister, 2017). The 'eastern' sub-population can be found along the south-'eastern' coast of Australia, including Tasmania and rarely further north than Sydney, with key aggregation areas in Portland and Warrnambool in Victoria. It is estimated at 257 individuals and is showing no signs of increase (Watson *et al.*, 2013; Bannister, 2017). A rate around 6-7% p.a. is considered the maximum biological rate of increase for SRWs (IWC, 2013). The Australian Government's SRW Conservation Management Plan (2011-2021) has given high priority to understanding life history parameters and measuring population growth of both Australian sub-populations (DSEWPac, 2012).

Head of Bight (HoB) in the Great Australian Bight (GAB), SA is a major aggregation area for SRWs in Australia and is close to the 'eastern' range of the 'western' sub-population. The rate of increase in total whales at HoB was estimated at 4.3% p.a. between 1991 and 2007 (Burnell, 2008). The comparable estimate for the 'western' population was approximately 5.2% p.a. (1993-2007 Burnell, 2008). The lower rate of increase estimated at HoB, compared to the overall 'western' subpopulation was an indicator of possible changes in habitat dispersal, immigration or emigration and movement between coastal aggregation areas (Burnell, 2001). A particularly low abundance year at HoB in 2007 influenced the lower rate of increase observed by Burnell (2008). The rate of increase between 1991 and 2006 was comparable between HoB of (5.4% p.a.) and the 'western' sub-population (6% p.a.) (Burnell, 2008).

Analysis completed to date on the HoB photo identification (ID) dataset includes life history parameters analysed using empirical photo-ID mark recapture data collected between 1991 and 1997 (Burnell, 2001) and 1991 and 2007 (Burnell, 2008). Population estimates, rate of increase and distribution of SRW are available through long-term aerial surveys between 1993 and 2016 undertaken through the Western Australian Museum (WAM) (Bannister 1999, 2001, 2011 and 2016). An updated assessment of life history parameters is needed to inform species recovery assessments.

Long-term monitoring of SRWs using photo-ID mark recapture methods can provide information on population estimates (Whitehead *et al.* 2000, Cooke *et al.* 2001, Best *et al.* 2005, Bannister, 2017; Jackson *et al.*, 2016), calving intervals (Burnell, 2001 & 2008; Cooke *et al.*, 2001; Best *et al.*, 2005), age of first calving (Burnell, 2001, 2008, Cooke *et al.*, 2001, Best *et al.*, 2005), site fidelity (Burnell, 2001; Carroll *et al.*, 2014; Charlton, 2017 – Chapter 4) and movements (Burnell, 2001; Pirzl *et al.* 2009; Carroll *et al.*, 2014; Roux *et al.*, 2015; Charlton, 2017 – Chapter 6). Life history parameters are fundamental to the assessment of population rate of increase and viability analysis and include calving intervals, age at first parturition, survival and mortality (Brandão *et al.*, 2011; Cooke *et al.*, 2001; Skalski *et al.*, 2005; Mace and Lande 1991; Zerbini *et al.*, 2010). Biological parameters are subject to variability due to density dependence, habitat occupancy, or other natural influences such as prey availability, health and body condition. A change in these factors can alter the rate of population increase over time. Life histories are an important indicator of population health and recovery. Analyses of long term datasets that enable assessment of life histories and changes to these parameters over time are critical for conservation and management.

This study aimed to assess the long-term trends in abundance and life history parameters of SRWs at HoB over 26 years (1991-2016). Life history parameters assessed included mean calving interval, mean age at first parturition and longevity. Mark recapture resight rates were calculated along with the subsequent number of new individuals not previously sighted at HoB

with a calf. The number of individuals sighted at HoB relative to the number of individuals recorded annually along the Australian coast for the 'western' sub-population was also assessed as an indicator of the relative significance of the calving site.

3.3 Methods

3.3.1 Study area

Head of Bight is in the GAB in the far west of SA ($31^{\circ} 29' S$, $131^{\circ} 08' E$, Figure 3.1) approximately 270 km west of Ceduna and 210 km east of the WA border (using shortest swim distance). The site is adjacent to Yalata Aboriginal Land on the Bunda Cliffs of the Nullarbor Plain. The HoB aggregation area is within the Marine Mammal Protection Zone (MMPZ) of the GAB Commonwealth Marine Reserve and the Far West Coast State Marine Park. The GAB Marine Reserve was established in 1995 to protect the SRW aggregation area at HoB. The study site is selected to include the primary aggregation area and extends approximately 15 km along the coast and 5 km offshore (Figure 3-1).

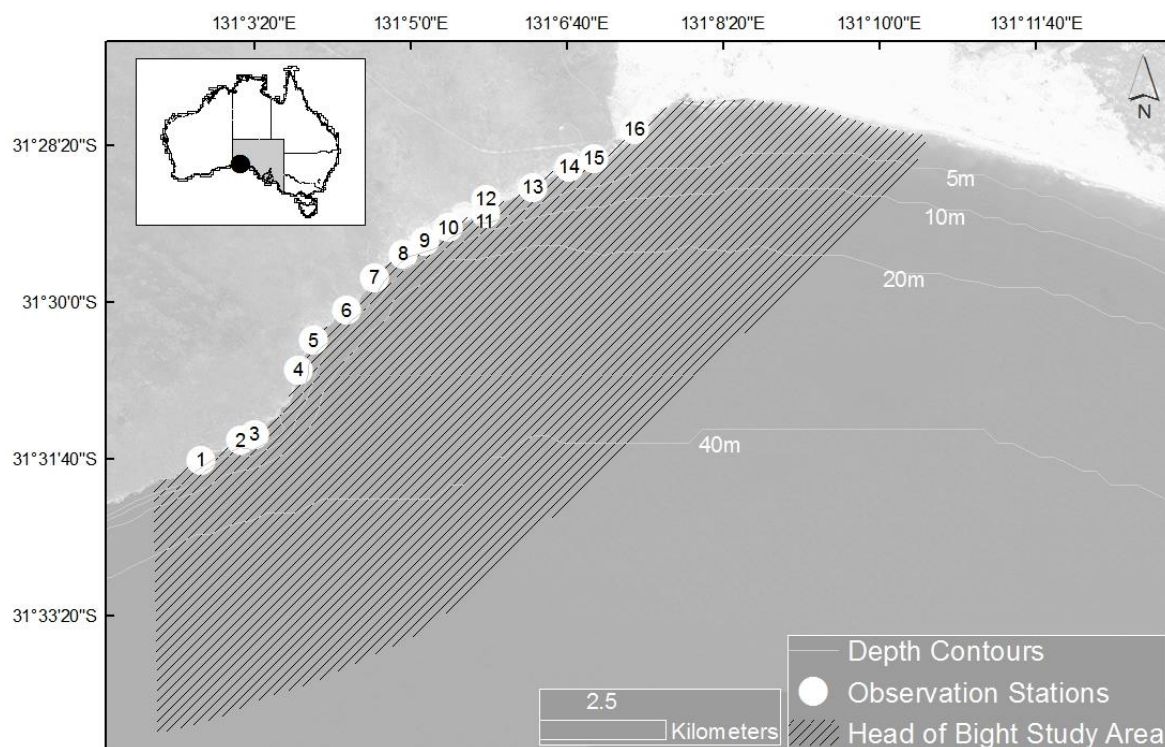


Figure 3-1: Boundaries of the study site and location of observation stations for Southern right whales at Head of Bight in the eastern Great Australian Bight, South Australia.

3.3.2 Study period

Land based field surveys were completed at HoB annually between May and October, 1991-2016. During each year, a minimum of eight days within a two-week period was surveyed

between August 15 and 31 to provide inter-annual comparisons of population trends at the site. The study period was selected because it was considered the peak period of abundance with high likelihood of sighting most females accompanied by a calf (Burnell and Bryden, 1997). Calving females (female accompanied by a calf of the year) are expected to have calved by the middle to end of August (Burnell, 2001), and it was assumed that the study period provided access to all calving females that selected HoB as calving/nursing habitat in that season (Burnell and Bryden, 1997, Burnell, 2001). Whilst it is recognised that immigration and emigration occurs, it is assumed that mother calf pairs that selected HoB as a nurse ground remained in the area long enough to be captured during counts and photo ID. Females accompanied by a calf were distributed along the Bunda Cliffs in late July-August where optimal photo-ID images can be collected (Charlton, 2017 – Chapter 2). Outside of the two-week field study (August 15-31), the study effort was variable across years (Table 2-1Table 2-1).

Survey methods for SRW counts and photo-ID at HoB study site were consistent with those described by Burnell and Bryden (1997) and Burnell (2001). Methodology for counts is described in detail in Charlton, 2017 (Chapter 2) and photo-ID methods are described below.

3.3.3 Counts

SRW within the study area were surveyed from 16 land based observation stations along a stretch of approximately 15 km of coastline out to 5 km from shore, with observer elevation between 33 m high in the east and 53 m high in the west. Observations consisted of systematic scans using 10x50 Bushnell binoculars and the naked eye. Duplicate sightings were obviated by recording distance and angle to whale from the observation station, marking the whale location on a map in real time, minimising the time taken to transit between each station, and collecting photo-ID images where possible to validate individuals sighted at the previous observation station. Surveys were completed in Beaufort Sea States of three or less to reduce bias in counts due to weather conditions.

Most animals, particularly females accompanied by a calf, were easily observed in the relatively clear and shallow waters at HoB and the probability of sighting within the study area was assumed to be one ($g(0)$) (Burnell, 2001; Bannister, 2017). Observer bias was reduced by using two trained and experienced observers and minimising rotation of researchers across the duration of the study. A minimum of eight counts was completed each year and the maximum daily count was used to inform population increase over time. The maximum daily count number is reflective of the number of individuals present in the HoB study site on one day during the study period. While the maximum daily count is indicative of numbers using the

site on a given day, it is likely an underestimate of the true maximum number using the site in a season, since whales immigrate and emigrate to and from the site throughout the season.

A breeding cohort is referred to as the group of females accompanied by their calves in each year. SRW females form breeding cohorts based on their mainly three-year calving intervals. Females display high site fidelity to calving grounds in the year of calving (Burnell, 2001; Payne *et al.*, 1990). It is assumed that the year of calving is followed by a 'rest' year with no migration (or migration to elsewhere), and then a lactating year when animals migrate to areas alternate to their selected calving ground (Best, 1994; Brandão *et al.*, 2011; Burnell, 2001; Cooke *et al.*, 2001). Therefore, annual monitoring is required to assess the trends in abundance and increase in each breeding cohort to understand the overall population trends and potential changes to the rate of increase over time (Bannister *et al.*, 2011).

For each SRW sighting the following variables were recorded: date, time, observation station, group composition (number and classification of individuals i.e. female accompanied by calf, unaccompanied adult (male or female not accompanied by a calf of the year), unknown status (undetermined if whale was accompanied by a calf of the year or not due to limited visual record), range and bearing. Environmental conditions including wind speed and direction in knots, cloud cover in percentage, Beaufort Sea State and swell height were recorded qualitatively at the start and end of each daily survey.

3.3.4 Photo identification

Photographs of individual whales were obtained for comparing and matching individuals photographed previously. Photographs used for identifying individuals (photo-IDs) taken from the 33-53 m high Bunda Cliffs provided the required vantage point for collecting high quality images of the dorsal surface of the whale at proximity. Photographs of the dorsal surface allow callosity patterns on the head that are unique to each individual to be documented. Callosity patterns are keratinised skin patches colonised by cyamids that provide unique markings on the dorsal surface of the rostrum, the lip line of the lower jaw and just posterior to the blowhole that persist throughout life (Payne *et al.*, 1983). To capture the unique callosity patterns, photographs of the rostrum from above and left and right lateral perspectives of the dorsal side of the whale were obtained when possible. The ventral side of whales was also photographed if presented, to document the size and shape of white pigmentation (also persistent and unique) and the ano-genital configuration (to give information on sex). Evident markings and scarring were also photographed. Photographs were taken using a Nikon 7100 or D100 digital SLR camera with a Nikon 500 mm (effective 750 mm) or Sigma 500 mm lens mounted on a tripod.

For the purposes of this study, collection of photo-ID of adults were targeted including mother/calf pairs and unaccompanied adults because their callosity patterns are well developed. Photo-ID effort for calves increased later each season when their callosity patterns were developed enough to enable future resights. This study provides the only individuals of known age for the Australian SRW population through identification of calves in their year of birth. For cliff-based photo-ID, capturing photos of adequate quality was not possible when whales were at greater distances than approximately 300 m from the cliff top. However, since whales commonly move within the aggregation area, many individual whales present at locations where photo-ID was not possible on a particular day, were often photographed at a location amenable to photo-ID later. Furthermore, in 2016, the use of Unmanned Aerial Vehicles (UAVs or drones) in collaboration with Murdoch University Cetacean Research Unit provided access to all whales in the site for photo-ID. The whale position, behaviour, group composition, age class and reproductive status were recorded for each whale. Photo-ID images obtained during this study were supplemented by similar images provided in-kind from aerial surveys across the entire 'western' population range completed through the Western Australian Museum (1993-2016) courtesy of J. Bannister.

3.3.5 Data Analysis

Long term trends in abundance and rate of increase

Long term trends in abundance and the annual rate of increase were estimated using all years of count data, except for 1991 where numbers of groups were recorded rather than individuals. Two methods were used to estimate the rate of increase in SRW at HoB to be comparable with past analysis for HoB (Burnell, 2008) and current analysis applied to the 'western' sub-population (Bannister, 2017). The two methods include: 1) compound annual growth rate (CAGR) (Burnell, 2008), and 2) linear regression of the natural logarithm of count data (Bannister, 2017).

For method 1), the mean compound annual growth rate was calculated using a three-year sliding average to consider the average 3 calving intervals of SRWs and subsequent cohort structured calving cycles. A simple exponential regression was fitted to the long-term count data and presented with 95% confidence intervals and standard deviation. For method 2), data were presented as a linear regression of the natural logarithm of the annual count data for 'all animals' and for females with a calf. The 95% confidence intervals were calculated for the rate of increase and data presented with R^2 value on exponential regression.

3.3.6 Life histories

Life history parameters including mean calving interval and mean age at first parturition were estimated using photo-ID images collected of calves in their year of birth and using photo-ID

resight data for individual whales collected over all years (1991-2016). To estimate life history parameters, only the sightings of females accompanied by a calf were used (Payne *et al.*, 1990; Cooke *et al.*, 2001). Sighting histories of individuals that were not previously sighted with a calf were not included in the analysis because their sex and maturity status were not always known (Cooke *et al.*, 2001). Calculation of mean observed calving interval considers calving intervals between one and five years only. It is assumed that individuals sighted at HoB with a calving interval of six years or greater were likely to have either calved somewhere else, were missed by observers, or represent a failed calving in the intervening period (Burnell, 2001; Cooke *et al.*, 2003; Brandão *et al.*, 2011).

Photo-ID resights were identified through matching photographs within and across years by cross matching with the long-term photo-ID catalogue developed in the Big Fish v6 Microsoft Access database (Pirzl *et al.*, 2007). Photographic quality was assessed and poor images of low resolution were discarded. Individuals were only matched when identifiable features were recorded sufficiently to identify both sides of the rostrum. Only individuals with complete profiles were added to the master catalogue. Identification images were compared manually by a small number of persons experienced in right whale photo-ID and matching. All matches were independently verified by at least one primary researcher. Digital photo-ID images were sorted daily in the field, including within season cross matching of individuals, to document the total number of individuals identified in that year and to confirm photo-ID success.

The following assumptions were made in Brandão *et al.*, (2011), and are relevant in this study:

1. Observed calving intervals are biased representations of the true calving frequency, because inter alia females on longer intervals are under-represented in the sample (having a greater proportion of incomplete calving intervals) (Brandão *et al.*, 2011).
2. No allowance is made for calving events missed by the observer. A female calving in a year might not be photographed because (a) the calf died before the survey, or was born after the survey, or (b) the female plus calf were outside the survey area at the time of the survey, or (c) they were in the survey area but were missed.
3. Age at first parturition is biased in that later maturing individuals may be relatively under-represented, and some first calving will go undetected.

To account for the assumptions described above, the recorded calving intervals or ages of first parturition were maximum intervals, with the possibility that a calving event was missed in surveys. Results present raw data on life history parameters. Data are provided for population modelling to validate raw results and extrapolate for comparison with international datasets from other SRW populations.

Cross matching completed to date between the HoB and the Western Australian Museum (WAM) catalogues (Burnell, 2008) were analysed to assess the mean calving interval using combined data. Cross matching of the catalogue to date includes years 1991-2007 of the HoB catalogue with 1993-2004 (and some individuals to 2007) of the WAM catalogue. Sighting histories available from the HoB and WAM catalogue for the 267 matched individuals were then updated to include all available sightings up to 2012 for WAM and 2016 for HoB catalogue. The results for apparent mean calving interval calculated for the HoB dataset (1991-2016) were compared with the analysis of HoB and WAM data combined. This study provides the most comprehensive assessment of SRW life histories in Australia. The analysis was needed to assess the error in estimates calculated for the HoB catalogue; given that HoB is an open population.

3.3.7 Longevity

The longevity of SRW was assessed using early sightings records from within the long-term photo ID resight database. Sightings included images and sightings collected opportunistically from as early as 1970 and including matching completed between the HoB and the WAM catalogues between 1975 and 2007 (Burnell, 2008).

3.4 Results

3.4.1 Trends in long-term abundance

A total of 805 daily cliff-top surveys were conducted between 1992 and 2016 at the HoB aggregation area. Counts from 1991 were excluded due to the inconsistent count method that year. An average of 35 surveys was completed per year, from eight in 2013 to 112 in 1993. Surveys resulted in 42,725 whale sightings over the 25-year study period. Of the total whale sightings recorded, 80% were females accompanied by a calf, 16% unaccompanied adults and 4% were of unknown status (Figure 3-2).

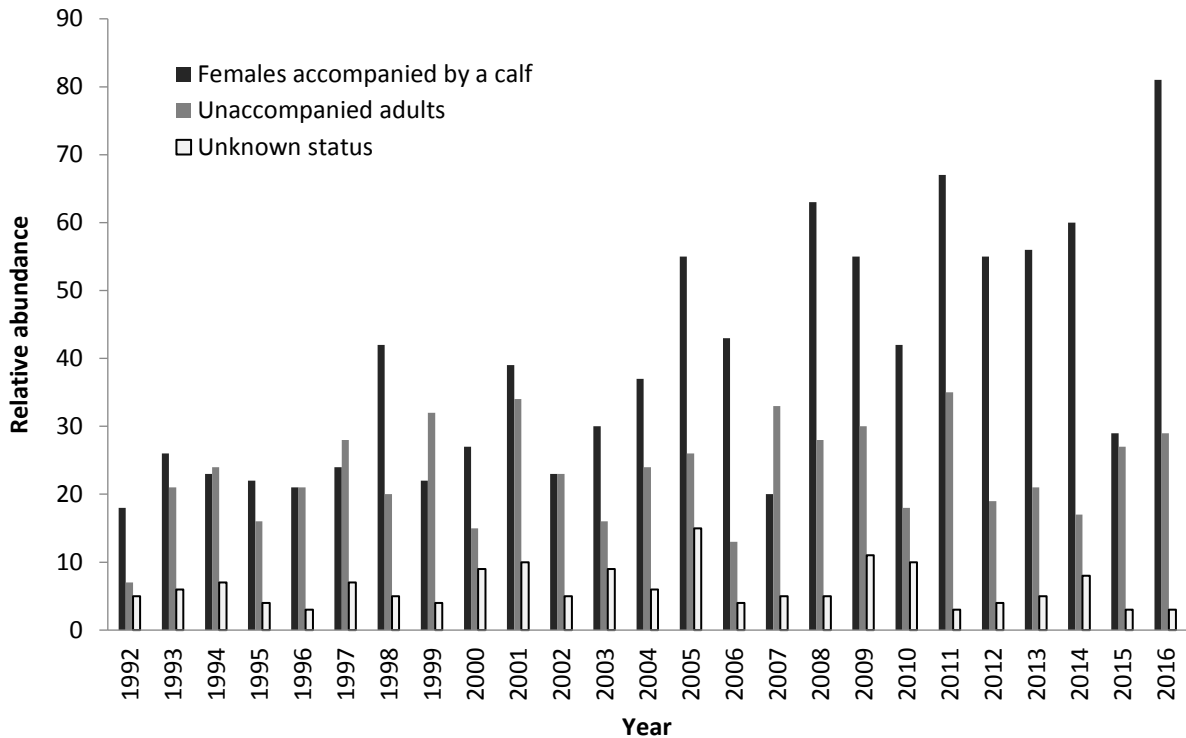


Figure 3-2: Abundance (or maximum daily count in a season) of Southern right whale females accompanied by a calf, unaccompanied adults and unknown status at Head of Bight, South Australia 1992-2016.

Within each year, the maximum count on any one survey day was extracted and used as a proxy for the number of whales using the aggregation area that year. The maximum number of all SRWs sighted (in a single survey day per year) increased from 43 in 1992 to 172 in 2016 at a mean rate of 5.5% (SD=2.5, ± 1.07 , 95% CI) p.a. based on the CAGR and 3.6% ($R^2=0.54$, ± 1.3 , 95% CI) based on a simple exponential regression (i.e. a linear regression of the natural log of the count on year) of the data (Figure 3-4 and Table 3-1). The maximum count was recorded in 2016 when a total of 172 individuals, including 81 females accompanied by a calf, and 29 unaccompanied adults, were sighted on one day in the HoB study area (Figure 3-3). Prior to 2016, the highest abundance was recorded in 2011 when a total of 172 individuals were also sighted on a single day, including 67 females accompanied by a calf and 35 unaccompanied adults. The growth rate of SRW at HoB showed no significant difference across years 1992-2016, however, the growth rate relative to the overall western population appears to have declined slowly over time, possibly representing saturation of the HoB aggregation (Figure 3-5).

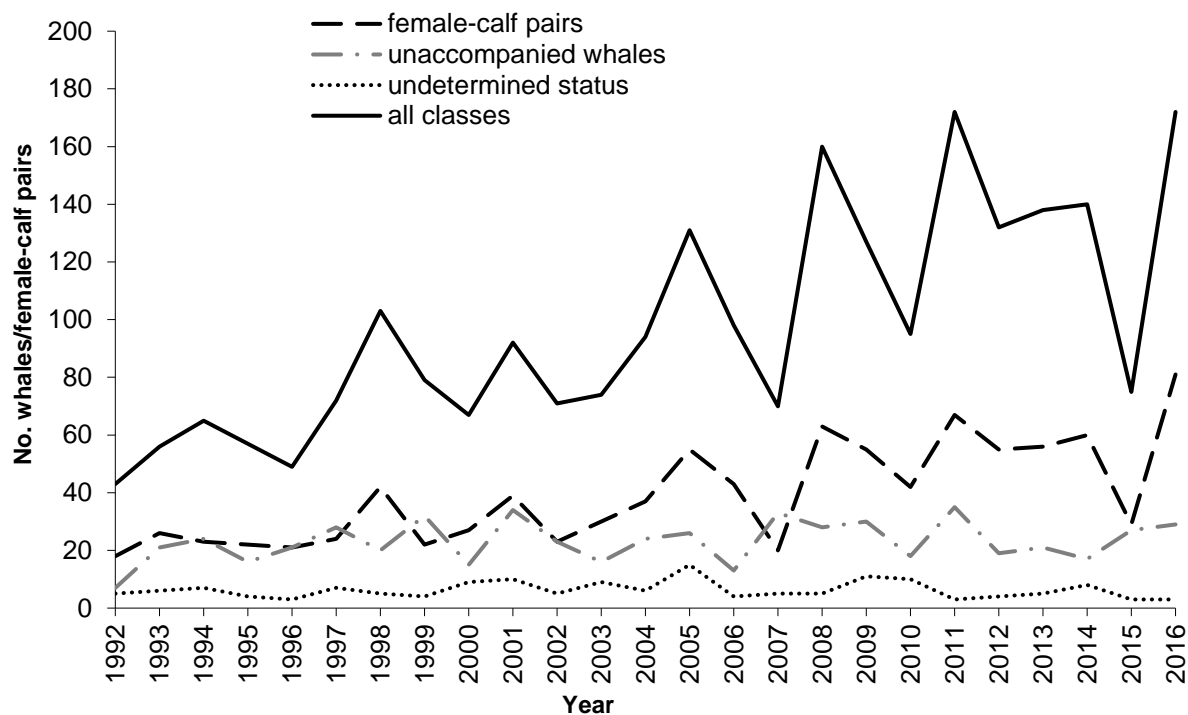


Figure 3-3: Southern right whale abundance trends at Head of Bight, South Australia between 1992 and 2016.

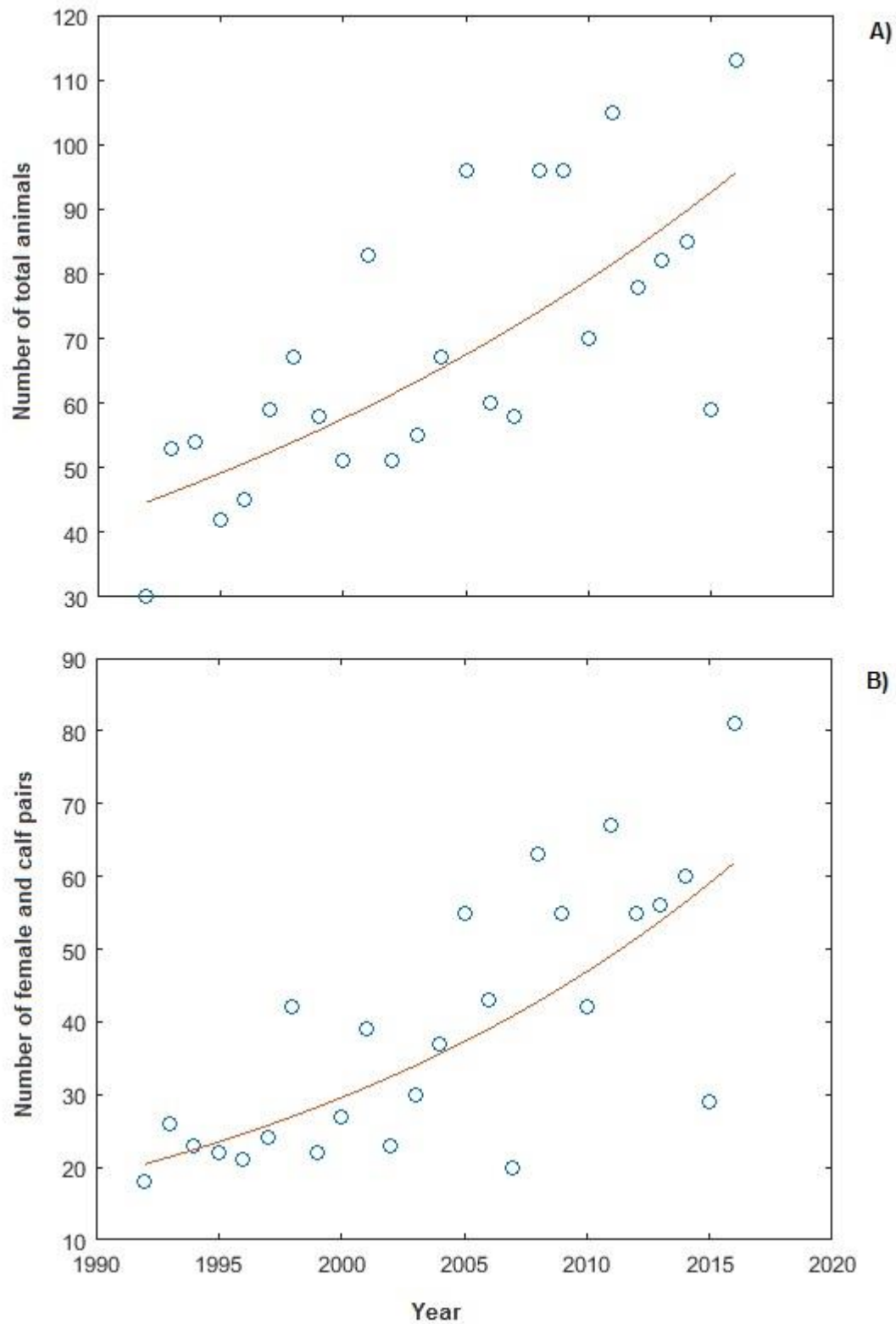


Figure 3-4: Linear regression of the logarithm value for the maximum count per year of Southern right whales at Head of Bight, South Australia between 1992 and 2016 for A) 'all animals' and B) female and calf pairs.

Table 3-1: The rate of increase calculated for 'all animals' and for females with a calf at HoB between 1992 and 2016 using Compound Annual Growth Rate (CAGR) and Linear Regression analysis.
*Taken from Burnell (2008), ** taken from Bannister (2017).

Year and area	All animals		Females with calves	
	CAGR	Linear regression	CAGR	Linear regression
HoB 1992-2006	5.3%*	4.1%, 95% CI ± 2.8 , $R^2=0.43$	5.4%*	5.4%, 95% CI ± 1.7 , $R^2=0.54$
HoB 1992-2007	4.3%*	3.4%, 95% CI ± 2.5 , $R^2=0.37$	3.6%*	3.6%, 95% CI ± 3.4 , $R^2=0.28$
HoB 1992-2016	5.5%, 95% CI ± 1.07 , SD=2.5	3.2%, 95% CI ± 1.3 , $R^2=0.54$	4.9%, 95% CI ± 0.85 , SD=1.9	4.61%, 95% CI ± 1.7 , $R^2=0.57$,
WAM 1993-2016 **		5.55%, 95% CI, 3.78, 7.36		6.01%, 95% CI, 3.78, 7.36

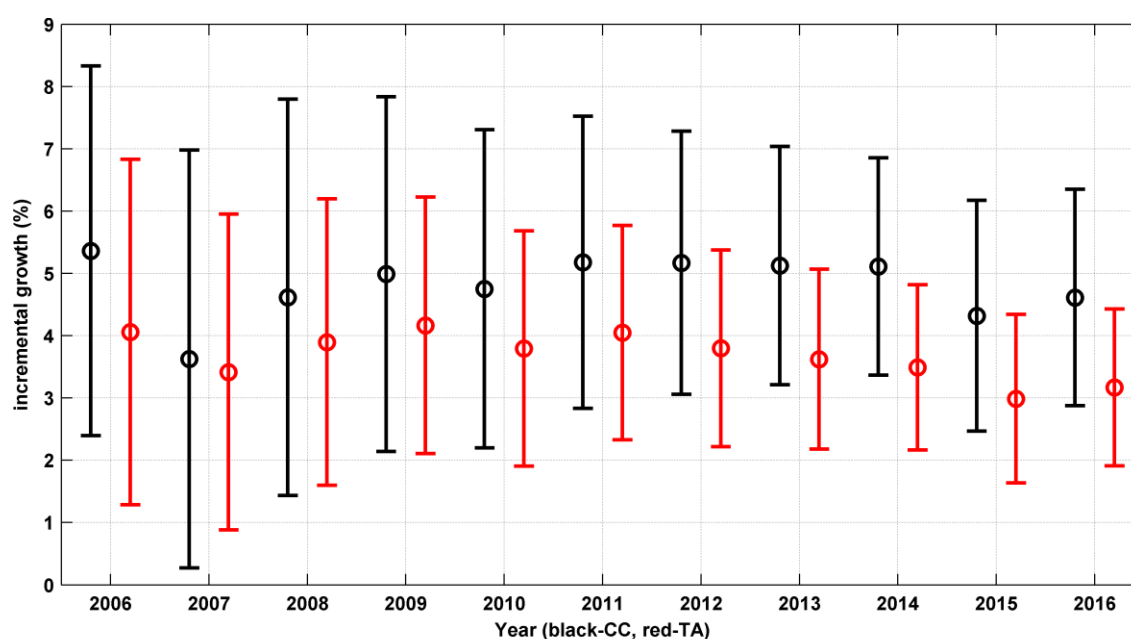


Figure 3-5: Incremental growth rate using a logarithm regression analysis for southern right whales at Head of Bight, South Australia between 2006 and 2016, for female and calf pairs (black-CC) and total adults (red-TA), with 95% error bars.

The sum of total females accompanied by a calf recorded during maximum daily counts across the 25 years was 980 individuals. The maximum number of females accompanied by a calf sighted increased from 18 in 1992 to 81 in 2016 at a mean CAGR rate of 4.9% (SD=1.9, ± 0.85 , 95% CI) p.a. or 4.6% ($R^2=0.57$, ± 1.7 , 95% CI) using the linear regression of the log value (Figure 3-4 and

Table 3-1). There was high annual variability abundance of females accompanied by a calf, due to pulses in calf production ($\bar{X}=39$, $SD=17.8$). The long-term abundance trend clearly demonstrates cohort structured calving cycles, with distinct peaks of calving females apparent every three to five years after 1998 (Figure 3-2). Triennial peaks in abundance were most commonly observed, representing three primary calving cohorts, for example, in 2005, 2008, 2011 and 2014.

Lower numbers than the prior year and the prior calving cohort year of females accompanied with a calf were recorded in 1998, 2007 and 2015 and these resulted in a reduced rate of increase in abundance. For example, in 2015, the maximum number of females accompanied by a calf ($n=29$) was 51% lower than in 2014 ($n=60$) and 47% lower than the same cohort year in 2012 ($n=55$).

The number of unaccompanied whales sighted within the HoB study area increased at a mean rate of 3.2% ($SD=3.5$, ± 1.4 , 95% CI) p.a. between 1992 ($n=7$) and 2016 ($n=29$), also based on the CAGR and (Figure 3). The annual rate of change was highly variable (range 7-35, $\bar{X}=23$, $SD=7.1$). The maximum number of unaccompanied whales recorded on one day during the study period was 35 individuals in 2011 (Figure 3-2 and Figure 3-4). A simple exponential regression using a linear regression of the logarithm of the annual count data resulted in a rate of increase in unaccompanied adults of 1.7 % ($R^2=0.1$, ± 2.0 , 95% CI).

Few animals of undetermined status were recorded, ranging from three in 1996, 2011, 2015 and 2016, to 15 in 2005 (range=3-15, $\bar{X} = 6$, $SD = 3$).

3.4.2 Proportion of SRW at Head of Bight relative to the ‘western’ population

The proportion of calving females sighted at HoB each year relative to the overall ‘western’ sub-population recorded through annual aerial surveys by Bannister (2016) between 1993 and 2016 varied with time. The relative proportion ranged from a maximum of 0.48 in 1994 to a minimum of 0.21 in 2002 ($\bar{X}=0.32$, $SE=0.01$) (Figure 3-6). Over the years, the proportion that SRWs at HoB represented of the overall ‘western’ sub-population showed a visual trend towards decreasing, however the regression fit was poor and the trend was not significant ($R^2=0.05$ with a polynomial best fit $p\text{-value} = >0.05$).

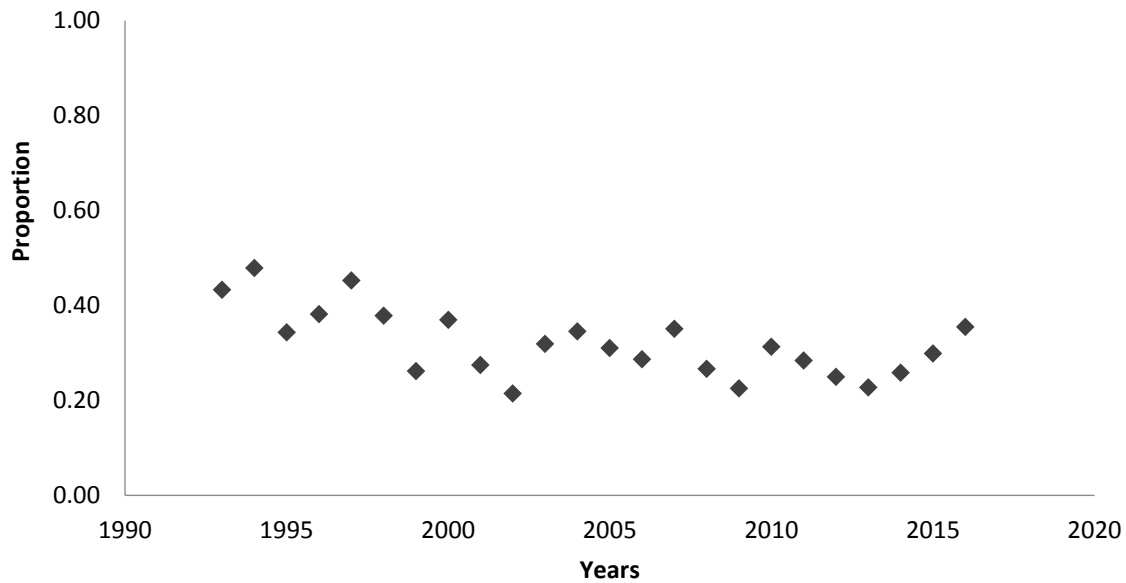


Figure 3-6: Proportion of Western Australian sub-population of Southern right whales sighted at Head of Bight annually, 1993-2016, based on aerial survey annual counts, Cape Leeuwin WA – Ceduna SA, and maximum annual counts from cliff based surveys at Head of Bight, South Australia.

3.4.3 Life history parameters

Life history parameters were estimated using mark recapture photo-ID data collected at HoB between 1991 and 2016. Matching was facilitated using the HoB digital photo-ID catalogue containing 10,879 images that included high quality images of 1,186 individual non-calf SRWs and 362 individual calves. A total of 459 individual reproductive females and 727 individual unaccompanied adults were identified.

Photo-ID success was achieved for 91% of the total 980 females accompanied by a calf sighted during daily cliff based counts. Percentages of whales with calves photographed ranged from 36% in 2009 to 150% in 2014 (\bar{X} = 91%, SD = 21.9). Photo-ID success greater than 100% occurred when a greater number of individuals was photo-ID'd throughout the season than the maximum daily count, indicating immigration and emigration of whales into and out of the site during the season. Resights of known individuals previously sighted at HoB were obtained for a mean annual total of 70% (range = 46-94%, SD = 15.5) of females accompanied by a calf HoB between 1996 and 2016 (Figure 3-7). The data for 1996-2016 (rather than from 1991) were analysed to account for a possible maximum calving cycle of five years, thus 1991-1995 was not included because the analysis requires a 5-year lead time.

3.4.4 New calving females not previously sighted at Head of Bight

The mean annual number of calving females not previously matched with the long-term photo-ID catalogue and therefore not previously sighted at HoB was 30% (SD=15.3) (Figure 3-7). The number of new calving females not previously sighted at HoB increased linearly from a minimum of 6% in 1999 to a maximum of 54% in 2011 at a maximum rate of 8.3% ($R^2=0.71$, $P\text{-Value}=<0.05$) p.a. (Figure 3-7).

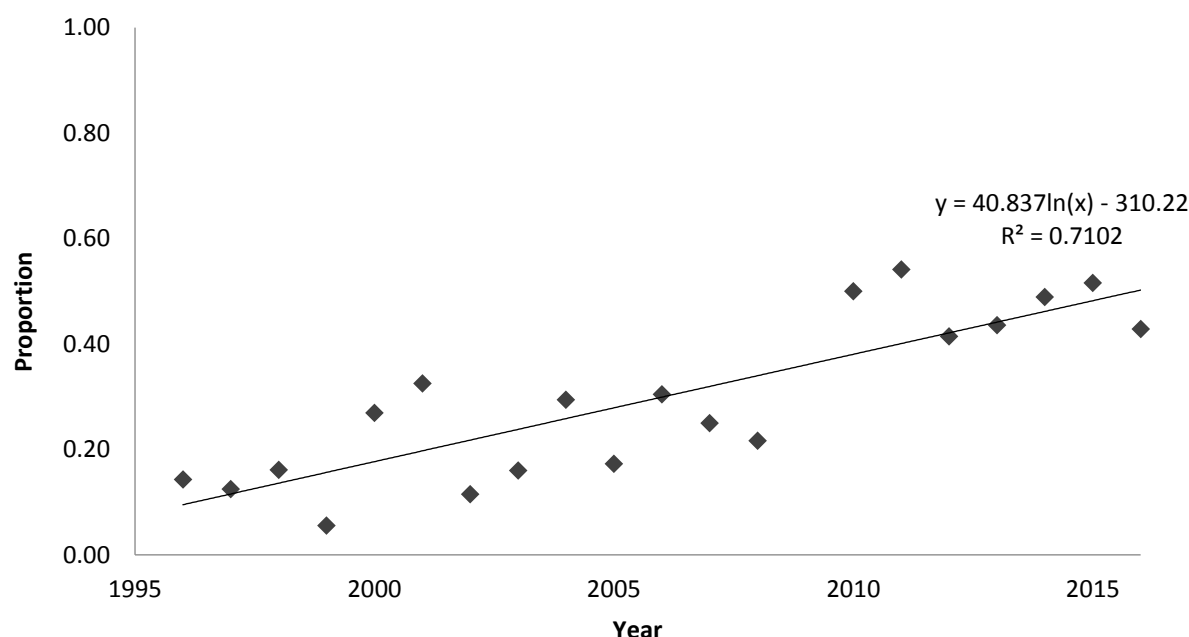


Figure 3-7: The proportion of southern right whale females with a calf not previously sighted at Head of Bight, South Australia compared with females that were known to have previously been identified at Head of Bight with a calf, 1996 to 2016.

3.4.5 Apparent mean calving interval

A total of 459 reproductive females were recorded at HoB, producing a total of 980 calves between 1991 and 2016. Of the 459 individual reproductive females, 186 (41 %) were recorded with a calf on two or more occasions, providing 471 inter-calf intervals ($n=663$ calves) for analysis of mean recorded calving interval (Table 3-2). Of the 471 inter-calf intervals, available for analysis, 78.9% of intervals recorded were five years or less and 21.1% of intervals recorded were greater than five years. Intervals of greater than five years were excluded from the analysis as they may represent a missed calving event: the animal may have calved at an alternate location or been missed by observers at HoB, or they may have had a still born calf or a calf that died earlier.

Table 3-2: Number of photographed female Southern right whales with a calf (bolded bottom cell of each column), and number of those same individuals photographed with a calf in subsequent years (in the row corresponding to the bolded cell) at Head of Bight between 1991 and 2016.

1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
20	0	0	11	3	3	10	3	4	8	3	3	8	2	6	6	0	6	0	0	0	0	0	4	1	2
	18	0	1	8	3	2	9	0	1	7	2	1	1	6	2	2	1	0	2	0	0	2	3	0	1
		26	0	0	8	4	5	5	1	4	9	1	4	7	4	1	5	0	2	1	1	1	2	2	3
			23	0	1	12	6	2	9	5	2	7	4	6	1	1	5	0	1	0	1	1	3	1	4
				20	0	0	8	2	0	6	2	2	2	6	2	1	2	0	1	0	0	0	2	0	1
					21	0	1	5	0	0	8	2	0	6	1	0	4	0	0	1	1	0	3	0	3
						24	0	1	13	5	2	10	3	4	10	1	3	0	1	0	0	2	3	1	3
							31	0	0	16	4	1	7	10	4	2	7	0	4	1	1	3	6	3	4
								17	0	0	6	3	0	7	3	0	6	0	0	0	0	0	2	0	3
									27	0	1	11	1	2	11	0	3	0	0	0	0	0	3	0	3
										40	0	0	13	16	2	6	7	0	2	2	0	6	6	3	6
											27	0	0	14	5	1	9	0	3	0	2	1	7	2	5
												25	0	0	17	1	4	0	1	2	0	0	4	0	2
													34	0	0	6	15	0	2	2	1	1	6	2	8
														61	0	0	19	0	0	5	1	6	14	2	9
															46	0	2	0	4	4	2	22	1	3	5
																16	0	0	6	2	0	4	3	1	4
																	60	0	0	8	2	0	11	7	10
																		20	0	1	1	2	1	1	2
																			29	0	1	7	5	1	2
																				47	0	2	7	4	6
																					18	0	0	0	9
																						39	0	0	4
																							90	0	0
																								31	0
																									91

The mean observed calving interval for individual reproductive females at HoB was 3.3 (SD=0.8, \pm 0.3, 95% CI) years, excluding observed intervals greater than five years (Figure 3-8 and Figure 3-9). The most frequent mean annual calving interval across all years between 1996 and 2016 was three years representing 59.6% of intervals, followed by four year intervals (26.5%), five year intervals (9.7%) and two year intervals (4.2%) (Figure 3-9). There was no significant difference in the mean recorded calving interval across years, although the last four years displayed a greater spread of data compared to prior years (Figure 3-9). The mean calving interval increased to above four years in 2015 and 2016 for the first time in the 26-year dataset. There were no three-year calving intervals recorded for calving females at HoB in 2015 and the second fewest three year intervals were recorded in 2016 (21% of calving females).

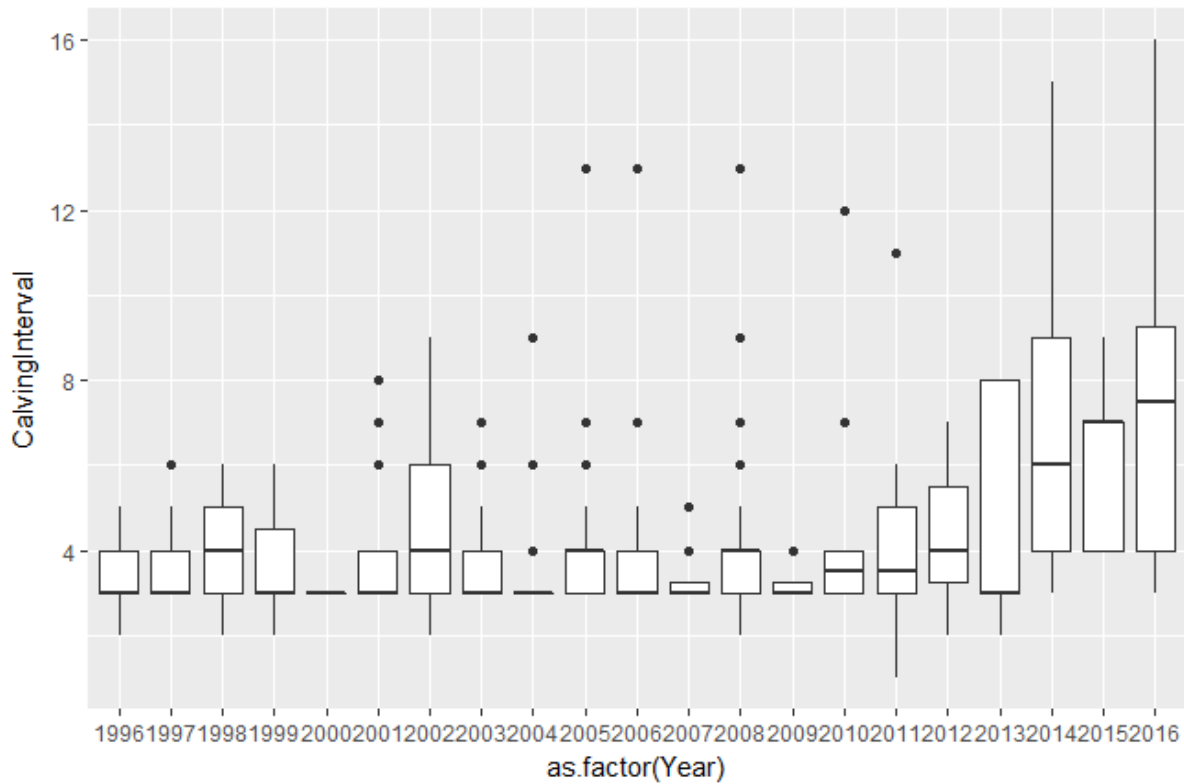


Figure 3-8: Mean calving interval for southern right whales identified in photographs between 1996 and 2016 at Head of Bight, South Australia, displayed as a box plot with the mean displayed as black horizontal line, standard deviation as white box and range displayed as vertical tails or black dots.

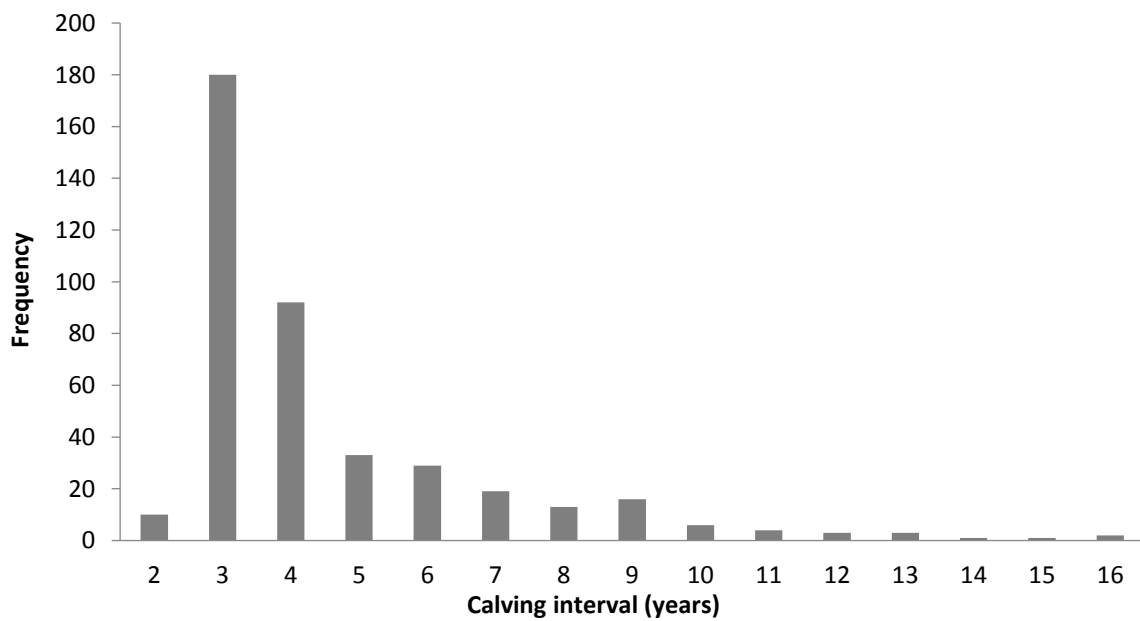


Figure 3-9: Frequency distribution of intervals between observed calving of individually identified southern right whales at Head of Bight, South Australia between 1996 and 2016.

Apparent mean calving interval using HoB and WAM data combined

A total of 267 individual females were matched to the WAM catalogue (1993-2004 and some individuals to 2007). The cross matching of the two datasets between 1991 and 2007 for HoB and 1993 and 2004 for WAM resulted in an additional 73 calving events for analysis, to add to the 500 calving events recorded in the HoB dataset in 2007 (Burnell, 2008). When sighting histories for the 267 matched individuals were updated from the WAM catalogue (1993-2012 inclusive) and the HoB catalogue (1991-2016 inclusive), 207 calving events recorded in the WAM catalogue contributed to the 910 calving intervals in the HoB catalogue. The matching exercise resulted in 27 additional reproductive females meaning that these individuals were sighted at HoB as unaccompanied adults and by the WAM surveys as calving females.

The mean observed calving interval for individual females recorded for the HoB data was 3.3 years (SD=0.78, \pm 95% CI 0.14), which is the same as the calving interval recorded for HoB data only of 3.3 years (SD=0.8, \pm 0.3, 95% CI).

3.4.6 Shifts in calving intervals

Shifts in calving intervals by reproductive females were observed for the Australian SRW population. The prior calving intervals were studied for individuals recorded with a four-year calving interval in 2015 and 2016 to see if a 'shift' in calving cohort had occurred and influenced the reduced number of observed three year intervals. On two occasions, a reproductive female shifted its calving interval from three to four years. One female had a prior calving interval of two years, followed by a four-year interval.

The increase in the mean calving interval recorded in 2015 and 2016 was also influenced by a greater proportion of calving intervals recorded above five years. For example, the mean percentage of individuals with greater than five year intervals in 2015 of 25.8% and 2016 of 25.3% significantly exceeded the overall mean of 9.8%.

3.4.7 Age at first parturition

A total of 362 individuals was photographed and identified in their year of birth, of which 69 were re-sighted in at least one subsequent year, and provide the majority of the individual whales of known age within the Australian population. Within the catalogue of known aged individuals, 23 were since sighted with a calf providing information on age at first parturition. The minimum age at first parturition recorded in this study was six years, showing that SRW can become sexually mature as early as five years old. The maximum age at first parturition recorded was 18 years. The individual first sighted with a calf at 18 years was considered to have likely calved at another location earlier and was excluded from the analysis. The median

age at first parturition was 9.5 years with a mean of 9.3 years ($n=22$, $SD=2.1$, $SE=0.46$, ± 0.9 , 95% CI) (Figure 3-10).

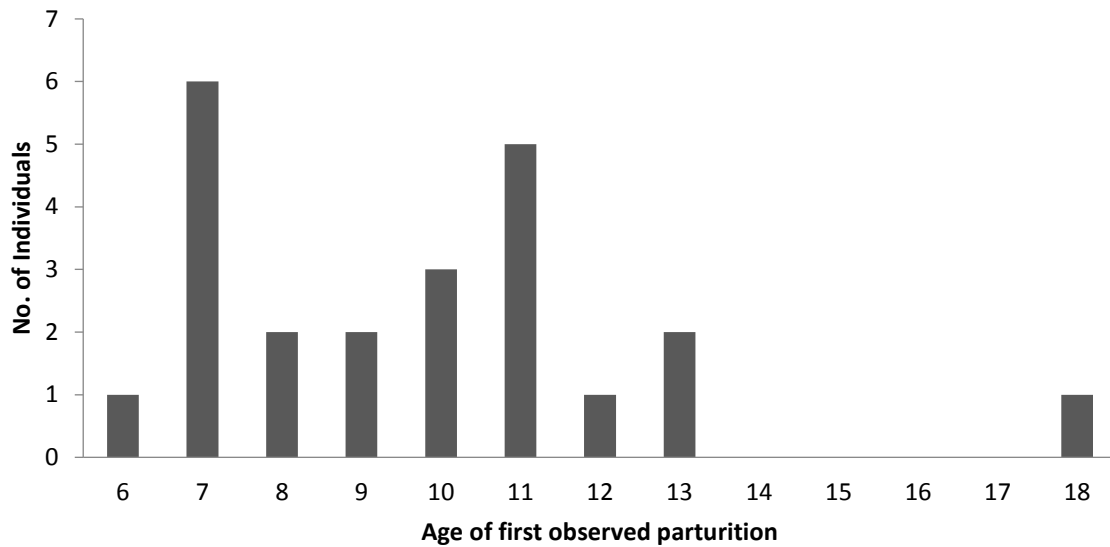


Figure 3-10: Frequency distribution of age at first parturition of Southern right whales of known age at Head of Bight, South Australia ($n=23$).

3.4.8 Longevity

The oldest known female is an adult female (H9220) first photographed in 1970 off Boston Bay, SA. She was sighted 14 times between 1970 and 2010 and 12 of those times were at HoB with the first in 1983. The next oldest SRW is a female (H9318) sighted with a calf in 1984 who returned to HoB with a calf 10 times between 1984 and 2016. Another three females were identified with a calf in 1984 and were last sighted at HoB in 2014, 2007 and 2005, respectively (the last sighting of these individuals were all with a calf).

3.5 Discussion

Long term trends in abundance and life history parameters provide critical information for population recovery assessment and monitoring of changes to a population over time. This study reports on the long-term trends in abundance and life history parameters including apparent mean calving interval and age at first parturition at HoB - the most important calving ground for SRWs in the 'western' sub-population in Australia. Abundance trends and life histories were presented using 26 years of unbroken time-series count and photo-ID data collected annually between 1991 and 2016. The estimates of the life history parameters presented in this analysis update those previously reported for this population for the years

1991 to 2007 (Burnell, 2001 and 2008) with a total of 26 years of data included in this assessment compared to 17 years reported by Burnell (2008).

The estimates presented here relate to a single large calving aggregation area on the Australian coastline at HoB, SA. This is not a closed population and the estimates were confounded to some extent by movements in and out of the site and from other coastal aggregation areas outside of HoB, primarily from the remainder of the 'western' sub-population.

3.5.1 Long term trends in abundance

To detect changes in the rates of increase and recovery of long lived and slow to recover marine mammals, long term monitoring in the order of decades is required. Detecting changes in the rate of increase in SRW requires annual monitoring due to their three to four-year calving cycles. To detect change on a time scale relevant for management, assessment of each breeding cohort is required (Bannister *et al.*, 2011, Burnell, 2001). At HoB, the updated estimated mean annual rate of increase of 5.5% (± 1.07) p.a. based on the mean CAGR for all whales sighted between 1992 and 2016 was consistent with estimates of 5.3% p.a. for the years between 1991 and 2006 (Burnell, 2008). Using a simple linear regression of the logarithm of annual count data, the rate of increase for 'all animals' was 3.7% and resulted in a lower value although within the bounds of the confidence intervals of the overall 'western' population of 5.6% (95% CI 3.78, 7.36) p.a. (Bannister, 2017). For reproductive females, the updated rate of increase at Head of Bight of 4.9% (95% CI 0.85) p.a. was slightly lower than the previous estimate of 5.4% p.a. for the years 1991-2006 (Burnell, 2008). When compared to the estimate for the 'western' sub-population of 6.01% (95% CI 3.49, 8.59) p.a. (Bannister, 2017), the rate of increase of 4.6%, is also lower, although within the bounds of the confidence intervals. The growth rate of SRW at HoB relative to the overall western population appears to have declined slowly over time, possibly representing saturation of the HoB aggregation. Current estimates suggest that SRW in the 'western' sub-population and at the HoB aggregation area, are increasing at or near the estimated biological maximum rate of increase for the species of 6-7% p.a. (IWC, 2013).

Changes in the rate of increase in abundance at HoB compared with the overall Australian population were reported for years 1992-2007 (Burnell, 2008) and are likely attributed to increased immigration and emigration across the aggregation areas in Australia, with an increasing population. Although known female SRWs at HoB display a high degree of philopatry (Burnell, 2001, Charlton 2017 – Chapter 4), coastal movements and changes in selected calving habitat are also known to occur (Burnell, 2001, Pirzl *et al.*, 2009, Charlton, 2017 – Chapter 6). As the population increases, what are likely to be historically used

aggregation grounds are re-emerging (Bannister, 2017; DSEWPaC, 2012). The finding in this study that the proportion of the annual sightings of individuals from the 'western' sub-population occurring at HoB has decreased from approximately one half to a fifth since the early 1990's supports the assumption that reproductive female whales emigrate from HoB to other small or emerging aggregation areas.

The rate of increase of reproductive females for the 'western' sub-population in Australia and at HoB is also lower than SRW populations elsewhere in the world. The South African population of SRWs has been increasing at an estimated 6.8% ($\pm 0.4\%$) p.a. between 1979 and 2008 (Brandão *et al.*, 2011). The Argentinean population is increasing at an estimated 6.0% ($\pm 0.5\%$, 90% CI) p.a. for years between 1979 and 2010 (IWC, 2013). In contrast, the NZ population and the 'eastern' Australian sub-population are estimated to be increasing at a different rate from other SRW populations. The difference in growth rates is considered to be as a result of increased historical whaling pressure being more concentrated in the South Pacific Ocean leading to the absence of a remnant stock of whales returning to the area (IWC, 2013). The NZ population of SRWs is estimated to be increasing at a rate of 4.8% (95% CI, 2.4% to 6.4%) p.a. between 2006 and 2016 (Davidson *et al.*, 2016), whilst the 'eastern' Australian sub-population is showing no signs of increase (Bannister, 2017). The lower rate of increase recorded at HoB is likely reflective of the site being an open population and regular movement of individuals into and out of the area, from the broader 'western' sub-population. Similarly, lower rates of increase were recorded for HoB compared with the overall 'western' sub-population for 1992-2006 reported in Burnell (2008).

Within the overall increasing trends in abundance at HoB, SRWs display three to five year peaks in abundance corresponding to different calving cohorts, driven by the three to five-year calving intervals. Individual female calving intervals can vary in time and result in changes to the size of each breeding cohort and subsequently result in trends in peaks in abundance at the site (Burnell, 2008). For example, the high abundance recorded at HoB in 1998 and in 2005 was a direct result of a number of calving females from 1994 and 2001 'switching' from the typical three-year interval to a four-year interval and effectively redistributing into the 1995 and 2002 breeding cohorts respectively (Burnell, 2008). Similar changes in calving intervals and shifts in calving cohorts have also been observed in Argentina and South Africa (Best *et al.*, 2001, Cook *et al.*, 2001).

3.5.2 New calving females not previously sighted at HoB

The number of new calving females not previously sighted at HoB grew from a mean of 15% of all female and calf pair sightings (1995-1999), to a mean of 48% (2012-2016). This increased percentage of new breeding females to HoB relative to individuals sighted

previously at HoB with a calf can only be due to increased emigration of females that had already calved or immigration of new calving females into the study area. Further modeling is required to compare the expected recruitment of first time breeders versus the immigration and emigration of calving females to and from the study area. To assess the within and across seasonal movements of whales between aggregation areas and to understand the mixing between the 'western' and the 'eastern' sub-populations and NZ, a comparison of SRW photo-ID's catalogues from Australia and New Zealand is required.

3.5.3 Mean observed calving interval

The mean observed calving interval shows no significant difference across the duration of this study, with an overall mean calving interval of 3.3 years (SD=0.8, \pm 0.3, 95% CI). A mean apparent calving interval of 3.4 years (95% CI, 3.29 - 3.46 years) for 1991-2007 at HoB was recorded by Burnell (2008). The mean observed calving interval for the HoB is comparable with estimates for the SRW population in South Africa of 3.16 years (95% CI, 3.13-3.19) (Brandão *et al.*, 2011) and the SRW in Argentina of 3.42 years (SE=0.11) (Cooke *et al.*, 2003). The increase in the observed mean calving interval in 2015 and 2016 of 4.2 and 4.1 years respectively, was influenced by a greater proportion of calving intervals above five years recorded. The extended field seasons during 2014-2016 meant that females passing through the area were captured through photo-ID and may have fidelity to other areas for calving/nursing and were just passing through HoB, thus possibly leading to increased recordings of five year intervals or above. It is also possible that calving events were not detected in prior years. Although a low occurrence of shifts in calving intervals was recorded in 2015 and 2016, this does not entirely explain the increased mean calving interval from three years to four years recorded in 2015 and 2016. Further investigation into the connectivity of whales from HoB to other Australian aggregation areas and assessment of potential links between reproduction, feeding, health and climate factors is required to assess drivers of observed changes in calving intervals.

Burnell (2001) hypothesised that a two-year calving interval represents a female that has lost a calf in the preceding year and has therefore become pregnant in the following year, resulting in a two-year cycle. A female (H9216) was reported with a two-year calving interval in 1994 and 1996, and was recorded losing her neonate calf in 1992 and 1994 (Burnell, 2001). The body condition of this female appeared moderate judging from the fat reserve on the post blow hole, based on visual observations of photo-ID images (1992, 1994, 1996, 1998, 2000). This individual has not been sighted at HoB since 2000.

Variation in calving rate (not due to measurement error or loss of calves) may have been influenced by climate factors impacting changes to calving intervals (Pirzl *et al.*, 2009). Links

between sea surface temperature in feeding areas and the calving success of Southern right whales in Argentina have been documented (Leaper *et al.*, 2006). Inter-annual variability observed in the Australian SRW population was related to Southern Ocean climate factors (Pirzl *et al.*, 2009). SRW reproductive success was linked to krill density and climate for SRWs in Brazil (Seyboth *et al.*, 2016). Climate associated changes in prey availability was linked to a depression in calving intervals and population growth of critically endangered North Atlantic right whales (Meyer-Gutbrod *et al.*, 2015). Reproductive success was linked to body condition for 'western' grey whales (Bradford *et al.*, 2008) and North Atlantic right whales (Miller *et al.* 2011 and 2012). Foraging and distribution patterns of SRWs in the Southern Ocean are poorly understood, causing difficulty in making a correlation between prey abundance, climate factors and demographic parameters. Further assessment is required to identify linkages between climate, prey availability, body condition and reproduction for right whales globally. At HoB, the positive anomalies in SRW calf production observed in 1998, 2005 and 2016, the negative anomaly observed in 2007 and 2015, and the increase in four-year calving intervals in 2015 and 2016 require further assessment.

Results demonstrate that the HoB population is an open population. Whilst females display philopatry to HoB, observations of calving events outside of HoB strengthen the analysis of life history parameters for this population. However, the additional sightings of 207 calving events available through the WAM catalogue resulted in no significant difference to the apparent calving interval of 3.3 years recorded for HoB. The analyses do not consider calving intervals of six years or greater and therefore calving events that may have been missed at HoB that were detected by the WAM surveys were not included in this assessment. For example, if an individual was recorded at HoB having a six-year interval when in fact she was sighted outside of the HoB by the WAM aerial survey on a three-year interval, this reduced calving interval is not accounted for the mean apparent calving interval analysis. Therefore, when including six year intervals, the mean may be lower for the WAM and HoB analysis compared with HoB alone.

3.5.4 Age at first parturition

Apparent age at first parturition data indicate that sexual maturity can be reached by age five, at least in some individuals. The median age of first parturition was 9.5 years and the oldest first-time mother observed was 18 years. The mean age at first parturition at HoB of 9.3 years (SD=2.1, \pm 0.9, 95% CI, n=22) is consistent with earlier calculation of a median age at first parturition of 9 years and a mean of 9.1 years (\pm 0.48, 95% CI) by Burnell (2008). A mean age at first parturition of 8.6 years was recorded off South Africa (Brandão *et al.*, 2011), and a mean age of 9.1 years was recorded off Argentina (Cooke *et al.*, 2001) and more recently at 8.4 years (IWC, 2013). To estimate age at first parturition of SRW in South Africa, only females

that have a white dorsal blaze were included (Brandão *et al.*, 2011). The slighter lower age at first parturition recorded in South Africa is likely attributed to the fact that the surveys in Argentina include the whole population whereas the surveys at HoB do not. It is possible that calving events may have occurred in areas outside of the study area and thus reflected a different mean age at first parturition.

3.5.5 Longevity

The oldest known female was first sighted in 1970 and based on size and body shape was assumed to be a mature adult at that time and therefore she would have already been about 9 years old. However, she has never been sighted with a calf and her age at first sighting is unknown. The female was sighted 12 times at HoB without a calf, with the last sighting in 2010, which would put her at about 50 years old. The oldest known breeding females were sighted with a calf in 1984 and therefore the mean age of first calving of nine years is assumed. The oldest recorded female was last sighted at HoB in 2016 and therefore was around 41 when she had her last calf and the other was last sighted with a calf in 2014 and was therefore around 39 when she had her last calf. Therefore, calving females between the ages of 6 and around 41 years were recorded at HoB. The oldest Right Whale reported was a female North Atlantic Right Whale that was photographed with a calf in 1935 and authors estimated that she was at least 10 at the time. Therefore, they used 70 as her age and she was last seen in August 1995 with a large propeller wound (Hamilton *et al.*, 1998). The lifespan of Bowhead whales, a close relative to the Right Whale is known exceed 200 years (Keane *et al.*, 2015).

3.5.6 Conclusion

In this study, long term trends in abundance and life history parameters for SRWs at their major aggregation ground at HoB are presented using 26 consecutive years of photo-ID mark recapture data. Data from the annual WAM aerial surveys were also integrated into this project. The combined dataset provides information to directly address key priorities and objectives in the Commonwealth SRW Conservation Management Plan to understand life history parameters and measure population growth. Baseline data are provided for assessment of potential before and after assessment of impacts associated with marine based activities in the broader area. Key findings of this study show that the rate of increase in the population of SRW at HoB is consistent with prior findings for this site, and are lower than recorded rates for the 'western' sub-population of SRWs in Australia and the maximum biological rate of increase for the species. The change in the relative proportion of SRW at HoB compared with the annual sightings for the 'western' sub-population indicates that movement of individuals into and out of the area is increasing with an increasing and

expanding population. Estimated demographic parameters including mean calving interval, age at first parturition compare favorably with previous research completed for this population (Burnell, 2001), and with studies on other SRW populations in the Southern Hemisphere (Payne *et al.*, 1990; Best *et al.*, 2001; Cooke *et al.*, 2001 and 2003; Brandão *et al.*, 2011). Information provided by this study can be used to inform population status and recovery assessment, expanding habitat use, linkages to health and climate factors, and global comparative studies of SRW populations. For a complete assessment of SRW life history parameters and recovery in Australia a national assessment collating all available photo-ID mark recapture datasets is recommended.

4 **Residency site fidelity and date of calving of southern right whales (*Eubalaena australis*) at the Head of the Great Australian Bight, South Australia 1991-2016**

Charlton C.M¹., R. Ward¹., R. McCauley¹., R. L. Brownell²., S.R. Burnell³

¹Centre for Marine Science and Technology, Curtin University Western Australia

²NOAA Fisheries, Southwest Fisheries Science Center, Monterey, California, USA

³Eubalaena Pty. Ltd.

Key words: Southern right whale, residency, site fidelity, photo identification, calving ground, South Australia

4.1 Abstract

Residency, site fidelity and date of calving for Southern right whales (*Eubalaena australis*) in South Australia were assessed using 26 years of photo-identification mark recapture data. Shore based count and photo-identification studies were undertaken annually at the major aggregation and calving area at the Head of the Great Australia Bight (HoB) between 1991 and 2016. Although the mean residency varies over time, females with calves of the year will spend up to 2-3 months in aggregation areas, while unaccompanied adults are more transient with much shorter residency periods. Over the 26 years documented in the study, the number of females identified calving at the site increased from 81 to 459. The mean within-year residency of females with calves declined from 70.1 days recorded during 1992-1994 compared with 40.0 days during the 2014-2016 period. Mean residency for unaccompanied adults of 20.4 days during 1992-1994 was recorded compared with 14.7 days during 2014-2016. Site fidelity was displayed for 67% of calving females, consistent with previous findings for this population. Site fidelity of females with calves to HoB was displayed for 41% (n=187) of the population that were sighted more than once with a calf. Females were recorded returning to the study site to calve up to 10 times with the mean number of calves per individual was two (SD=1.7). The calculated mean date of calving at HoB is July 23. Evidence of natal site fidelity was provided (n=23). The probability of calves being resighted at HoB was greater six years after birth, supporting the theory that calves may disperse to other areas and return to their site of birth once they reach sexual maturity. Results highlight the importance of wintering aggregation areas for southern right whales and the need to understand more about the movement and connectivity of the population across southern Australia.

4.2 Introduction

Southern right whales (SRWs) *Eubalaena australis*, have a circumpolar distribution between 16° and 65° S and migrate to the Southern Hemisphere aggregation areas between May and November to calve, mate and rest. SRWs were protected from commercial whaling in Australia in 1935, although signs of population increase were delayed until the 1970's due in part to illegal pelagic catches by the Soviet Union (Tormosov *et al.*, 1998). Signs of the return of SRW to the Australian coastline were recorded in the 1960's and 1970's (Bannister, 1994).

Female SRWs typically show strong fidelity to calving and nursing grounds (Best and Scott, 1993; Burnell, 2001; Crespo *et al.*, 2017; Rowntree *et al.*, 2001). Long-term photo-identification (ID) studies show that females return to the same areas to calve over several decades (Bannister *et al.*, 2011; Best *et al.*, 2001; Burnell, 2001; Charlton, 2017 – Chapter 3). Early SRW sightings globally were restricted to areas where the largest remnant populations existed (Burnell, 2001; Rowntree *et al.*, 2001, Bannister, 2001). Conspecific attraction and historic whaling effort combined with philopatry appear to be the main drivers of SRW calving ground occupation (Payne, 1986; Best *et al.*, 2001; Burnell, 2001, Rowntree *et al.*, 2001; Pirzl, 2008). While site fidelity of SRWs to calving grounds is typically high, there is evidence that SRWs can shift selected calving habitat and display flexibility in their philopatric behaviour (Best *et al.*, 1993; Groch *et al.*, 2005; Carroll *et al.*, 2014; Charlton, 2017 – Chapter 5). Movement of calving and non-calving adults has been recorded across broad distances within and across seasons (Pirzl *et al.*, 2009; Charlton, 2017 – Chapter 6; Roux *et al.*, 2015).

The long-term relative abundance and distribution of SRWs in Australia is well understood through annual aerial studies undertaken by J. Bannister of the Western Australian Museum (WAM) since 1976 (Bannister, 2001 and 2017; Bannister *et al.*, 2011). The current population estimate for SRWs in Australia is 2,500, with 2,200 in the western sub-population and less than 300 in the eastern sub-population (Bannister, 2017). The western sub-population is showing signs of increase at a rate of approximately 6% per year, which is at or near the biological maximum for the species of 6-7% (IWC, 2013), while the eastern sub-population is not showing any signs of increase (Bannister, 2017). SRW wintering aggregations are distributed between Albany in Western Australia (WA) and Warrnambool in Victoria, with rare sightings recorded as far north as Exmouth in WA and Moreton Bay, Queensland on the east coast. In Australia, SRWs have dispersed their winter habitat range into small and emerging aggregation areas with increased abundance in south-western Australia in recent years (Bannister, 2017; DSEWPac, 2012; Charlton, 2017 – Chapter 6).

Shore based research on the population biology of SRWs has been undertaken at one of Australia's largest and most important calving aggregation areas at the Head of the Great

Australian Bight (HoB) in South Australia (SA) (31°28'S, 131°08'E) from 1991 to present (Burnell, 2001; Burnell and Bryden, 1997; Charlton, 2017 – Chapter 2 and 3). Coastal aggregation areas on the southern coast of Australia are occupied by SRWs between May and October with peak numbers recorded in August (Burnell, 2001; Charlton, 2017 – Chapter 2). Females with calves are known to reside in calving grounds for two to three months (Burnell, 2001). Information on residency and site fidelity for the Australian SRW population was reported for years 1991-1995 (Burnell and Bryden, 1997; Burnell, 2001). Mean residency periods of 70.9 days were recorded for female and calf pairs and 20.4 days for unaccompanied adults (individuals not accompanied by a calf of the year) (Burnell and Bryden, 1997). Site fidelity to the HoB aggregation area was reported for 69% (n=56) of females with a calf sighted at HoB between 1991 and 1995 (n=81) (Burnell, 2001). For unaccompanied adults, site fidelity to the HoB aggregation area was reported for 23.4% (n=46) of the total 197 individuals identified at HoB between 1991 and 1995 (Burnell, 2001). Of the 20 calves identified at HoB during 1991-1995, 17 (85%) displayed site fidelity to their place of birth. Natal site fidelity could not be assessed because at the time of the Burnell (2001) study, the calves identified in their year of birth (1991-1995) had not reached sexual maturity. The mean date of calving for SRW was reported as July 16 (Burnell and Bryden, 1997). An additional 19 years of data is now available from annual research undertaken at HoB during 1996-2016 to update previous findings on residency, site fidelity and date of calving of SRWs in Australia (Burnell and Bryden, 1997; Burnell, 2001). During this time the abundance and number of photo-IDs in the HoB catalogue has significantly increased. Between 1991 and 1995 the mean maximum abundance recorded on a single day per year at HoB was 55 (SD=9.1, range=43-65) individuals and the number of individuals identified was 350 (Burnell, 2001). Mean maximum abundance recorded on a single day per year at HoB between 1996 and 2016 was 105 (SD=36.9, range=49-172) individuals and the number of individuals identified was 836 (Charlton, 2017 – Chapter 3).

The long-term photo-ID study at HoB (1991-2016) provides an unbroken time series dataset with sighting histories of known individuals. The HoB photo-ID catalogue currently (to the end of 2016) includes 1,186 adults including 459 reproductive females and 910 calving events (Charlton, 2017 – Chapter 3). The HoB photo-ID dataset provides the only information on known aged individuals photographed in the year of their birth to assess natal site fidelity for the Australian SRW population.

With an increasing population and evidence of habitat dispersal of SRWs in south-western Australia, there is a need to assess changes to residency and site fidelity to inform management of changes to the site occupancy of SRW in wintering aggregation areas in Australia. Recovery actions in the Commonwealth Conservation Management plan for the

SRW include research into the population biology, movements and connectivity of SRWs. This study aims to assess residency, site fidelity and date of calving of SRWs at major calving aggregation area at the HoB in SA using 26 years of photo-ID mark recapture data (1991-2016).

4.3 Methods

4.3.1 Study site

Head of Bight is in the Great Australian Bight (GAB) in the far west of SA ($31^{\circ} 29' S$, $131^{\circ} 08' E$, Figure 4-1) approximately 270 km west of Ceduna and 210 km east of the WA border (using shortest swim distance). The site is adjacent to Yalata Aboriginal Land on Bunda Cliffs of the Nullarbor Plain. The HoB aggregation area is within the Marine Mammal Protection Zone of the GAB Commonwealth Marine Reserve and the Far West Coast State Marine Park. The GAB Marine Reserve was established in 1995 to protect the wintering SRW aggregation at HoB. The study site is selected to include the primary aggregation area and extends approximately 15 km along the coast and 8 km offshore (Figure 4-1). The HoB study was completed from land based vantage points of 33 m – 53 m elevation.

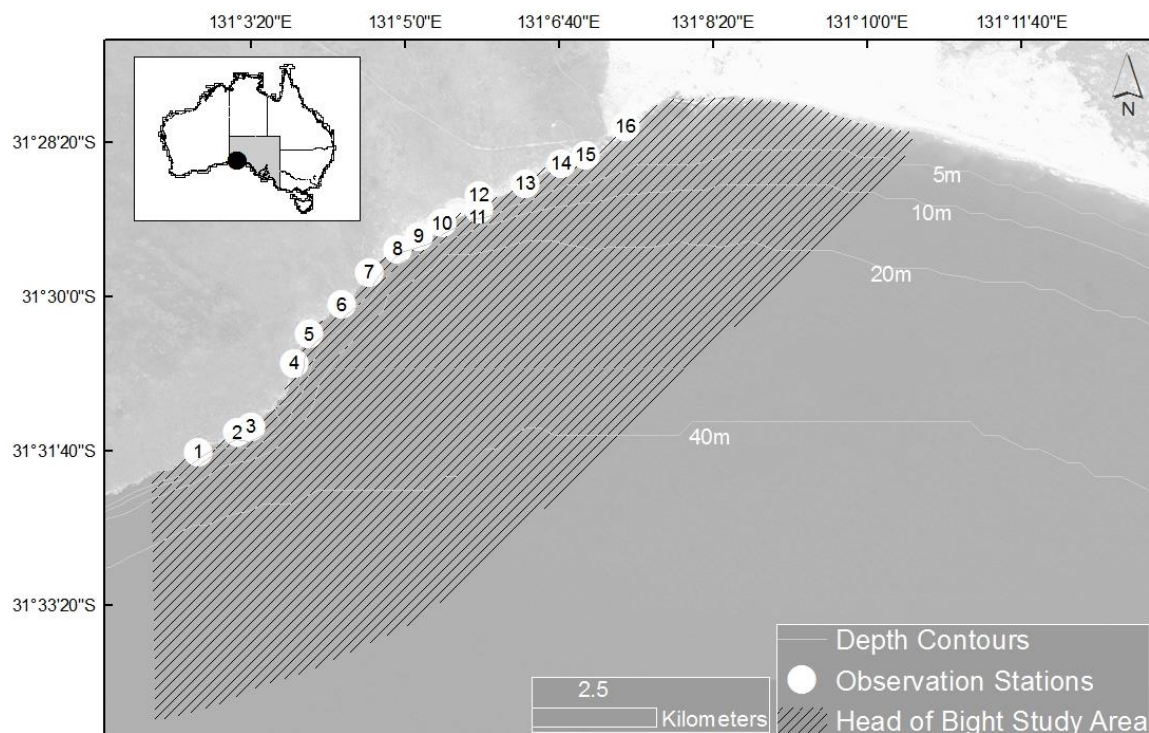


Figure 4-1: Boundaries of the study site and location of observation stations for southern right whales at Head of Bight in the central Great Australian Bight, South Australia.

4.3.2 Data collection

The study methods are consistent with the long-term shore based population census and photo-ID study, completed annually at HoB between 1991 and 2016 (Burnell and Bryden, 1997; Burnell, 2001; Charlton, 2017 – Chapter 1 and 3).

Study period

Field surveys were completed at HoB annually between June and October 1991-2016. For inter-annual comparison of maximum daily counts during the peak season, surveys were completed between mid to late August. Outside of that period, the study effort was variable across years. During 1991-1997 and 2014-2016 surveys were undertaken between June and October and provide comparable data to assess SRW residency and date of calving. Site fidelity is assessed using 26 years of photo-ID mark recapture data at HoB.

Photo identification

Photo-ID of SRW is achieved through photographing the callosity patterns on the rostrum and lower lips of individual whales and resighting individuals over time. Callosity patterns are keratinised skin patches colonised by cyamids that form on the dorsal surface of the rostrum, the lip line of the lower jaw and just posterior to the blowhole on SRWs (Payne *et al.*, 1983). Callosities that appear white from a far provide individually unique markings on SRWs that persist throughout life (Payne *et al.*, 1983). To record callosity patterns and other unique identifying marks, high resolution telephoto images are taken from the cliff top vantage points at HoB. A Nikon 7100 or D100 digital SLR camera with a Nikon 500 mm (effective 750 mm) or Sigma 500 mm lens mounted on a Manfrotto tripod is used for ID photography.

Dorsal and ventral photographs are obtained wherever possible. Left and right lateral perspectives of callosity patterns, as well as the size and shape of ventral pigmentation (also persistent and unique) and the ano-genital configuration (sex) are documented with opportunistic photographs. Markings and any scarring are likewise photographed. Photo-ID is not possible when whales are further offshore than 300 m, nor for whales residing in the area off the beach at the eastern end of the study site. Since movement around the aggregation area is common, many of the individual whales present are likely to be available for photo-ID at some stage during the surveyed days. Photography was concentrated primarily on adults as callosity patterns are well developed. Photo-ID effort for calves was increased later in the season, as they are generally too young to distinguish unique callosity patterns for future identification mark-recapture early in the season.

Digital photo-ID images were sorted daily in the field, including within season cross matching of individuals to document the total number of individuals identified in that year. Individuals

were then matched against the long-term catalogue (Big Fish v6 Microsoft Access), including all calves photographed in previous years to document previously sighted and newly sighted whales.

Photo-ID images were contributed by J. Bannister of the WAM from annual aerial surveys completed at HoB (2014-2016) and the long-term HoB photo-ID catalogue includes sighting histories from matches completed with the WAM catalogue 1993-2007 (Burnell, 2008). The methodology for collection of images during annual aerial surveys are outlined in Bannister (2016) and summarised in Charlton (2017- Chapter 6). Individual sighting records from aerial survey photo-ID images contribute to the assessment of site fidelity and residency. Because of the 3-4-month duration of the study period in 2014-2016, the aerial survey data from the single survey contributed single resights of individuals that were sighted many times throughout the season. Therefore, the observer bias introduced by including aerial survey images is obsolete.

In collaboration with Murdoch University, Unmanned Aerial Vehicles (UAVs) were used in 2016 to photograph SRW at HoB and these images contributed to the assessment of residency. The collection of photo-ID images using UAV's was a part of a wider study to assess SRW body condition by Murdoch University Cetacean Research Unit: <http://mucru.org/our-research/research-projects/baleen-whale-body-condition/>. Aerial surveys and UAV's provide access to whales in the east of the study area that are unavailable for cliff based photography.

4.3.3 Data Analysis

Residency

Residency of females with calves and unaccompanied adults within a season were assessed using photo-ID mark recapture resights between June and September 2014-2016. Mean residency periods recorded for 2014-2016 were compared with earlier published data for 1992-1994, collected between June and October (Burnell and Bryden, 1997). Residency was assessed for individuals that were sighted at least twice and the date of first and last sighting was considered the residency period. The assessment of residency was limited by the survey duration and the residency is considered a minimum duration that SRWs occupy the site. Residency recorded during 2014-2016 is compared with prior studies for this area during 1992-1994 (Burnell and Bryden, 1997). The early 1990's study was completed for a mean of 116 days across three seasons, whilst this study was completed for a mean of 98 days across three years. Therefore, the results are skewed due to the shorter survey period in 2014-2016.

The resights collected using UAVs are excluded from the comparison of mean residency period between 2014-2016 and 1992-1994. The UAV resights are used for a comparison of the mean residency of female and calf pairs and unaccompanied adults in 2016 using two

methodologies: 1) cliff based photo-ID only, and; 2) cliff based and UAV photo-ID. The comparison of mean residency using the two methods improves the assessment of residency and provides data to inform the future direction of the research.

Site fidelity

Site fidelity was assessed for the calving female population using 26 years of inter-annual resights using photo-ID mark recapture. An individual was considered to display a degree of fidelity to HoB if it was sighted at least twice at HoB in different years, either with a calf or without. The fidelity of females with a calf was assessed based on the number of sightings of a female with a calf in different years.

The site fidelity of SRW seen only once at HoB and not sighted elsewhere was deemed indeterminable (Burnell, 2001). This study assessed only sighting histories recorded at HoB and does not consider other sightings of the same individuals in other areas in Australia. Therefore, an individual that displayed site fidelity to HoB may also display fidelity to another area. For example, an individual may have been sighted with a calf in two different years at HoB but also been sighted during the WAM aerial surveys with a calf on three occasions in Esperance, WA. This study attempts to assess only site fidelity to HoB. Burnell (2001) assessed the site fidelity of individuals to HoB relative to other areas by including sighting histories of individuals from the south-west and the south-east of Australia. Given the number of non-calf individuals identified in the HoB dataset alone ($n=1,186$) and the Western Australian dataset ($\sim 2,500$), it was not feasible to assess all sighting histories in this study.

Natal site fidelity

Calves identified in their year of birth at HoB that were later sighted with a calf of their own at HoB were considered to have natal site fidelity. The mean number of calves for each individual with natal site fidelity was assessed. The probability of sighting the calves at HoB prior and post maturity was assessed by plotting the total number of calves identified against the number of calves resighted prior to the mean age of first parturition of nine years (Charlton, 2017 – Chapter 3).

Date of calving

The date of calving was estimated using data from three seasons (2014-2016) when data was collected between mid-June and the end of September and resight information on pregnant females is available. A female was determined pregnant if she was sighted as an unaccompanied adult and later that season sighted with a calf. The mean date of calving was estimated using the average between the last day an individual was sighted as a pregnant female (or unaccompanied adult) and the first date sighted with a calf. There is a bias

considering that the exact date of calving is unknown. By selecting the mean date between sightings the adult without a calf (underestimate) and with a calf (overestimate) is considered counteract the bias. This data builds on the assessment of date of calving completed by Burnell and Bryden (1997) using data from 1993-1994.

4.4 Results

4.4.1 Residency

Photo-identification success

The photo-ID success and effort varied among years. Whilst the study period was consistent among years with surveys completed across 100 days in 2014 and 2016 and 98 days in 2015, the photo-ID effort varied. The number of sightings recorded per year between 2014 and 2016 for female and calf pairs was 552, 203 and 247, respectively and for unaccompanied adults was 157, 133 and 44, respectively. Inter-annual variation in maximum abundance of SRWs at HoB and in number of individuals photo-ID'd in the study site was also observed between 2014 and 2016 (Table 4-1).

Table 4-1: Southern right whale study periods at Head of Bight, South Australia, 1992-1994 and 2014-2016, mean residency periods for calving females and unaccompanied adults, maximum daily counts per year and photo identification success, and mean number of resights.

		Mean days within aggregation area and range		Maximum daily count, (number of individual's photo identified) and photo ID success (%)		Mean resights per individual (range)	
Year	Start-Finish dates and study period (days)	Calving females	Unaccompanied adults	Calving females	Unaccompanied adults	Calving females	Unaccompanied adults
1992	25 Jun - 10 Oct: 111	72	18	18 (17) 94%	7 (18) 257%		
1993	18 Jun - 13 Oct: 120	75	20	26 (26) 100%	21 (41) 195%		
1994	19 Jun – 12 Oct: 116	66	21	23 (24) 104%	24 (74) 308%		
Mean 1992-1994	116 days	70.9 (1-118)	20.4 (1-93)	22 (67) 100%	17 (133) 256%		
2014	19 Jun - 28 Sept: 100	23 (1-73)	13 (1-52)	60 (87) 145%	17 (47) 276%	3 (1-10)	2 (1-6)
2015	18 Jun - 25 Sept: 98	47 (1-92)	18 (1-47)	28 (36) 129%	27 (78) 289%	6 (1-17)	2 (1-5)
2016	16 Jun - 25 Sept: 100	48 (1-99)	14 (1-47)	81 (92) 114%	29 (105) 362%	6 (1-22)	2 (1-8)
Mean 2014-2016	99 days	40 (1-99)	14.7 (1-52)	169 (215) 127%	73 (230) 315%		

Photo-ID success was high and exceeded 100% when the number of individuals photo-ID'd was compared to the maximum daily count of the year, for female and calf pairs and unaccompanied adults. The total number of female and calf pairs photo-ID'd between 2014 and 2016 ($n=215$), exceeded the maximum daily counts ($n=169$), by a third. There was some inter-annual variation in the number of individuals photo-ID'd relative to the maximum daily count. For example, the number of female and calf pairs photo-ID'd exceeded the maximum daily count by 1.45 times in 2014, 1.29 times in 2015 and 1.14 times in 2016 (Table 4-1). For unaccompanied adults the total number of individuals photo-ID'd between 2014 and 2016 ($n=230$), exceeded the maximum daily counts ($n=73$) by three times (Table 4-1). There was also inter-annual variability in photo-ID success for unaccompanied adults. Photo-ID success ranged from 2.89 times the maximum daily count in 2014, to 3.62 times the maximum daily count in 2015.

Residency periods

Residency periods were available for an average of 78% ($SD=20\%$) of females with calves and 38% ($SD=10.4\%$) of unaccompanied adults that were sighted at least twice in a season (2014-2016). The mean number of photo-ID resights of individual whales between 2014 and 2016 was five ($SD=2.3$, range=1-22) for female and calf pairs and two ($SD=1.2$, range=1-8) for unaccompanied adults. The number of resights of individuals per year varied across years (Table 4-1).

Mean residency for female and calf pairs at HoB between 2014 and 2016 was 40.0 days ($SD=13.8$, range=2-99 days) and for unaccompanied adults was 14.7 days ($SD=1$, range=2-52 days) (Table 4-1). There was inter-annual variation in the mean residency period recorded for females with a calf, with the lowest mean residency of 23 days recorded in 2014 compared with 47 days in 2015 and 48 days in 2016 (Table 4-1). The inter-annual variation was significant when comparing 2014 with 2015 and 2016 ($p\text{-value} < 0.0001$), however there was no significant difference in the mean residency periods recorded in 2015 and 2016 ($p\text{-value}=0.79$). The mean residency of unaccompanied adults was consistent across years and ranged from 13 days in 2014 to 18 days in 2015.

Residence periods were assessed using additional sightings contributed in 2016 from the Murdoch University UAV study. An additional 777 sightings of females with a calf and 55 sightings of unaccompanied adults were collected during the UAV study. Additional sightings resulted in a mean residency of 61 days ($SD=21$, range=2-99 days) for female and calf pairs and 15 days ($SD=12$, range=2-52 days) for unaccompanied adults. When

using the UAV and cliff based sightings, the mean residency is significantly greater (p -value= < 0.0001 , $SD=22.43$) for female and calf pairs and not significantly different for unaccompanied adults (p -value= 0.65 , $SD=12.7$), compared to using the cliff based sightings alone. The contribution of UAV sightings resulted in a 12 day increase in the mean residency for female and calf pairs and 1.4 day increase for unaccompanied adults.

4.4.2 Site fidelity

Site fidelity was assessed for calving females ($n=459$) with sighting histories available from at least two sightings in different years between 1991 and 2016. Sighting history was available for individuals that were matched to individuals previously sighted at HoB in the long-term photo-ID catalogue. The mean annual number of calving females that were matched to the long-term photo-ID catalogue between 1991 and 2016 was 67% ($SD=20\%$). A maximum of 94% of females with calves were matched to the catalogue in 1999 and a minimum of 46% of individuals were matched to the catalogue in 2011. Therefore, 67% of calving females display some site fidelity to HoB. Of the 459 calving females in the HoB photo-ID catalogue, 186 (40.5%) were sighted with two or more calves at HoB. The number of calves recorded at HoB for calving females that displayed site fidelity to the area ranged from two to ten calves, with two being the most frequently recorded number of calves for each individual ($n=68$ individual) after a single calf ($n=273$) (Table 4-2, Figure 4-2).

Table 4-2: Number of calvings for reproductive females at Head of Bight, South Australia. 1992-2016

No. calves	1	2	3	4	5	6	7	8	9	10
# (n. 459)	273	68	46	26	17	12	11	4	1	1
%	59.5	14.8	10.0	5.7	3.7	2.6	2.3	0.9	0.2	0.2

Resights of calves occurred for 69 (16.8%) individuals out of the 410 calves photographed in their year of birth. The proportion of calves resighted increases after six years after birth (Figure 4-3). The maximum number of calves resighted in a single year was 15 out of 25 resights (60%) recorded in 1993.

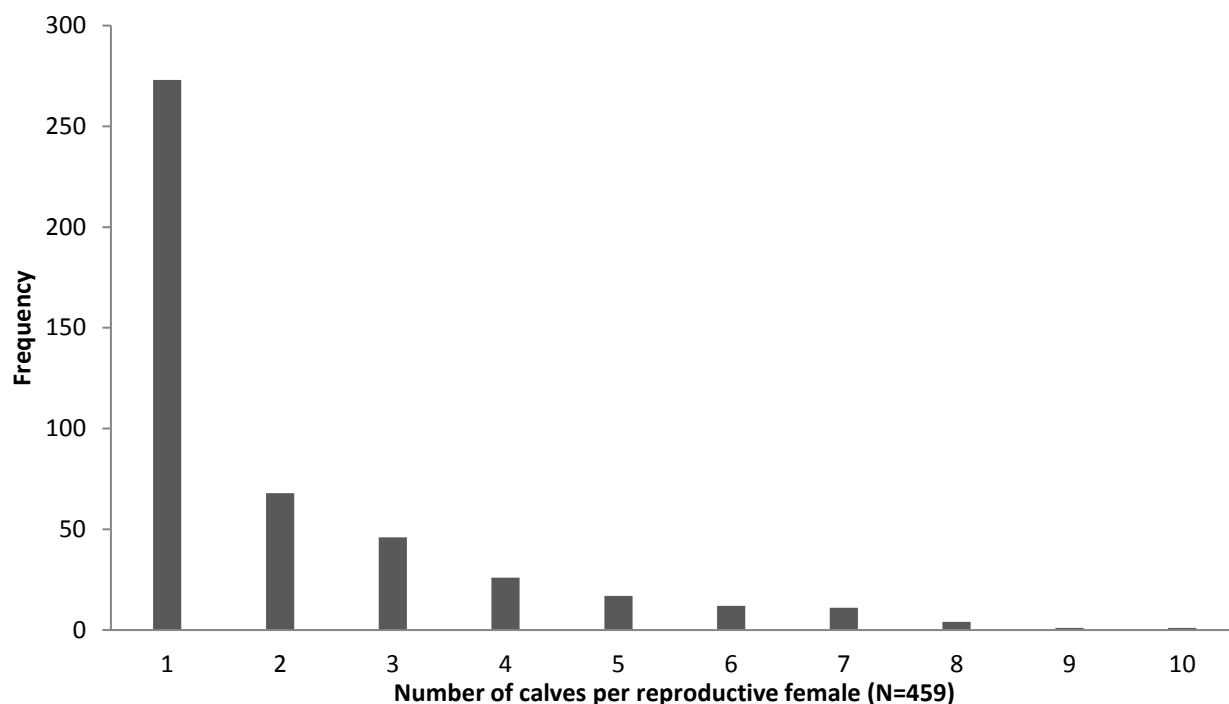


Figure 4-2: Frequency distribution of number of calves produced at Head of Bight by known reproductive females (n= 459).

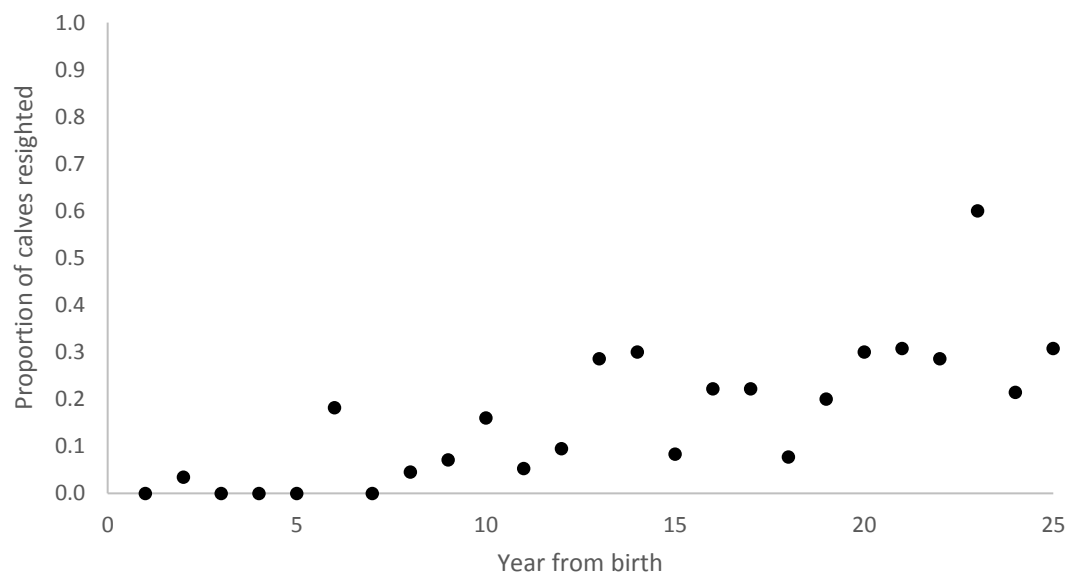


Figure 4-3: The proportion of southern right whale calves resighted at Head of Bight, South Australia, recorded between 1991 and 2016 with the year from birth starting at 1991 extending to 25 years after birth in 2016.

4.4.3 Natal site fidelity

Natal site fidelity was displayed for 23 of the 69 calves that were identified in their year of birth at HoB and resighted there in later years. The number of calves recorded for

individuals that displayed natal site fidelity ranged from one to five, with a mean of two calves (SD=1.3). The number of sightings of individuals that returned to HoB as juveniles or unaccompanied adult with natal site fidelity HoB ranged from zero to five sightings, with a mean of 1.4 sightings (SD=1.3). For calves that displayed natal site fidelity, 43% returned to HoB as yearlings and 60% returned to HoB as sub-adults in their first six years after birth.

4.4.4 Date of calving

The date of calving was estimated for 19 individuals between 2014 and 2016, that were sighted as an unaccompanied adult (pregnant) and later sighted in the same season with a calf (Table 4-3). The minimum number of days between sighting as pregnant and then with a calf was one day, providing evidence that at least some SRW must calve within the HoB study area. The mean date of calving was July 23 (SD=14.6). The last sighting of a pregnant female occurred on July 30. The number of calves sighted at HoB increased between June 15 (the start of the study period) and August 20 at HoB between 2014 and 2016 (Figure 4-4).

Table 4-3: Mean date of calving for female southern right whales at Head of Bight, South Australia (N=19), using the average date between the last sighting of female unaccompanied (UA) and the first date of sighting with a calf (Cow Calf = CC). Table includes HoB code for known individual, the year that the female was sighted as pregnant, the date of last sighting as an unaccompanied adult (UA) and date of first sighting with a calf (Cow Calf = CC)

HoB Code	year	date last sighted UA	Date first sighted CC
H9357	2014	25-Jun	20-Jul
H0807	2015	25-Jun	31-Jul
H1507	2015	2-Jul	7-Aug
H1509	2015	1-Jul	15-Aug
H1510	2015	9-Jul	16-Aug
H1511	2015	19-Jul	17-Aug
H0451	2015	2-Jul	27-Aug
H1501	2015	27-Jun	1-Jul
H1608	2016	25-Jun	1-Jul
H0150	2016	25-Jun	3-Jul
H1611	2016	25-Jun	2-Jul
H1613	2016	2-Jul	19-Jul
H9401	2016	19-Jul	20-Jul
H0945	2016	29-Jun	14-Jul
H0703	2016	29-Jun	6-Jul
H1622	2016	8-Jul	3-Aug
H1625	2016	19-Jun	3-Aug
H1628	2016	18-Jul	4-Aug
H1638	2016	30-Jul	22-Aug
	Mean	3-Jul	26-Jul

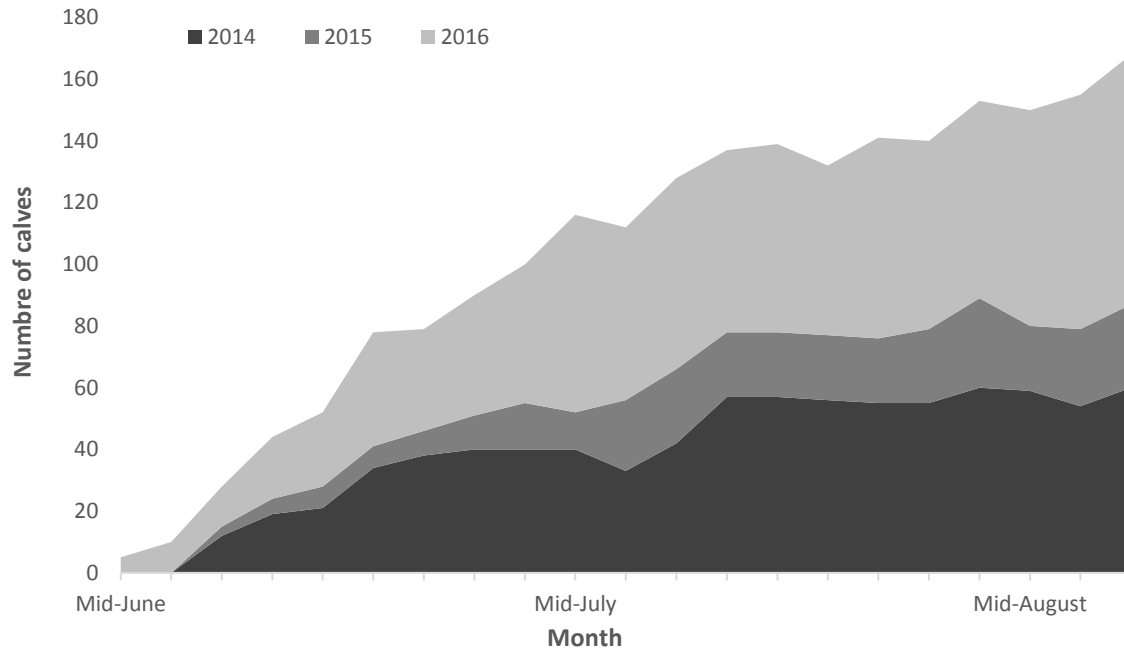


Figure 4-4: Stacked plot of number of southern right whale calves sighted at Head of Bight, South Australia in 2014, 2015 and 2016, between mid-June and reaching a maximum abundance by August 20.

4.5 Discussion

4.5.1 Residency

Southern right whale females with a calf and unaccompanied adults displayed residency at HoB. Residency periods for SRW calving females are known to be significantly greater than those for unaccompanied adults (Burnell, 2001). There was variation in the mean residency period for calving females between 2014 and 2015/2016. The lowest mean residency was recorded in the year with the greatest recorded movement of female and calf pairs into and out of the area (2014), based on the number of individual's photo ID'd ($n=87$) exceeding the maximum daily count for female and calf pairs ($n=60$) by almost half. In 2014, females with calves were recorded in the area for less than a week for 20% of all sightings greater than one day. In contrast, of the female and calf pairs resighted at least once, no female and calf pairs resided for less than a week in 2015 and 3% of female and calf pairs resided at HoB for less than a week in 2016. Thus, movement of individuals through the area for short periods (<7 days) in 2014 resulted in a lower mean residency period. Using historical abundance trends and cohort structured breeding groups driven by the mean calving interval of 3.3 years for the population, 2014 is recognised as the largest breeding cohort (Charlton, 2017 – Chapter 3). In the year of the largest breeding cohort, the movements of individuals into and out of the study area throughout the season

increased and resulted in a lower mean residency period. Individuals moving into the area later in the season and staying for shorter periods of time also reduced the overall mean residency in 2015 and 2016.

When using the UAV and cliff based sightings, the mean residency is significantly greater for female and calf pairs and not significantly different for unaccompanied adults, compared to using the cliff based sightings alone. The use of UAV's provide access to whales in the eastern end of the study area that are not available for photo-ID from the cliff line. Females and their calves primarily occupy habitat in the shallow sandy gentle sloping bay in the east of the study area in the months of June and July. As the season progresses and the calf develops the female and calf pairs move along the cliffs to the centre and west of the study area and become available for photo-ID from the elevated Bunda cliffs (Charlton, 2017 – Chapter 2). UAV's provide excellent image quality and access to the whales and are recommended for future use in this study.

The mean residency period for calving females was significantly different (p -value= 0.036) when comparing 2014-2016 with 1991-1994. The mean residency of 40 days during 2014-2016 was lower when compared with the mean residency of 71 days during 1992-1994 (Burnell and Bryden, 1997). Some of this variation is attributed to the longer study periods in 1992-1994 (\bar{X} =116 days) compared to 2014-2016 (\bar{X} =99 days), although it is likely to be primarily attributed to the increased abundance of whales at the site (resulting in reduced sampling frequency for individual female-calf pairs) and the increased movement into and out of the area. The lower abundance in the early 1990's meant that the likelihood of collecting resights of individuals increased, introducing an observer bias. The maximum residency period recorded for a female and calf pair was 99 days (2016), compared to the maximum recorded for 1992-1994 of 118 days (1993). The total number of female and calf pairs photo-ID'd at HoB was 67 during 1992 to 1994 compared to 215 during 2014 to 2016. Between 1992 and 1994 the total number of individuals identified at the site (n =67) did not exceed the maximum number of female and calf pairs sighted on one day. However, 27% (n =215) more individuals were identified during 2014-2016 than the maximum daily counts (n =169), indicating movement into and out of the site with increased abundance. Results suggest that on average females reside for longer periods at HoB when there are fewer whales at the site. In years of high abundance, spatial pressures or conspecific attraction may enhance movement out of the area and subsequently reduce the mean residency.

There was very little variation across years for the residency period for unaccompanied adult at HoB and the mean residency period of 14.7 days during 2014-2016 was not significantly different (p -value=0.16) to the mean residency period of 20.4 days recorded for 1992-1994 (Burnell and Bryden, 1997). The maximum residency period for an unaccompanied adult was 52 days in 2014, compared with 93 days in 1993. The maximum residence period of unaccompanied adults was driven up in 1992 (n =93 days) and 1994 (n =76 days) with the presence of an individual H9220, whose residence period greatly exceeded the mean residency for unaccompanied adults (Burnell and Bryden, 1997). H9220 was sighted at HoB a total of 12 times between 1988 and 2010 and is a known female that has never been sighted with a calf of her own but was regularly observed socialising with other female and calf pairs. This individual returned to HoB on two year intervals from 1992 until she was last sighted in 2010, with the exception of her presence three years in a row at HoB between 1994 and 1996.

The HoB study area provides a unique site to observe whales in their calving habitat from cliff top vantage points throughout the calving season with high cost efficiency. The whales at HoB primarily aggregate with an area of approximately 10 km by 1 km (Charlton, 2017 – Chapter 2). Whilst it is known that whales spend extended periods residing in the wintering aggregation areas (Best and Scott, 1993; Carroll *et al.*, 2014; Crespo *et al.*, 2017; Rowntree, 2001), this study and Burnell and Bryden (1997) provide the only published observations of SRW residency periods in their calving ground across three decades between June and October. A maximum residency period of 58 days was reported for a SRW female and calf pairs in mainland New Zealand, with distances between capture and recapture of 610 km (Carroll *et al.*, 2014). Extended seasonal presence of SRWs to Saldanha Bay on the west coast of South Africa were observed along with year-round presence of right whales, however residency of individual whales was not assessed (Barendse and Best, 2014). Off the coast of Chile, sightings of ‘eastern’ South Pacific SRWs were recorded between July and October with resident times of up to three months (Galletti *et al.*, 2014).

4.5.2 Site fidelity

Site fidelity of SRW calving females to HoB is consistent across the survey years. A total of 67% of the breeding population identified between 1991 and 2016 (n =459) were sighted more than once and displayed a degree of fidelity to the site. Similarly, site fidelity was recorded for 69% of the breeding females identified between 1991 and 1995 (n =81) (Burnell, 2001). Whilst almost three quarters of the calving population display a degree of

site fidelity to HoB, less than half have been sighted with a calf more than once and display site fidelity to the wintering habitat for calving. Whilst individuals females were recorded with a calf at HoB up to ten times, the mean number of times that females were sighted with a calf at HoB was two, indicating that whales may chose alternative habitat to calve and reinforcing that the HoB aggregation is an open population. The number of new individuals being sighted at HoB increased annually at an exponential rate and the proportion of the western population of SRW (in the Australian context) that HoB represents has reduced with time (Charlton, 2017 – Chapter 3). Fidelity shown to HoB by calving females does not imply exclusive use of the area by the individual whale. It is known that females display choice in breeding site selection and that movement and shifts in selected calving habitat occur for SRW (Best *et al.*, 1993; Carroll *et al.*, 2014; Charlton, 2017 – Chapter 3 and 6).

Within and between season movements of SRWs on the southern Australian coastline are documented (Burnell, 2001; Pirzl *et al.*, 2009; Carroll *et al.*, 2011; Charlton, 2017 – Chapter 6). Shifts in selected calving habitat were recorded for females that had previously displayed breeding fidelity to HoB and then re-selected calving habitat to adjacent habitat at Fowlers Bay, SA. Charlton (2017- Chapter 6) reported that shifts in calving habitat from HoB to Fowlers Bay in years of high abundance at HoB were driven by spatial pressures and the HoB site having possibly reached a finite saturation capacity. Habitat dispersal of SRW from primary aggregation areas into alternative habitat with population growth was also recorded for right whale populations in Argentina and Brazil (Rowntree *et al.*, 2001; Danilewicz *et al.*, 2016; Seyboth *et al.*, 2016), South Africa (Barendse and Best, 2014) and NZ (Carroll *et al.*, 2011 and 2014).

4.5.3 Natal site fidelity

Of the 69 calves that were resighted at HoB since the year of birth, 23 individuals displayed natal site fidelity and were sighted at HoB at least once with their own calves. The sex of all calves was unknown so a percentage of female calves that return to calve was not calculated, although close to 50:50 male female sex ratio is reported for SRW (Best, 2012). The probability of calves being resighted at HoB increased six years after their birth. Overall, the proportion of calves that returned to HoB within the first six years was 10% of resights. This data supports that calves may disperse to other areas and return to their site of birth once they reach sexual maturity. Age of first parturition for the Australian population of SRW is a minimum of six years and a mean of 9.3 years (Charlton, 2017 – Chapter 3). Of the calves that displayed natal site fidelity (n=23), 60%

returned to the site within the first six years since birth and 43% were sighted at HoB as a yearling. Results suggest that the return of juveniles to their site of birth, particularly as yearlings, may increase the likelihood of natal site fidelity.

It is assumed that the level of difficulty in photographing calves when their callosities have developed increased with increased abundance. The development of callosities suitable for photo-identification recapture occurs when the calf is approximately 2-3 months old, which means that calf photo-ID's can only be collected during late-August and September. The female and calf pairs depart the site from August- October and thus there is only a small window of opportunity to photograph calves. Photo-ID images were collected during daily counts and the need to maintain consistency in the count and keep track of the whales often limited the amount of time that was spent with each female and calf pair to successfully collect photo-ID images of all calves.

4.5.4 Mean date of calving

The mean date of calving recorded in this study of July 23 is comparable to the estimated date of calving of July 16 reported previously for this population (Burnell, 2001).

The calving season varies for different populations of SRW in the Southern Hemisphere. For example, in South Africa, SRW's can be sighted all year round but females with calves are sighted between June and December, and peak numbers recorded in September (Best and Scott, 1993). In Peninsula Valdes, Argentina, the calving season is between May and December, with the maximum number of whales reached from August to September (Crespo *et al.*, 2017; Rowntree *et al.*, 2001; Payne, 1986). The reasons for changes to the breeding season is unknown but could be related to the distances travelled to feeding grounds *i.e.* SRWs in Australia must travel further to southern feeding grounds and therefore the breeding season is shorter than Argentina and South Africa that are at higher latitudes and therefore shorter distances to feeding grounds. Triggers for arrival and departure to wintering aggregation areas also include weather and climate factors such as local storm events, air and water temperature influencing thermoregulation, but are most likely influenced by the arrival of spring plankton blooms (Burnell and Bryden, 1997) and physical condition (Lockyer, 1981).

This study improves the understanding of residency site fidelity and date of calving of SRWs within a coastal wintering aggregation area in Australia. It highlights the importance of calving aggregation areas and the need to understand more about the movement and connectivity of SRWs between aggregation areas in Australia. With an increasing

population and increased dispersal of SRWs to wintering aggregation areas it is important to understand site occupancy to direct future management planning.

5 Southern right whales (*Eubalaena australis*) return to a former wintering ground: Fowlers Bay, South Australia

Charlton C.M¹., R. Ward¹., R. McCauley¹., R. L. Brownell³., S. Guggenheimer¹., C. Salgado Kent¹., J. Bannister³.

¹Centre for Marine Science and Technology, Curtin University Western Australia

²NOAA Fisheries, Southwest Fisheries Science Center, Monterey, California, USA

³Western Australian Museum.

Contributors: Rod and Simone Keogh from Fowlers Bay Whale Eco Tours

Key words: Southern right whale, calving ground, photo-identification, abundance, distribution, conservation

5.1 Abstract

Southern right whales (SRWs) *Eubalaena australis*, have begun utilizing some of their historically important former winter habitat ranges in recent years along the southern Australian coast. Fowlers Bay (FB) in 'western' South Australia was a shore based whaling station in the early 19th century. Since whaling stopped, few SRWs have been sighted at FB until the mid-2000s. Here we present findings of increased abundance of SRWs at FB since 2004. This study investigates relative abundance trends, distribution and site occupancy for SRWs at FB, using sighting and photo-identification data from annual aerial surveys (1993-2016) and vessel surveys (2014-2016). Only three female and calf pairs in total were sighted during annual aerial surveys at FB between 1993 and 2003, compared with 62 female and calf pairs and 154 unaccompanied adults between 2004 and 2014. The estimated rate of increase in SRWs abundance at FB between 2004 and 2014 of 38.8% p.a. has high variability (SE=29.7) however, it exceeds the biological maximum for the species of about 7%. The only explanation for this rapid increase is that there is high immigration of SRWs into the FB area. Maximum abundance over the years was recorded between 20 July and 17 August, with a maximum daily count in 2011 of 16 female and calf pairs (range=0-16, \bar{X} =4.8, SD=4.6) and 23 unaccompanied adults (range=0-16, \bar{X} =5.7, SD=6.9). Minimum mean residency was 24.5 days (range=1-74 days, SE=4.28) for females accompanied by a calf and two days (range=1-7 days, SE=0.33) for unaccompanied adults. FB since 2004 highlights the renewed significance of the area as

a calving and aggregation area. The high variability in abundance and reduced sightings in 2015 and 2016 compared with the years 2004-2014 suggest that re-establishment to FB is not consistent between years, or that it is in part due to the different cohorts of adult females using FB. Conservation and management of potential disturbance to the SRWs is important to promote their establishment in this historically important area in the future. To collected the data needed to monitor the population annual surveys need to be continued. This is especially true because of the different cohorts of females that calf along the southern Australian coast.

5.2 Introduction

Southern right whales (SRWs) *Eubalaena australis*, were heavily exploited and reached near extinction globally owing to commercial whaling mainly in the 19th century (Dawbin, 1986) and again in the mid-20th century (Tormosov *et al.*, 1998; IWC, 2013). Whaling took place in Australia from approximately 1805 to the early 1900s and included bay whaling and ship based operations, with SRWs being the main target of the industry. Bay whaling involved shore based stations along the southern coasts where whales visited to calve, mate and rest during the austral winter months. Ships from at least America, Britain, France and Australia sheltered in bays and inlets, hunting whales while they were there (Dakin, 1938). Shore and ship-based whaling was heavily concentrated in south-'eastern' Australia west to Adelaide in South Australia (SA) and east to New Zealand (NZ) where two thirds of the estimated minimum of 26,000 SRWs were caught from 1827 to the early 1900s (Dawbin, 1986). Most of this whaling took place between 1835 and 1844 (Dawbin, 1986). There were approximately 115 Australian shore-based whaling stations in approximately 50 areas along the southern coast of Australia (Pirzl, 2008). Recordings of the number of whale takes and species are few, with the humpback whale being the other main species hunted (*Megaptera novaeangliae*). Estimates of historical catches were based on oil yields (by converting barrels, gallons or tons to the number of whales (Dawbin, 1986; IWC, 2013).

The only available record of the number of whales taken at Fowlers Bay (FB) in a single year is from the log of the American ship 'Amazon' which took 33 SRWs and eight humpback whales in 1840 (Bannister, 1986). Kemper and Samson (1999) reported that at least 65 SRWs were taken by bay whalers during 1840-1844 from the FB region. FB was thus an historically important calving and nursery area, although very few sightings were recorded during aerial surveys completed between 1980 and 2003, during which SRWs were increasing in south-Western Australia (Bannister, 1990).

Despite almost a century of protection since 1935, SRW sightings have been restricted to areas where the largest remnant populations existed (Burnell, 2001; Rowntree *et al.*, 2001; Bannister *et al.*, 2011). At these locations signs of population increase at or near the maximum plausible rate of around 7% per annum (p.a.) were recorded (Best *et al.*, 2001; Bannister, 2017; Cooke *et al.*, 2003). Conspecific attraction (safety in numbers) and historic whaling effort combined with philopatry appear to be the main drivers of southern right whale calving ground occupation (Payne 1986, Best *et al.*, 2001; Burnell, 2001; Rowntree *et al.*, 2001; Pirzl, 2008). These factors are considered key drivers for the differences in mitochondrial DNA haplotype frequencies between the ‘western’ and ‘eastern’ sub-populations in Australia, and the New Zealand, Argentinian and South African populations (Baker *et al.*, 1999, Patenaude *et al.*, 2007, Carroll *et al.*, 2011, Jackson *et al.*, 2016). In contrast to the typically strong fidelity to calving grounds, there is also evidence that SRWs can shift selected calving habitat and display flexibility in their local philopatric behaviour (Best *et al.*, 1993; Groch *et al.*, 2005; Carroll *et al.*, 2014).

The current population estimate for SRWs in Australia is around 2,500 individuals divided by genetic and geographical diversity into two sub-populations; the ‘western’ sub-population in the south-west of Australia of around 2,200 individuals and the ‘eastern’ sub-population in the south-east of Australia of less than a few hundred individuals (Bannister, 2017; Carroll *et al.*, 2011; Jackson *et al.*, 2016). In Australia, SRWs have dispersed their habitat range with increased abundance in south-Western Australia in recent years. There are now 13 recognised aggregation areas along the southern coastline of Australia: including large established aggregation areas at Doubtful Island Bay and Israelite Bay in Western Australia (WA) and Head of Bight in SA; small established aggregation areas regularly occupied, including Yokinup Bay in WA, Fowlers Bay SA and the Warrnambool region in Victoria. Other aggregation areas that are sporadically occupied include Flinders Bay, Hassell Beach, Cheyne/Wray Bays, Twilight Cove in WA, and Encounter Bay in SA (DSEWPaC, 2012). SRWs are mainly concentrated along the south-west coast of Australia (representing the ‘western’ sub-population), between Cape Leeuwin, WA and Ceduna, SA (Bannister, 2001; Pirzl, 2008).

Annual aerial surveys conducted through the Western Australian Museum (WAM) since 1976 provide information on long-term trends of the ‘western’ sub-population of SRWs in Australia (Bannister, 2001, 2010 and 2016; Bannister *et al.* 2011). The annual aerial survey programme began following increasing reports of SRWs off the south coast of WA in the early 1970s (Bannister, 1990). From 1976 to 1992 surveys were undertaken between Cape Leeuwin, WA and Israelite Bay and occasionally to Twilight Cove, WA. From 1993

to 2016 aerial surveys have been undertaken between Cape Leeuwin, WA and Ceduna, SA. Whilst there is knowledge on the broad scale distribution and abundance trends (Bannister, 2001, 2010 and 2016; Bannister *et al.*, 2011), spatial ecology (Pirzl, 2008), and fine scale demographics at the primary aggregation area at Head of Bight (Burnell and Bryden, 1997; Burnell, 2001; Charlton, 2017 - Chapter 3 and 3), it is prioritised in the Commonwealth SRW Conservation Management Plan to understand the characteristics of SRWs in small established and emerging aggregation areas (DSEWPaC, 2012). Knowledge of SRWs in established and emerging aggregation areas is required to facilitate recovery planning, including management of potential anthropogenic impacts and setting of population recovery targets, with the aim of seeing the species delisted from its endangered status in Australia.

FB is a small established aggregation area at the 'eastern' range of the 'western' sub-population of SRWs and approximately 160 km south-east of the most important calving ground at Head of Bight. Increased sightings of SRWs at FB have occurred since the mid-2000s based on aerial surveys (Bannister, 2011) and anecdotal reports by tourism operators since 2010. In this study, the long-term and seasonal trends in abundance, residency, distribution and within season movement of SRWs at FB are quantified, using 23 years of count data from annual aerial surveys undertaken through the WAM (1993-2016) and three years of vessel-based research (2014-2016).

5.3 Methods

5.3.1 Study Site

Fowlers Bay (32° 0' S 132° 30' E) is on the far west coast of SA approximately 710 km west of Adelaide, SA (34° 55' S, 138° 35' E), 110 km west of Ceduna (32° 08' S, 133° 41' E), which is the 'eastern' range of the 'western' subpopulation, and 370 km east of the SA/WA state border (31°41' S, 129° 00' E) (Figure 5-1). FB is approximately 160 km south-east of the aggregation area at Head of Bight, SA (31° 29' S, 131° 08' E) in the Great Australian Bight Commonwealth Marine Reserve, and is located within the Great Australian Bight which extends from Cape Arid, WA to Port Lincoln, SA. Fowlers Bay is approximately 95 km² in area and is in a habitat protection zone within the Nuyts Archipelago Marine Park (Figure 5-2). The area is open to fishing and no access or fishing restrictions apply in the Marine Protected Area. SRWs are known to occupy shallow gently sloping sandy bays in water depths of less than 10 m and within 2 km of the coast (Pirzl, 2008). FB provides sheltered sandy habitat, protected from the prevailing south-westerly weather conditions, and has water depths ranging from 0-20 m within 5 km of the shore.

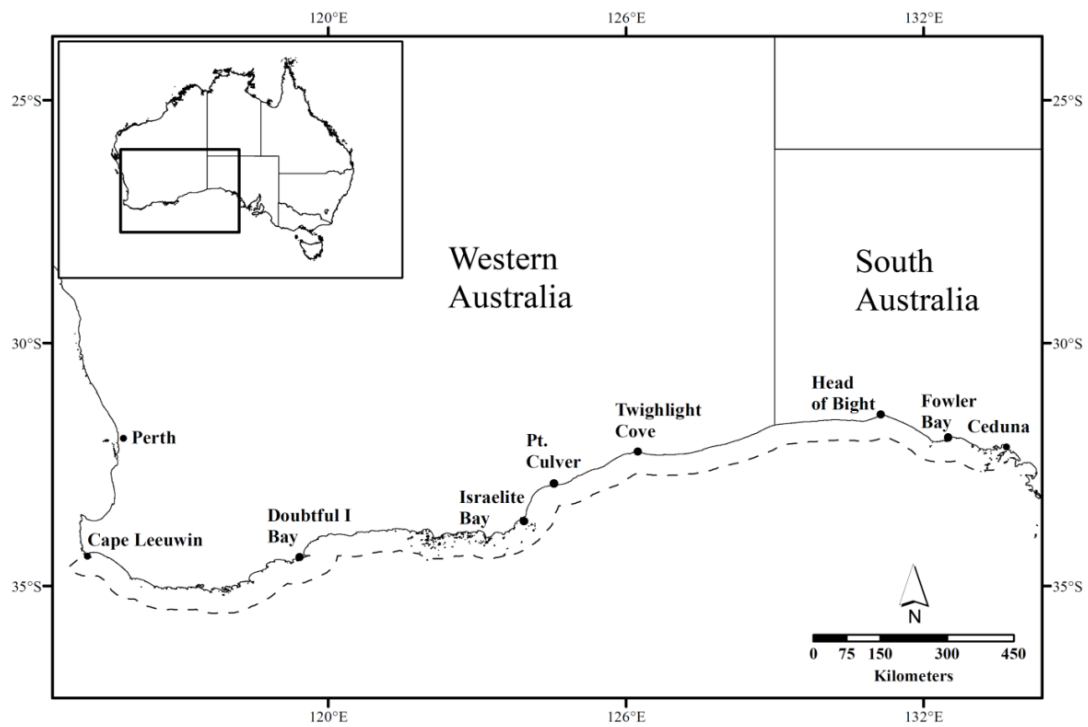


Figure 5-1. Southern right whale aerial survey off southern Australia from 1993 to 2016. Dashed line represents approximate survey route but further offshore so that contour is visible (Source: Bannister, 2017).

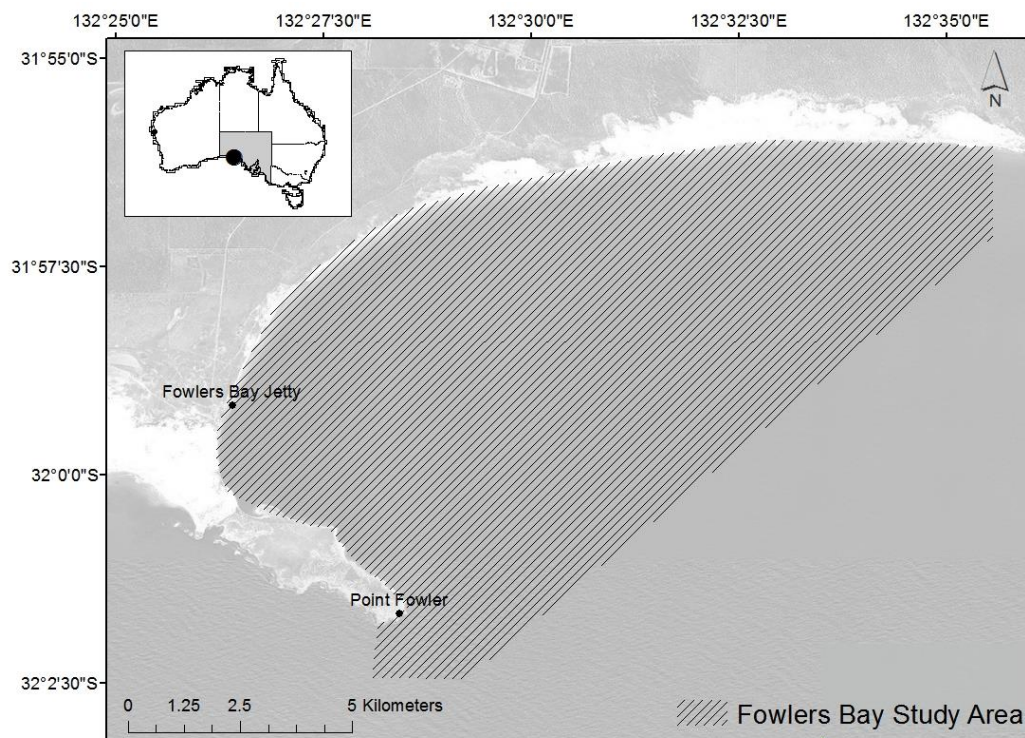


Figure 5-2: Southern right whale vessel survey study area at Fowlers Bay, South Australia.

5.3.2 Data collection

Data were collected using a combination of aerial and vessel-based surveys.

Aerial survey

Aerial surveys of the 'western' sub-population of SRWs were undertaken by J. Bannister of the WAM annually from 1993 to 2016 between Cape Leeuwin (34°22'S and 115°08'E), WA and Ceduna, SA (Bannister, 2001, 2011 and 2016) (Figure 5-1). Count data and photo identification (ID) images collected at FB during annual aerial surveys were contributed to this research by J. Bannister of WAM.

The annual aerial survey design and methods are described in Bannister (2016). The surveys consisted of a single transect running parallel to the coast approximately between 0 km and 1.85 km offshore (ca 0-1 nautical miles) of the coast as SRWs are known to aggregate in shallow waters close to shore on breeding grounds along the southern Australian coast. The distance from shore was dependent on whale sightings as once a whale was sighted; they were circled by the aircraft after which the aircraft returned to the transect line. Within FB, the aerial survey transect covered approximately 10 km of coastline. . Parameters of a large proportion of the population can be measured with these near-shore surveys. A single transect was completed from west to east on an 'outward' leg, followed by a second count on an 'inward' (return) leg from east to west, weather permitting. The higher count of the two flights on the single transect has been taken as the minimum estimated abundance of whales in the area. Within FB, the aerial transect was undertaken within a single day, as part of the longer leg of the aerial survey from Head of Bight to Ceduna. A five-day weather window is allowed between August 15 and September 15 each year for completion of the whole survey. The surveys are considered comparable for recording minimum number of SRWs occupying the Australian coast each year. Mean residence periods of 49 days (Charlton 2017 – Chapter 4) and 81 days (Burnell, 2001) were recorded for SRW calving females at Head of Bight and patterns in seasonal abundance show that whales depart the general region in September/October. Therefore, it is assumed that locations of female and calf pair sightings during the aerial surveys represent their selected calving and/or nursing habitat for that season. Unaccompanied adults are highly transient within season and therefore aerial surveys capture a snapshot of information on habitats used by unaccompanied adults. Surveys were completed using a high-wing, single engine aircraft (Cessna 172), crewed by a pilot/observer and photographer/observer, flying at 304m (1000 ft.) and

speeds of 185 km hr⁻¹ (100 knots) for searching while on transect and 148 km hr⁻¹ (80 knots) when circling whales for counting/photography.

Flights were undertaken only in wind speed conditions of <8 km hr⁻¹ (15 knots) for comparability in counts. When a group of whales was sighted, the group size and composition ('unaccompanied' animals; i.e. juveniles or adults not unaccompanied by a calf of the year and female and calf pairs) were recorded and individuals circled for verification of group size and composition and to obtain photo-ID images (Bannister, 2017). Methodology for photo-ID is described below. GPS location was recorded in degrees and decimal minutes. Most animals, particularly female and calf pairs are easily observed in the relatively clear and shallow waters on the south coast and the probability of sighting is assumed to be 1 (g (0)) (Bannister, 2017). Observer bias is reduced where possible by using experienced observers and the same pilot and observer/photographer from year to year.

Vessel surveys

Vessel-based surveys were undertaken on-board one of three FB Eco Whale Tours charter vessels between July and September from 2014 to 2016 (Table 1). The vessel used by the tourism operator depended upon availability. The vessels included: a 13.58 m (45 ft.), aluminium Cathedral hull vessel, with 600HP Yanmar inboard engines, with a 4.5 m vantage height (named *Asheera*); a 6 m (20 ft.) Fibreglass Tri Hull vessel with 2 x 70HP Yamaha outboard engines and a 1.5 m vantage height (named *Jaguar*); and a 15 m (50 ft.) fibreglass catamaran with 395 kW Volvo Penta inboard engine, with a 5 m vantage height (named *Calypso*). Surveys were conducted opportunistically in Beaufort Sea State conditions of three or less. The operational area extended approximately 12 km in the SW to NE direction and six km from shore in the NE to SE direction, covering an approximate area of 35 km². Tracks were haphazard in their spatial coverage since they were determined by the tourism operation. Vessel tracks were recorded using a Holux M-1000C GPS data logger that recorded the latitude and longitude of the vessel every second.

During vessel surveys, two observers searched for whales using a combination of the naked eye and Nikon 10 x 50 marine grade binoculars from the foredeck of the boat. This vantage point allowed unrestricted, 180° views forward of the vessel. When searching, one observer scanned from 0° forward to 180° on the port side of the vessel, while the second observer scanned from 0° forward to 180° on the starboard side of the vessel. Scanning was undertaken by continuously searching the entire visible area of the ocean

from the horizon down to the vessel, or shore to the vessel. The detection range was limited to approximately 4 km by the relatively low vantage point.

When an individual or group of SRWs was sighted, the vessel changed from search mode to closing mode with a minimum approach distance of 150 m (required by the licence conditions). Once the group of whales was approached, the following data were recorded at the closest distance reached to the whale: GPS location of the vessel in latitude and longitude; range (if possible) using Bushnell Elite 1600 ARC laser rangefinders; bearing from the vessel to whale using a compass; group size and group composition (female accompanied by a calf, unaccompanied adult i.e. juvenile or adult not accompanied by a calf of the year, or unknown); behaviour; time and date. To ensure that error in the compass was not introduced by nearby ferromagnetic metal, observers did not stand near non-aluminium metal and ensured they did not have any metal objects on them. The following weather conditions were recorded qualitatively at the start of each survey: wind speed, wind direction, Beaufort Sea State, swell height (m), and percentage of cloud cover. In addition, water and air temperature were recorded from instruments on the vessel. Photographs of individual whales were collected opportunistically for identification. Once data were obtained from the group and the whale-watch interaction terminated, the vessel departed the group and continued its search. Interactions with whales generally ranged from 2 to 30 minutes.

Photo Identification

Photographs of individual whales were obtained for comparing and matching individuals photographed previously. Photographs of the dorsal surface allow callosity patterns on the head, unique to each individual, to be documented. Callosity patterns are keratinised skin patches colonised by cyamids that provide individually unique patterns on the dorsal surface of the rostrum, the lip line of the lower jaw and just posterior to the blowhole, that remains recognisable for life (Payne *et al.* 1983). In addition to callosity patterns, dorsal blazes and notable scars were also be used as identifiable features when present.

Images for photo-ID were obtained using a Nikon 5200 Camera fitted with a Nikon 300 mm lens. Photos of the left, right and front of the head including perspectives from the left and right posterior and anterior of each animal were obtained when possible. Digital photo-ID images were sorted daily in the field, including within season cross matching of individuals to document the total number of individuals identified in that year and photo-ID success. Quality of images was dealt with by grading images and selecting the best images for future matching. The grading scale for images included excellent, good, and

poor. Only excellent or good images were used for future matching, although all images were stored. Images collected during aerial surveys were provided by J. Bannister of the WAM directly after the survey so that vessel-based images could be compared with aerial images in the field. For between year comparisons, Photo-ID resights were identified through matching photographs photo-ID catalogue developed in Big Fish v6 Microsoft Access database (Pirzl *et al.*, 2007).

5.3.3 Data analysis

Long term trends in abundance were assessed using count data from single aerial surveys undertaken annually between 1993 and 2016. Within and among seasonal trends in relative abundance were assessed using vessel survey counts undertaken during July-September between 2014 and 2016.

Long-term trend in abundance (using aerial survey count data)

Long-term trends in abundance were assessed and the annual rate of increase estimated using aerial count data from 1993 to 2016. General linear models (GLMs) with a log link (Poisson distribution) were fitted to the count data and loess smoothers used to show the overall trend using packages ggplot and GLM. The mean rate of increase is presented with confidence intervals, standard error and standard deviation. The percentage that the SRW represent relative to the overall 'western' sub-population was calculated by dividing the annual aerial survey count from FB by the 'western' sub-population derived from aerial survey data, as provided through WAM.

Within and among seasonal trend in abundance (using vessel based counts)

Within and among seasonal trends in relative abundance were assessed using SRW count data collected between July and September during the years 2014 to 2016. The highest daily count was used on days when two vessel surveys were completed. The variation in relative abundance of each population class (females accompanied by a calf, unaccompanied adults) was assessed using highest maximum daily counts. Relative abundance counts were not corrected for effort and are considered the minimum number of whales present in the area on the day of survey. The proportion of the maximum count of the season in July, August and September were calculated and displayed as a stacked bar chart using the R package ggplot to assess the relative seasonal usage of the area

Residency

Residency of females accompanied by a calf and unaccompanied adults were assessed through resighted animals captured by photo-ID during vessel surveys and aerial surveys

between 2014 and 2016. Resights within season were logged and residency was considered the minimum period that an individual spent in FB because observations were limited to the period in which survey effort occurred. If no sightings were recorded for days between resights it is possible that the animal left the area and then returned or was outside of the vessel survey area. Sightings of resident whales were generally regular and thus the date of first and last sighting was considered the residency period of SRW in FB.

Distribution

Spatial data processing used purpose built programs in MATLAB software to generate whale locations. Maps were generated in MATLAB from Australian Hydrographic Service charts under Seafarer GeoTIFF license No 2618SG (Curtin). GPS location of the vessel, the range between vessel and whale and the angle of the vessel height were considered when calculating the whale location. Errors in location data are within 100m. Spatial data were normalised for effort to number of whales per km² and displayed as kernel density distribution plots using ArcMap v10. Whale distribution was normalised for effort by dividing the number of whales sighted by the minutes of observation spent in each 500m² grid. For relative abundance assessment, the maximum daily count represents the minimum number of individuals in the study area. All times were presented in Australian Central Standard Time (UTC + 9.5 hours). Various handheld GPS units were used to log position, all using the WGS 84 chart datum (equivalent to GDA 90). Bathymetry was retrieved from the Geoscience Australia ~250 m resolution grid (Whiteway 2009).

Movement

Movement patterns between days from resights within the season were available for female and calf pairs that displayed residency to FB in 2015 and 2016. In 2014, the identification of the individual was not recorded with the location of each sighting and therefore individual movements could not be assessed. The location and identification of each female and calf pair were recorded for each resight. The locations of known individuals were mapped using ArcMap v10, with a number representing sightings of the same individual recorded on different days. If an individual is sighted greater than once on a single day, the same value is used twice. Maps present location data showing site use and movement patterns.

5.4 Results

5.4.1 Long-term trend in abundance between 1993-2016 (WAM aerial counts)

A total of 139 individual sightings of SRW adults were recorded during annual aerial surveys at FB between 1993 and 2016, of which 74 were unaccompanied adults and 65 were females accompanied by a calf of the year. SRW group compositions at FB included 53% unaccompanied adults and 47% females accompanied by a calf.

Few SRWs were sighted at FB between 1993 and 2003, and from 2004 onwards, sightings were recorded annually. During aerial surveys, a total of six different individuals were sighted at FB over the 10 years between 1993 and 2003, including one female and calf pair in 1993 and two female and calf pairs in 1999 (Figure 5-3). In comparison, a total of 216 different individuals were sighted over the 10 years between 2004 and 2014, including 74 unaccompanied adults and 62 females accompanied by a calf. No SRWs were sighted during aerial surveys at FB in 2015 or 2016. The mean rate of increase in abundance for total individuals was 38.8% p.a. (SE=29.7) and 29.2% p.a. (SE=31.2) for female and calf pairs between 2004 and 2014. In comparison, there was no sign of increase in abundance between 1993 and 2003 or between 2015 and 2016. However, SRWs were present during vessel surveys in 2015 and 2016 (See Section 5.4.2,

Table 5-2). The post-hoc test indicated differences in the rate of increase between all years between 1993 and 2003 and all years between 2004 and 2016. SRWs sighted at FB represent a minimum percentage of the 'western' sub-population of approximately zero from 1993-2001, 0.9% in 2002 and 7.4% in 2009.

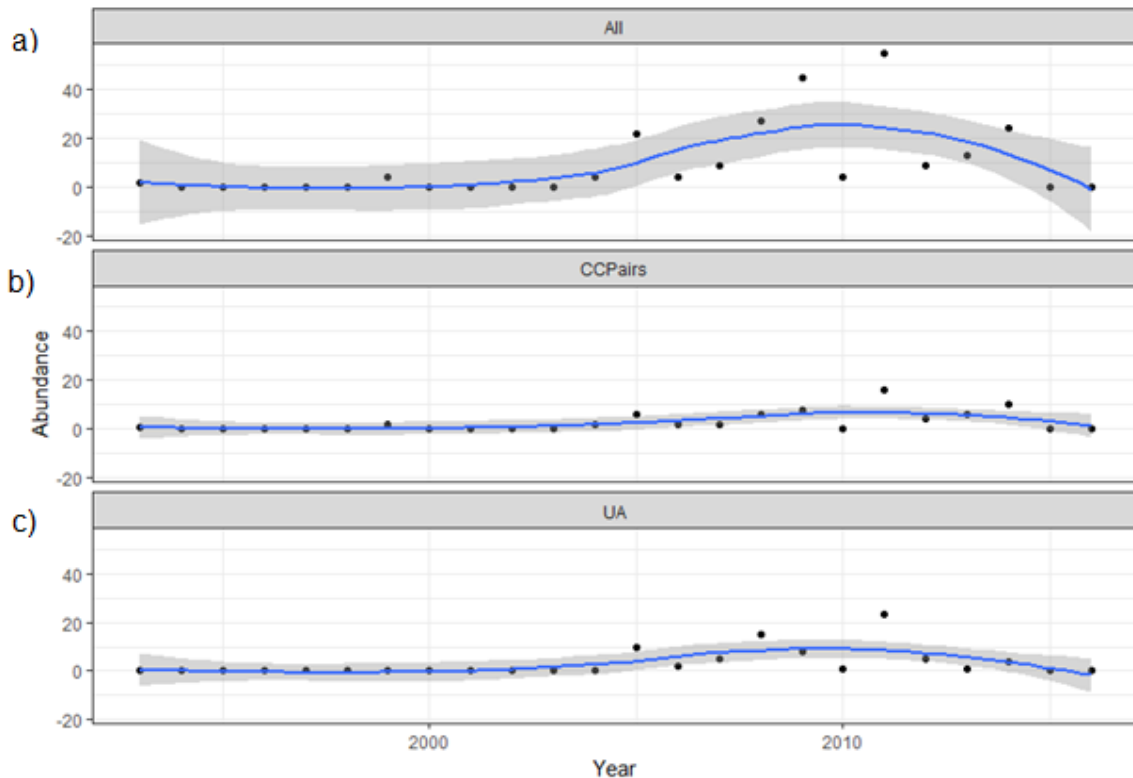


Figure 5-3: Abundance of southern right whales at Fowlers Bay South Australia from Western Australian Museum aerial surveys 1993-2016 (fitted with loess smoother with 95% CI), a) total individuals (All), b) abundance of females accompanied by a calf (CCPairs), and c) abundance of unaccompanied adults.

Inter-annual variation in abundance ($SE=29.7$) was high during years when whales were present. Triennial peaks in SRW numbers were observed in 2005, 2008, 2011 and 2014 and an additional peak in 2009 (Figure 5-3). Between 2004 and 2014, females accompanied by a calf were sighted annually, except for 2010 when no female and calf pairs were sighted. The mean daily maximum number of females accompanied by a calf recorded between 2004 and 2014 was 5.6 (range=0-16, $SD=4.5$, ± 2.7 95% CI). A maximum of 55 total individuals were sighted during the 2011 aerial survey, including 16 females accompanied by a calf and 23 unaccompanied adults. Unaccompanied adults were observed annually during the aerial survey between 2004 and 2014 with a mean maximum sighting of 6.7 individuals (range=1-23, $SD=7.0$, ± 4.1 , 95% CI). Triennial peaks in abundance were also observed for unaccompanied adults in years 2005, 2008 and 2011 (Figure 5-3).

5.4.2 Seasonal trends in abundance between 2014-2016 (Vessel surveys)

A total of 147 hours of observation was undertaken in 65 days during 73 vessel surveys between 4 July and 18 September, 2014-2016 (Table 5-1). On eight days, two surveys were completed on a single day, one in the morning and one in the afternoon. The vessel used varied throughout the surveys, with 53% of all surveys completed on *Ashera* with a vantage height of 4 m above sea level; 29% of surveys completed on *Tuna Explorer* with a 4.5 m high vantage height, and; 15% of surveys completed on *Jaguar* with a 1.5 m vantage height (Table 5-1). Whilst the distance to the horizon ranged from 4.4 to 7.6 km, the maximum visual detection range was considered <5 km from all platforms, measured through sighting frequency histogram. The average vessel speed was 11.5 km (6.2 knots) (Range=0-24kn, SE=0.047). While the vessel tracks varied between years, the survey effort was primarily concentrated between one and eight km north east of the FB jetty, with effort expanding in 2016 out to the area around Fowlers Point and into the middle of the bay due to fewer SRWs in the region (Figure 5-4).

Table 5-1: Vessel survey effort during 2014, 2015, and 2016 in Fowlers Bay, South Australia.

Year	# surveys	Total Effort (vessel hours)	Number of surveys undertaken per vessel			Survey dates
			Tuna Explorer	Jaguar	Ashera	
2014	31	58	21	10	0	4 July – 12 September
2015	27	49	0	2	25	26 July – 29 August
2016	15	40	0	0	15	17 July – 18 September
Total	73	147	21 (29%)	12 (16%)	40 (55%)	4 July – 18 September

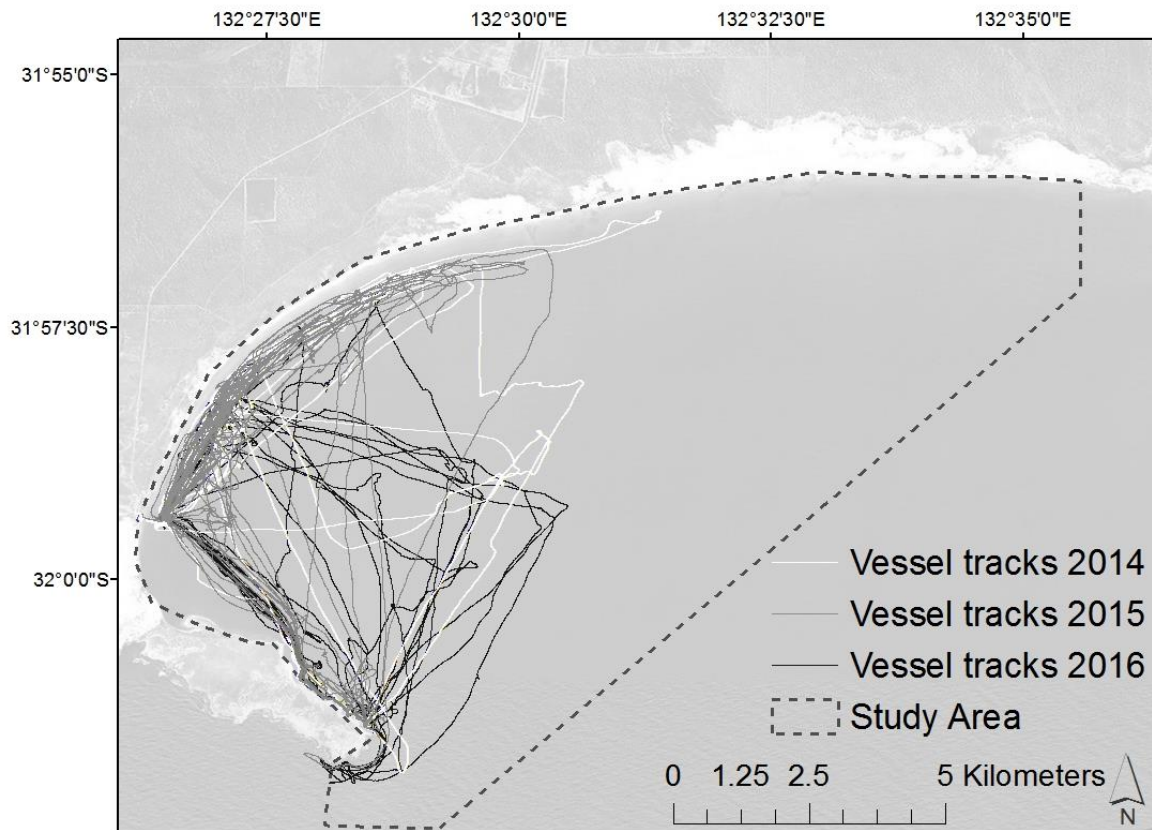


Figure 5-4: Vessel tracks from surveys conducted between June and September, 2014-2016 on-board Fowlers Bay Eco Whale Tours vessels in Fowlers Bay, South Australia.

A total of 440 sightings of individual whales were recorded during the 73 vessel surveys at FB. Out of all surveys, 79% (n=173) were females accompanied by a calf and 21% (n=90) were unaccompanied adults. Relative abundance of SRWs varied across years and within seasons at FB between 2014 and 2016 (

Table 5-2; Figure 5-5). Variation in effort between years was not corrected, however, maximum daily counts completed between July and September were comparable for this assessment. Variation in effort was influenced by visual observation of whale locations made from land. The mean maximum relative abundance recorded between years through daily vessel surveys was, six total individuals with a range of 0-22 individuals (SD=5.3, ± 1.23 , 95% CI) between 2014 and 2016. Between 0 and 10 female and calf pairs were sighted on one day, with a mean of maximum daily count of two females and calf pairs (SD=2.5, ± 0.59 , 95% CI). Between 0 and 7 unaccompanied adults were sighted on one day and the mean maximum daily count was one unaccompanied adult (SD=1.8, ± 0.41 , 95% CI).

Table 5-2: SRWs sighted at Fowlers Bay, South Australia in 2014, 2015 and 2016.

	2014			2015			2016		
	Daily range	\bar{X}	SD	Daily range	\bar{X}	SD	Daily range	\bar{X}	SD
Females-Calf Pairs	0-10	9	3.1	1-2	1.2	0.7	0-2	1	0.5
Unaccompanied Adults	0- 4	0.7	1.2	0-7	2.2	2.2	0-5	0.9	1.6
Daily Total	0-22	9	6.6	0-9	4.5	2.3	0-7	2.9	1.9

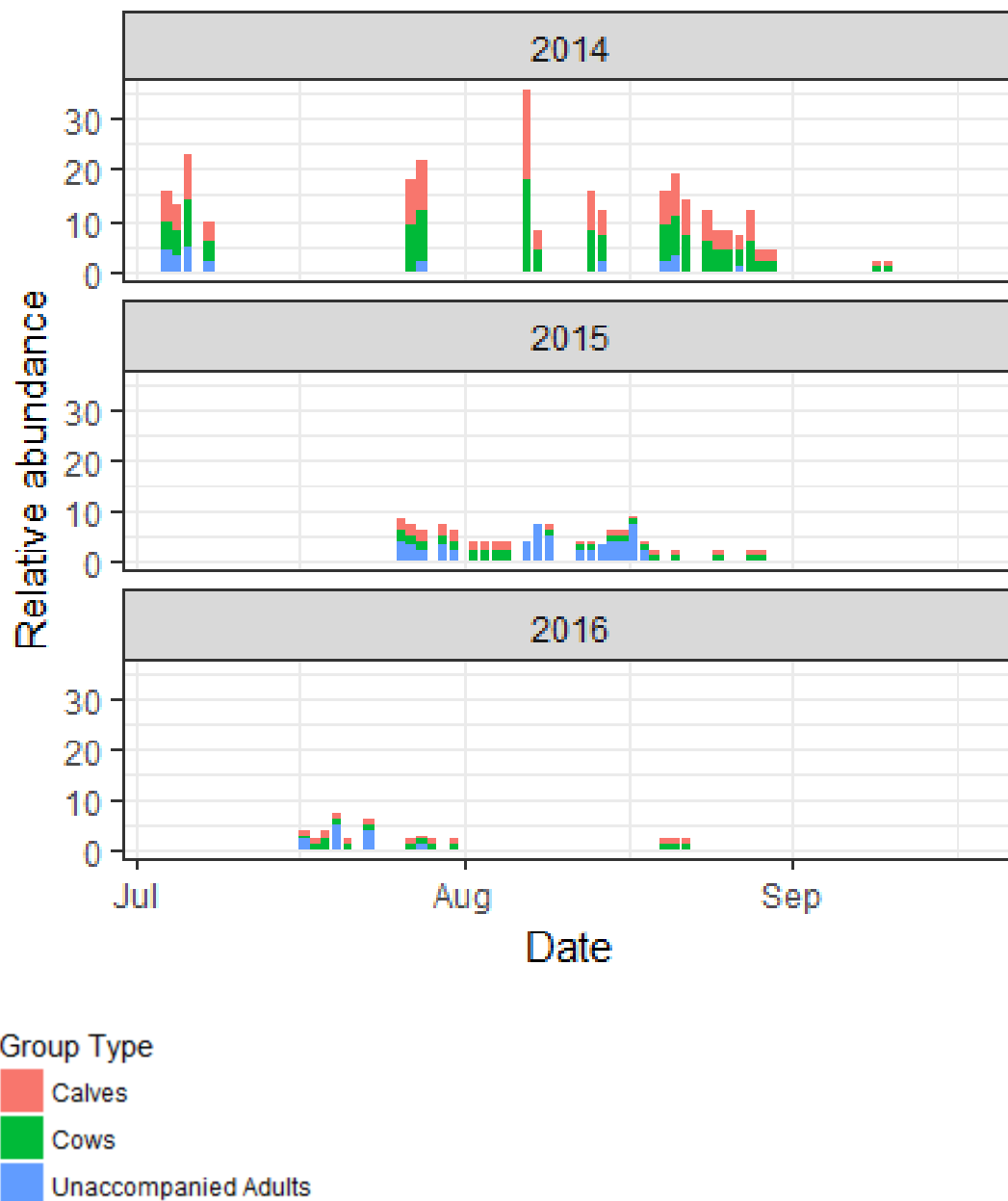


Figure 5-5: Southern right whale maximum daily vessel based sightings of females accompanied by a calf of the year (cow), calves and unaccompanied adults at Fowlers Bay, South Australia between 4 July and 12 September 2014, 26 July and 29 August 2015, and 17 July and 18 September 2016.

Within season trends in abundance show variation in SRW abundance between July and September, with peak numbers recorded in July and August. The period of peak abundance, indicated through vessel based maximum daily counts (2014-2016) was recorded between July 20 and August 17 (Figure 5-5). When normalised to the maximum daily count each year and calculated as a percentage of overall sightings between 2014

and 2016, a total of 60% of all whales was observed in July, 39% in August and only 1% in September. Female and calf pairs occupied the site throughout the study period (July to September). Between 20% and 100% of females accompanied by a calf were present at FB at the start of the study period in mid-July and between zero and 50% of females accompanied by a calf remained in the study area at the end of the study period in late September. There was variation in within seasonal trends in abundance between years (Table 5-2; Figure 5-5).

Unaccompanied adults were more transient and their abundance more variable than females accompanied by a calf. Unaccompanied adults occupied the site in the greatest abundance in July and August, with up to 57% of all unaccompanied adults observed in mid-July and no unaccompanied adults sighted in FB in September. Variation in daily count data indicates immigration and emigration into and out of the area throughout the season, particularly for unaccompanied adults (Table 5-2; Figure 5-5).

5.4.3 Residency

Residency was assessed using successful photo-IDs of 46 individual adults obtained during daily vessel surveys between 2014 and 2016. When compared with maximum annual relative abundance counts, a total of 0.87 (or 87%, $n=14$) of females accompanied by a calf and 1.76 (or 176%, $n=32$) of unaccompanied adults were successfully identified (Table 5-3). Photo-ID results showed that the number of unaccompanied adults photographed exceeded the maximum daily count in all seasons, suggesting movement of individuals into and out of the area within a season.

Within season resights were recorded for 72% of all individuals' photo-ID'd during vessel surveys, including 100% of females accompanied by a calf and 44% of unaccompanied adults (Table 5-3). The number ranged from 0 to 20 between 2014 and 2016, including a maximum of 20 resights ($\bar{X}=6$, $SD=5.4$) for females accompanied by a calf and 6 resights ($\bar{X}=1.2$, $SD=1.9$) for unaccompanied adults (Table 5-3).

Table 5-3: Number of SRW photo-identified, number resighted, range in the number of times animals were resighted, days of site occupancy (range and mean) for 2014, 2015, and 2016 at Fowlers Bay, South Australia.

Year	Group type	# Photo-ID'd	SRW # resighted	Range in the # of times SRWs were resighted	Range in site occupancy (days)	\bar{X} site occupancy (days)
2014	CC	11	11	0-11	1-75	27
	UA	8	2	1-3	1-2	1
2015	CC	2	2	3-20	11-35	29
	UA	17	12	1-6	1-15	4
2016	CC	1	1	12	12	12
	UA	7	0	0	1-1	1
total	CC	14	14	0-20	1-75	23
	UA	32	14	0-6	1-15	2

Females accompanied by a calf displayed residency to FB whilst unaccompanied adults were more transient through the area. Residence periods for females accompanied by a calf of up to 74 days (range 1-74 days, \bar{X} =24.5 days, SD=20) were recorded and seven days (range=1-7 days, \bar{X} =2 days, SD=1.8) for unaccompanied adults. Anecdotally, in 2015 a female and calf pair was in the Bay when the surveys began on 26/07/2015 and remained for 25 days after the survey finished on 29/08/2015 (total residency was 59 days for this animal). Residency periods varied across years at FB with whales displaying greater residency periods in years of higher relative abundance (

Table 5-2 and Table 5-3).

One calving female in 2014 was first sighted as a pregnant female and sighted 22 days later with a calf in FB, indicating that females are calving in the area and selecting FB as a nursing habitat.

5.4.4 Distribution

The distribution of SRWs at FB was available from sightings data collected on vessel surveys from 2014 to 2016. A total of 440 sightings of SRW individuals were recorded on vessel surveys between 2014 and 2016, with 280, 117 and 43 sightings recorded in 2014, 2015 and 2016, respectively. The maximum group size recorded on daily surveys for females accompanied by a calf was 11 individuals (range=2-11, \bar{X} =2.5, SD=1.5) and for unaccompanied adults was four (range=1-4, \bar{X} = 2.3, SD=1.0). The median group size for unaccompanied adults and for females accompanied by a calf was two.

There was little variation in distribution of female and calf pairs or unaccompanied adults when comparing 2014 and 2015. In 2015 and 2016 whales were sighted around Point Fowler. In comparison, in 2016 females accompanied by a calf were recorded very close to the shore and unaccompanied adults sighted were recorded further away from the shore and around Point Fowler (Figure 5-6).

SRW sightings at FB during vessel surveys (2014-2016) were predominantly within the 10 m depth contour within 1-2km from shore, and most commonly within a few hundred metres of shore. SRW sightings in the study area were between Point Fowler and 8 km south east of the FB jetty and were most common 1-5 km north-east of the jetty (Figure 5-7). Whale sightings were overlayed with vessel tracks to show the density distribution of whales compared to spatial effort (Figure 5-7).

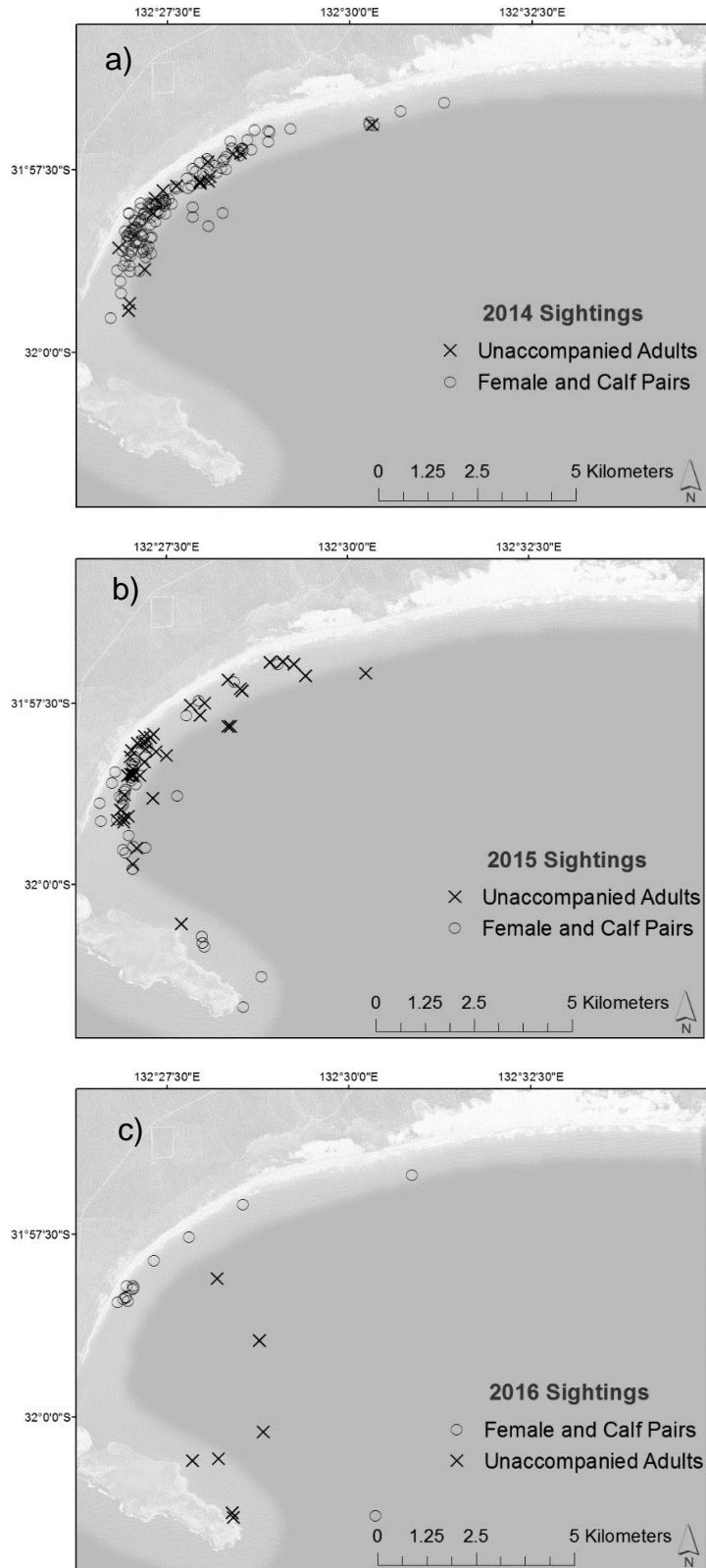


Figure 5-6: Southern right whale sightings of female and calf pairs (open circles) and unaccompanied adults (x) recorded within the Fowlers Bay South Australia study site during vessel surveys between 4 July 2014 and 12 September 2014 (a); 26 July 2015 and 29 August 2015 (b); and 17 July 2016 and 18 September 2017 (c).

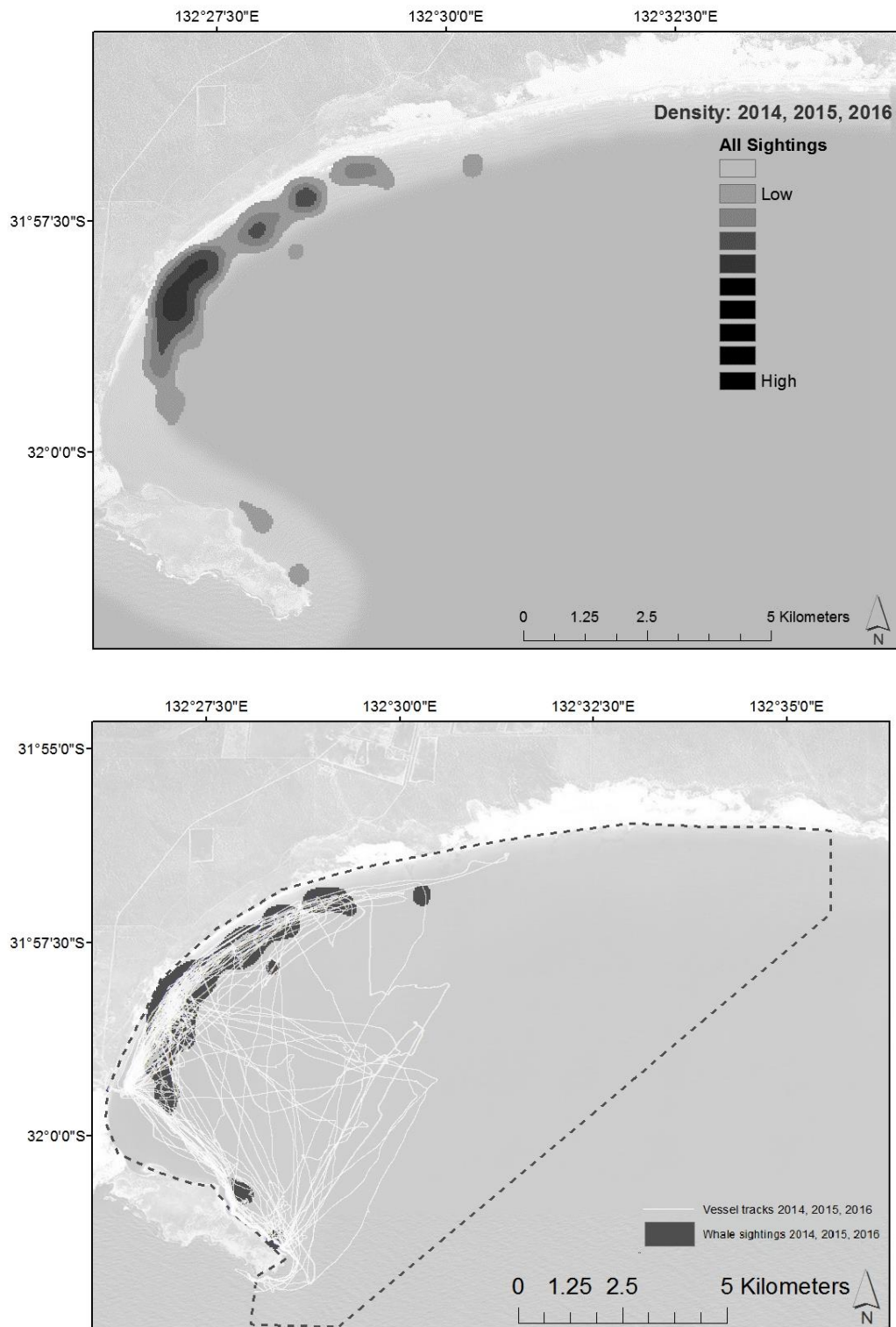


Figure 5-7: Kernel density distribution of southern right whales normalised for effort per km² using sightings data collected during vessel surveys at Fowlers Bay, South Australia between 2014 and 2016 (top). Kernel density plot overlaid with vessel tracks to show effort (bottom).

Whilst, in general, SRWs at FB displayed little within seasonal variation in distribution, there was evidence that the fine scale distribution patterns varied within season among some individuals. For example, a female and calf pair sighted 20 times in 2015 across 33 days displayed very little movement during the first 12 days (sighting #1-9) and then expanded its occupancy range on days 15 to 33 (sighting #10-20) before departing the site (Figure 5-8).

Site use patterns and range in occupancy varied among individuals (Figure 8). For example, in 2015, there were two female and calf pairs sighted at FB (CC1 and CC2) with resident periods of 35 days and 12 days, respectively. CC1 displayed a greater occupancy range within the FB study site than CC2 (Figure 5-8). Both female and calf pairs sighted at FB in 2015 displayed westerly movement and were later sighted during that season at the annual cliff-based SRW population monitoring at Head of Bight, 160 km to the west of FB. CC1 was sighted three times at Head of Bight between 8 September and 17 September, and CC2 was sighted once at Head of Bight on 15 August.

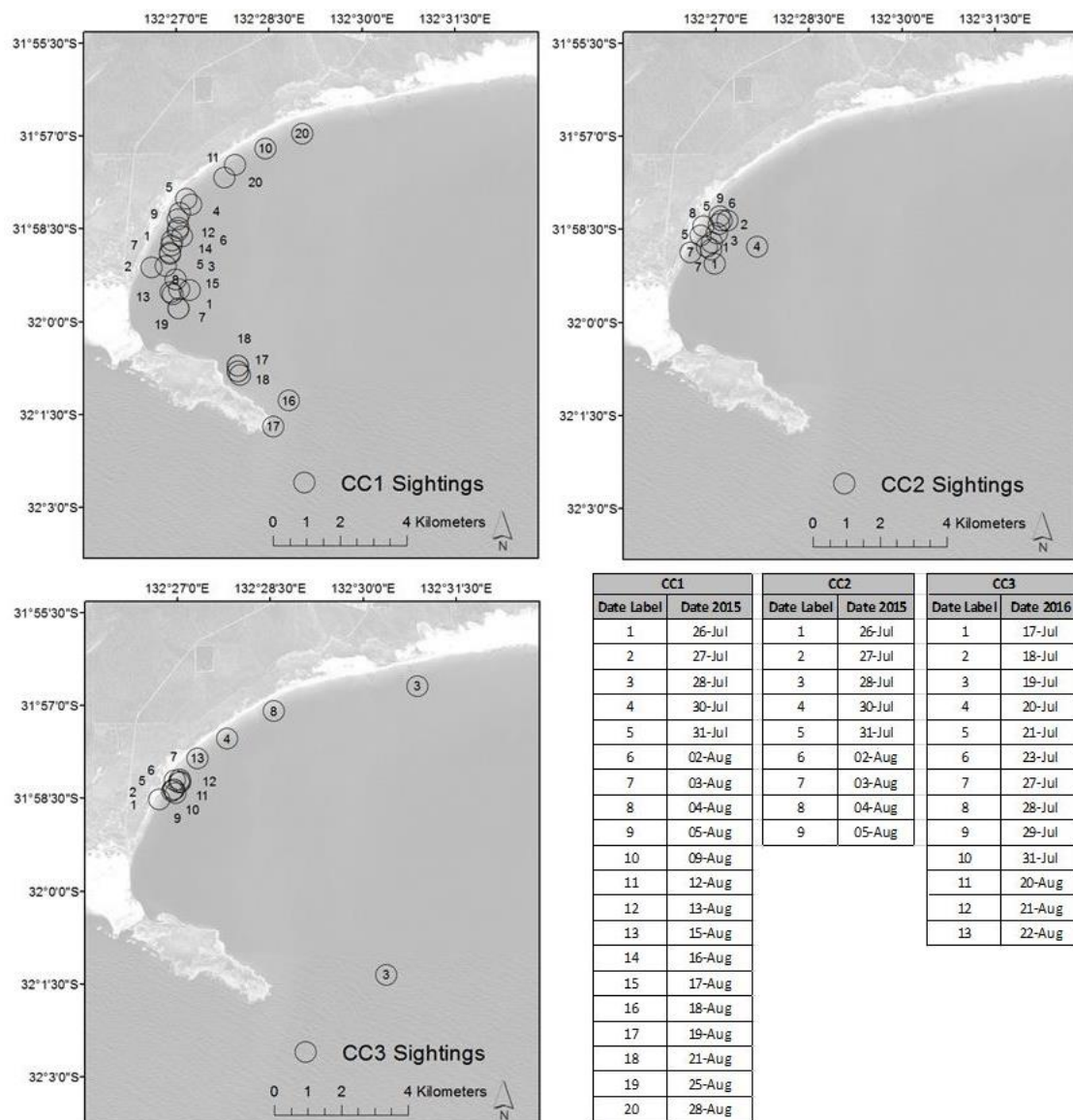


Figure 5-8: Examples of the movement patterns of SRW females accompanied by a calf at Fowlers Bay, South Australia in 2015 and 2016; individual whale ‘CC1’ sighted 20 times between 26 July 2015– 28 August 2015 (top left); CC2 sighted 9 times between 26 July 2015 and 5 August 2015 (top right), and; CC3 sighted 13 times between 17 July 2016 and 22 August 2016- (bottom right). The sightings numbers are in chronological order and correspond to a date in the tables displayed at the bottom right of the figure. Multiple values represent more than one sighting in one day.

5.5 Discussion

SRW numbers in FB have increased since 2004, with the area representing an expanding critical habitat for resident females accompanied by a calf. The abundance of SRWs at FB was highly variable across years ($SE=16.8$), but had a marked increase after 2003. The estimated rate of increase in SRW abundance recorded at FB between 2004 and 2014 of 38.8% p.a. (± 58 , 95% CI) for total individuals exceeds the biological maximum for the species of 6-7% p.a. (IWC, 2013) and the rate of increase estimated for the 'western' sub-population of SRWs in Australia of 5.55 p.a. (95% CI 3.78, 7.36) (Bannister, 2017). The accelerated rate of increase in abundance of SRWs at FB since 2004 suggests that there is high immigration of SRWs into the site since it is not biologically possible for a remnant population of SRWs to increase at that elevated rate.

SRWs sighted at FB represent a small but increasing percentage of the 'western' sub-population, going from zero between 1993-2001, to 0.9% in 2002 and 7.4% in 2009. The percentage of SRW that FB represents of the overall 'western' sub-population provides information on how the site is used over time and the growing importance of the area for SRWs. While there is an increase in the percentage of the 'western' sub-population of SRW sighted in FB, the relative proportion sighted at nearby HoB is decreasing. For example, in the early 1990's, SRWs at HoB represented up to 48% of the total 'western' subpopulation and in 2016, the SRWs at HoB represented 25% of the overall 'western' sub-population (Charlton, 2017 – Chapter 3). Results suggest that as the population of SRW grows there is increased emigration of animals from HoB, and increased immigration to FB.

The estimates of abundance are limited to the count data recorded from a single aerial survey undertaken in mid-late August to early September (1993-2016). Counts are consistent across years 1993-2016 with a single aerial survey completed annually in late August or early September. Vessel based surveys completed throughout the season (July-September, 2014-2016) compared with overlapping aerial surveys indicate that a greater number of individuals occupied FB throughout the season than the number of individuals sighted during the aerial survey on a single day. No SRWs were recorded during aerial surveys in 2015 and 2016. However, 27 adults and three calves were photo-identified in both seasons during vessel-based surveys and had departed the area prior to the aerial survey. Resident periods of animals sighted in 2015 and 2016 at FB ranged from 1 to 15 days for unaccompanied adults and 11 to 35 days for female and calf pairs.

Aerial surveys provide a snapshot of the SRW distribution on the day of the survey and represent a minimum number of individuals occupying the area in a season.

Variability in SRW abundance is generally driven by pulses in calf production due to their three to four-year calving cycles from different cohorts of females (Burnell, 2001; Charlton, 2017 – Chapter 3). Triennial peaks revealed in long-term abundance trends at FB compare with peaks recorded for the ‘western’ sub-population and Head of Bight (Bannister, 2017; Charlton, 2017 – Chapter 3). Peaks in abundance were recorded at FB and Head of Bight in 2005, 2008, 2011 and 2014. High years of abundance at Head of Bight typically correlated with high abundance at FB. For example, the maximum daily count of total individuals was recorded at FB in 2011 (n=55) which was the second highest abundance recorded at Head of Bight (n=172) (Charlton, 2017 - Chapter 3). It is hypothesised that the increased abundance of SRWs at FB is influenced by the adjacent habitat at Head of Bight reaching saturation capacity and individuals re-selecting to alternate suitable habitat at FB.. The increased abundance at FB is also likely a result of females calving before reaching Head of Bight and then selecting FB because it is the closest suitable habitat. In years of high abundance, it can be assumed that the number of females that calve early and don’t make it to Head of Bight also increases. Cross matching of individuals’ photo-ID’d at Fowlers Bay to other available photo-ID catalogues is required to assess where the individuals sighted at FB come from, or what proportion of the population represents a remnant population or first time breeders to the site.

In contrast to the mirrored years of high abundance at Head of Bight and FB, in 2016 record numbers of female and calf pairs were sighted at Head of Bight (172 total individuals and 81 female and calf pairs) (Charlton, 2017 – Chapter 3), while the lowest number of female and calf pairs in more than a decade was sighted in FB (no SRWs were sighted during aerial surveys and a single female and calf pair recorded residing in the Bay by vessel survey. A maximum of five unaccompanied adults were sighted on one day at FB in 2016 (

Table 5-2). SRW abundance at FB in 2016 was lower than expected and was the second consecutive year that whale numbers were low in FB. The lower than expected numbers observed in 2015 and 2016 at FB together with the high annual variation in abundance, suggest that the established use of the area is not consistent between years. One possibility would be that human disturbance leads to variation in the use of the area by right whales. Possible disturbances to the whales in FB include recreational and commercial fishers and whale watching tourism. Further study of possible sources of

anthropogenic disturbance is needed but at this time [subjective analysis leads to the conclusion that] levels do not seem sufficient to deter whales from using FB. A key driver of variation in abundance in right whales is the cohort structured breeding cycles based on an average of three-year calving intervals. Typically, key drivers of habitat occupancy are conspecific attraction, philopatry and topography. Lower than expected SRW abundance was observed for the 'western' population between Cape Leeuwin, WA and Ceduna, SA in 2015 (Bannister, 2017; Charlton, 2017- Chapter 3). High variability of SRW abundance for populations elsewhere in the Southern Hemisphere was also observed in recent years (Brownell *pers. comm.*). Variability in SRW abundance requires further investigation for possible correlation with drivers such as climate factors and prey availability (Leaper *et al.*, 2006).

Industrial or recreational human use activities have the potential to impact SRW habitat occupancy in Australia. Known and potential threats that may have individual or population level impacts to SRWs include: entanglement in fishing gear, vessel disturbance, climate variability and change, noise interference, habitat modification and overharvesting of prey. Ship strike and elevated underwater noise from vessel traffic has had a significant impact on critically endangered North Atlantic right whales (*Eubalaena glacialis*) (Clarke *et al.*, 2009; Rice *et al.*, 2014). Currently, entanglement in fishing gear is the major cause of death in North Atlantic right whales. There is a need to manage potential anthropogenic disturbances to SRWs inside aggregation areas and on coastal and offshore migration pathways (although migration routes for Australian SRW are currently unknown). Geographic isolation and low population of humans has resulted in low levels of potential anthropogenic disturbance to SRW in much of their Australian coastal range. However, as the population of SRW increases and habitat range expands, the increase in encounters between humans and whales is inevitable. There is a need for further studies into anthropogenic impacts to SRW in Australia.

SRWs display within-season variation in abundance at FB that can be explained in part by unaccompanied adult immigration and emigration to and from the area within season. Whilst unaccompanied adults displayed mean residency periods of two days, but ranging up to 15 days, female and calf pairs were recorded residing in the area for up to two and a half months, with mean residency periods of 23 days. Collection of resights may be biased towards female and calf pairs because they generally occupy the area for longer providing more opportunity to collect images and build profile of left and right side of head from low elevation vessel surveys. Mean residency periods recorded at FB are shorter than at the adjacent aggregation area at Head of Bight. Charlton (2017 – Chapter 4)

reported a mean residency at Head of Bight between 2014-2016 of 40 (range=23 in 2014 and 48 in 2016) days for females accompanied by a calf and 15 days for unaccompanied adults. Burnell (1999) reported mean residency periods at Head of Bight of up to 71 days for female and calf pairs between 1991 and 1997. Residency was assessed at Head of Bight between May and October (Burnell, 2001) and at FB between July and September. Therefore observer bias may influence residency periods. Anecdotal records from tourism operators who operate charters at FB between June and October provide few sighting records outside of the research period, suggesting that the observer bias is minimal. Residency periods recorded at FB were greater in years of higher abundance within the Bay. For example, in 2014, a maximum daily count of 10 female and calf pairs was recorded and resident periods reached 74 days, whereas a maximum of two female and calf pairs recorded in 2016 had a resident period of only 12 days. SRW mother and calf pairs were recorded in Peninsula Valdes, Argentina for up to four months between June and November (Thomas and Taber 1984).

Kernel density distribution plots corrected for effort with number of whales per km² at FB support that the most occupied habitat by SRWs in FB is 1-5 km to the east along the coast from the pier and within 1 km from shore inside the 10 m depth contour (Figure 5-7). This supports the findings that SRWs generally occupy habitat with a shallow sandy bottom in a SE facing bay (Bannister, 2017; Burnell, 2001; Payne 1986; Pirzl, 2008).

Range expansion and recolonization to new areas has been observed for other SRW populations. SRWs in Brazil (Danilewicz *et al.*, 2016), Argentina (Arias *et al.*, 2017; Rowntree *et al.*, 2001), South Africa (Barendse and Best, 2014) and New Zealand (Carroll *et al.*, 2011, Carroll *et al.* 2014), show evidence of re-colonisation into former areas around the main nursery area in association with population growth. For SRWs in Brazil, Groch *et al.*, (2005) reported rapid re-colonisation to Santa Catarina in southern Brazil at a rate greater than is biologically plausible for the species, based on data collected between 1987 and 2003, suggesting immigration or re-dispersal from alternate habitat, such as Peninsula Valdes. Similarly, Carroll *et al.*, (2014) presented evidence of SRWs re-colonising former wintering grounds on the mainland of NZ, after nearly four decades post whaling, presumably from a remnant population that persisted in the NZ subantarctic islands. As populations increase, increased resource pressures at major SRW aggregation areas can be expected to promote increased use of connective pathways and increased abundance into small and emerging aggregation areas. The origin of breeding females sighted at FB is unknown. It is possible that the increased number of SRWs represents: a remnant population, post commercial whaling, re-colonising the area;

females that are first time breeders selecting FB as a calving ground; or, whales are re-selecting calving habitat and shifting from other areas, such as Head of Bight. The connectivity and movement of SRW from FB with other aggregation areas in Australia and New Zealand is assessed in Chapter 6, to provide insight into where the whales in FB have come from.

5.5.1 Conclusion

While FB was known historically as a location occupied by SRWs for calving and nursing their young, aerial surveys conducted between 1993 and 2003 indicate that the location was rarely used before 2003. However, this study presents evidence of the re-colonisation of SRWs into FB. This study addresses the objective in the Commonwealth SRW Conservation Management Plan and characterises the SRW abundance, distribution and residency at the small established aggregation area at FB. The occurrence of SRWs at FB since 2004 highlights the increasing significance of the area as a calving and nursing ground. The significant decline in SRW numbers recorded through aerial and boat-based surveys in 2015 and 2016 and the high variability in annual abundance suggests that re-establishment of FB as a key SRW habitat is fragile and that further investigation into population demographics, climate drivers and human disturbances is needed.

6 Connectivity and movement of southern right whales (*Eubalaena australis*) between Fowlers Bay, South Australia and other aggregation areas in Australia and New Zealand

Charlton C.M¹., R. Ward¹., S.R. Burnell²., R. McCauley¹., R. L. Brownell³., M. Watson⁴., J. Bannister⁴.

PhD Supervisors: R. McCauley¹., R. L. Brownell Jnr³., C. Salgado Kent¹

¹Centre for Marine Science and Technology, Curtin University Western Australia

²Eubalaena Pty. Ltd.

³NOAA Fisheries, Southwest Fisheries Science Center, Monterey, California, USA

⁴ Department of Environment, Land, Water and Planning, Victoria

⁵Western Australian Museum.

Contributors: Rod and Simone Keogh from Fowlers Bay Whale Eco Tours, Sacha Guggenheimer, Will Rayment Otago University, New Zealand, Catherine Kemper of the South Australian Museum, Pin Needam.

Key words: Southern right whale, photo identification, calving female, coastal movements, selected calving habitat

6.1 Abstract

Images of southern right whales (SRWs) *Eubalaena australis*, identified at Fowlers Bay (FB), South Australia (SA) while on their winter ground during 1983-2016 were cross-matched to available major Australian photo identification (ID) catalogues to assess: the connectivity and movement of SRWs between FB, SA and other aggregation areas in Australia and New Zealand. The origins of calving females, site fidelity and shifts in selected calving habitat were also assessed. Photo identification of 40 calving females and 58 unaccompanied adults was achieved at FB. Sighting histories were available for 81% of individuals from successful matches to the photo-ID catalogue from south-west Australia. No matches were made with the single catalogue of individuals from the 'eastern' sub-population of SRW in Australia. FB was the recorded place of origin for 40% of calving females (n=9), representing a remnant population or first-time breeders. Site fidelity of calving females to FB was low (21%) and shifts in selected calving habitat were

recorded for 45% of calving females. Within and between season movement was recorded across eight locations, most commonly between FB and Head of Bight (HoB), 160 km apart. Increased abundance at FB correlated with high abundance of female and calf pairs at HoB and likely represents a spill over from that primary habitat as it has reached a saturation capacity (space). A total of 65% (n=26) of all calving females and 36% (n=21) of all unaccompanied adults identified at FB were also identified at HoB. One animal was cross matched between the Auckland Islands, New Zealand 3,410 km to the south-east. Increased SRW abundance at FB represents the expansion of a small remnant aggregation as the depleted population recovers. However, the high rate of increase is above what is biologically possible and therefore is due in part to immigration of whales from other winter grounds.

6.2 Introduction

Southern right whales (SRWs), *Eubalaena australis*, were severely depleted by commercial whaling in the 19th and 20th centuries. Today's distribution of SRWs reflects historical exploitation - with winter aggregations that experienced little whaling having higher numbers of whales in comparison with those heavily exploited (Bannister, 1990, Burnell, 2001, Carroll *et al.*, 2011, Rowntree *et al.*, 2001). SRWs off the southern coast of Australia were overexploited by the whaling industry as in other parts of their range. Although SRWs became protected in 1935, signs of population increase were delayed until the 1970's due in part to illegal pelagic catches by the Soviet Union (Tormosov *et al.*, 1998). In Australia, the SRW population was most recently estimated at 2,500 individuals in 2016 (Bannister, 2017). The Australian population is divided into two sub-populations; the 'western' (~2,200 individuals) and the 'eastern' (<300 individuals) based on genetic differentiation (Carroll *et al.*, 2011), site fidelity based on photo identification (ID) data (Burnell, 2001) and different recovery [increase] rates between the two areas (Bannister, 2017). The 'western' sub-population is increasing at a rate of approximately 5.5% per year, while the 'eastern' sub-population is not showing any sign of increase (Bannister, 2017). The maximum biological rate of increase for SRWs is estimated at 6-7% per year (IWC, 2013).

Along the southern coastline of Australia, SRWs occupy 13 recognised wintering aggregation areas. The largest aggregations include Doubtful Island Bay and Israelite Bay in Western Australia (WA) and Head of Bight (HoB) in South Australia (SA). Smaller areas regularly occupied include Yokinup Bay in WA, Fowlers Bay (FB) in SA and Warrnambool and Portland in Victoria, and emerging aggregation areas include Flinders Bay, Hassell Beach, Cheyne/Wray Bays, and Twilight Cove in WA, and the sporadically occupied Encounter Bay and Victor Harbor region in SA (DSEWPaC, 2012). SRWs are predominantly concentrated along the south-west coast of Australia (representing the 'western' sub-population), between Cape Leeuwin, WA and Ceduna, SA (Bannister, 2001, 2011 & 2016; Burnell, 2001, Pirzl, 2008). Strong site fidelity and social cues are thought to limit the capacity for SRWs to establish aggregations in new or previously occupied locations (Pirzl, 2008, Roux *et al.* 2015). However, in the last two decades dispersal into former habitat ranges has been recorded in Australia (Pirzl, 2008, Bannister, 2017).

SRWs migrate during the Austral winter to aggregation areas, where pregnant females give birth to their calves in 'calving grounds' where they are nursed and reared. Shifts in selected calving (and nursing) habitat by calving females (a female accompanied by a calf of the year) are known to occur occasionally (Groch *et al.*, 2005, Carroll *et al.*, 2015; Rowntree *et al.*, 2001). In Australia, SRWs are known to reside in aggregation areas for up to three to four months (mean 65 days) (Charlton, 2017- Chapter 4). Because of resident periods of up to 4 months recorded for female SRW's accompanied by a calf, the location where a female and calf pair is sighted during mid-season is assumed to be the selected calving habitat. However, the exact location of calving is generally unknown, but is normally assumed to be in the nursing area as females with calves have been seen without calves earlier in the season (Burnell, 2001).

Fowlers Bay is a small, established aggregation area for SRWs (DSEWPaC, 2012), located approximately 160 km south-east of HoB and 150 km west of Ceduna, which is considered the 'eastern' range of the 'western' sub-population. HoB (31° 29' S, 131° 08' E) in the Great Australian Bight Commonwealth Marine Reserve is the largest established aggregation area for SRWs in Australia, representing up to 48% of the 'western' sub-population (Charlton, 2017 – Chapter 3). Regular sightings of SRWs were recorded at FB during annual aerial surveys and vessel based surveys conducted between 2004 and 2016, with a maximum of 22 female and calf pairs and 23 unaccompanied adults sighted in 2011 (Bannister, 2011, Charlton, 2017 – Chapter 5). SRWs sighted at FB represent a minimum percentage of the 'western' sub-population of approximately between 0.9% in 2002 (zero from 1993-2001) and 7.4% maximum in 2009 (Charlton, 2017 – Chapter 5).

Prior to 2004 very few SRW sightings were recorded at FB (based on surveys between 1993 and 2004). However, over the subsequent decade (2004 – 2014), SRW abundance increased significantly. While SRW have occurred in FB in greater numbers, the variability from year to year is high. For example, no whales were recorded in FB during aerial surveys in 2015 and 2016 (Charlton, 2017 – Chapter 5), and few were observed during vessel surveys over this period.

The increased abundance at FB since 2004 exceeds the biologically plausible maximum for the species (6-7%). Therefore, it is not feasible that the increased abundance is from the remnant population and it must be from immigration to the site from elsewhere. The connectivity and movement of SRW between FB and other aggregation areas in Australian and New Zealand (NZ) is unknown. The question remains: where have the whales at Fowlers Bay come from? FB is on the 'eastern' range of the 'western' sub-population and the connectivity between the two sub-populations is poorly known. Therefore, it is of interest to know whether the whales at FB are immigrants from the 'western' or 'eastern' sub-population. Photo-ID images obtained at FB during annual aerial surveys (1993-2016) and direct sightings (2014-2016), as well as opportunistic sightings prior to 1993, were compared with available major Australian photo-ID catalogues plus a NZ catalogue, to provide sighting histories.

This study uses available sightings data to assess the connectivity and movement of SRW between FB and other winter aggregations in Australia and NZ. The first sighting locations of a female with a calf were used to assess the origin and shifts in selected calving habitats.

6.3 Methods

6.3.1 Study site

FB (32° 0' S 132° 30' E) is on the far west coast of SA approximately 720 km from Adelaide (Figure 6-1). FB is located within the region known as the Great Australian Bight (GAB). The bay is approximately 95 km² in area and is within a habitat protection zone within the Nuyts Archipelago Marine Park.

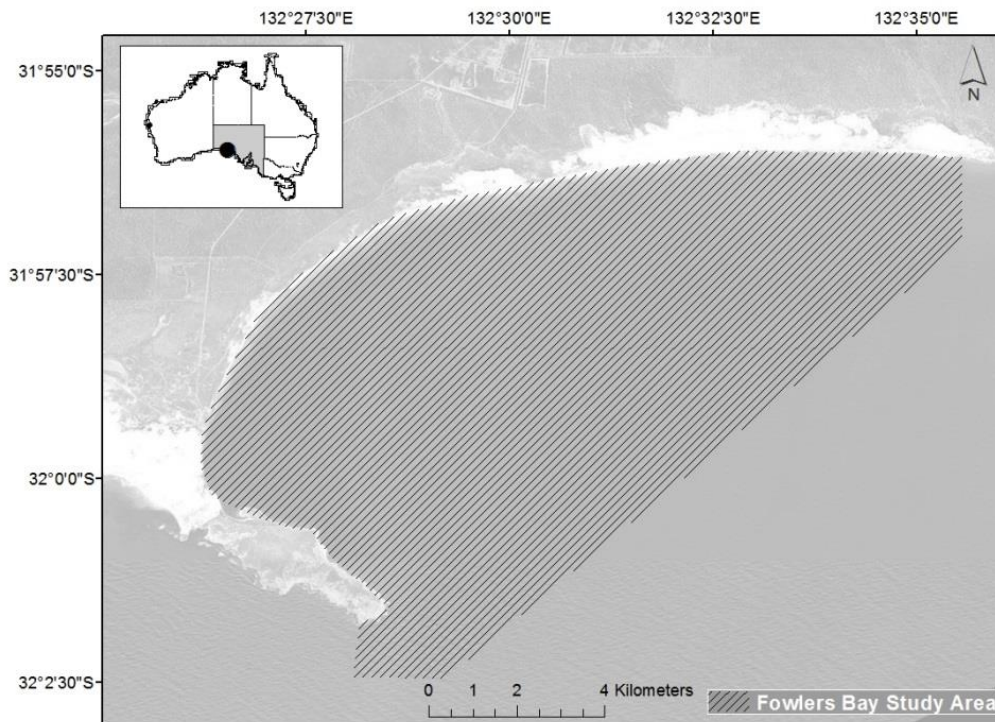


Figure 6-1: The location of Fowlers Bay, South Australia (source: Charlton 2017- Ch4).

6.3.2 Data collection

SRWs have natural markings (callosities) that form on the dorsal surface of the rostrum, the lip line of the lower jaw and just posterior to the blowhole (Payne *et al.* 1983). Callosities that appear white from a far, provide individually unique markings that remain recognisable for life (Payne *et al.* 1983). Callosity patterns can be used to identify whales over time, as can additional markings such as scars, pigmentation patterns and undulations along the lower lip line (Kraus *et al.* 1986). Long-term monitoring of SRWs using photo-ID mark-recapture methods can provide information on population size (Whitehead *et al.* 2000, Cooke *et al.* 2001, Best *et al.* 2005, Bannister, 2017), calving intervals (Burnell, 2001, 2008, Cooke *et al.* 2001, Best *et al.* 2005, Charlton, 2017 – Chapter 3), age of first calving (Burnell, 2001, 2008, Cooke *et al.* 2001, Best *et al.* 2005, Charlton, 2017 – Chapter 3), site fidelity (Burnell, 2001, Carroll *et al.* 2014, Charlton, 2017 – Chapter 4) and movements (Burnell, 2001, Pirzl *et al.*, 2009, Carroll *et al.*, 2014, Charlton, 2017 – Chapter 6, Roux *et al.*, 2015).

Photo-ID images of SRWs sighted at FB were obtained through annual aerial surveys completed through the Western Australian Museum (WAM) between 1993 and 2016, and vessel based research completed in FB between 2014 and 2016. Detailed methodology for collection and processing of photo-ID images at FB during aerial and vessel surveys

is available in Bannister (2016) and Charlton (2017 – Chapter 5), respectively. Opportunistic sightings that were contributed to major datasets from pre-1993 were also contributed to this assessment, including sightings records from aerial surveys undertaken by the South Australian Museum 1984-1991 between Port Lincoln SA and Eucla WA (and as far west as Twilight Cove, WA post 1988).

Aerial surveys were carried out by J. Bannister through the WAM since the mid-1970s in WA and were extended to include the ‘western’ sub-population (including FB) between Cape Leeuwin WA and Ceduna SA, from 1993. Surveys were planned annually between August 15 and September 15 and included a single flight in a west to east direction and return trip in an east to west direction. The flight followed a single transect parallel to the coast at 152-305 m (500-1000 ft.) above sea level and surveyed whales within 2 km from shore. During aerial surveys count and photo-ID data were collected for assessment of SRW distribution, abundance and life histories (Bannister, 1986 & 2016, Bannister *et al.*, 1990). ‘Overhead’ photo-ID images were obtained, with images captured whilst a whale was at the surface to record rostral callosity and dorsal or ventral blaze patterns.

Vessel based surveys were completed on board a local tourist operator vessel with a focus on SRWs between June and September 2014-2016. The vessel survey period of 2-3 months between 2014 and 2016 at FB resulted in increased sighting effort during those years compared to the single aerial survey completed during 1993 to 2016, potentially causing a bias in the data. That bias is particularly relevant for within season movements. Researchers recorded SRW location, classification (female and calf pair, unaccompanied adult) and opportunistically obtained photo-ID images. The vessel survey area extended approximately 12 km SW-NE and 6 km from shore NE-SE, covering an approximate area of 35 km². Vessel tracks were haphazard in their spatial coverage as they were determined by the tourism operation. Images for photo-ID were obtained opportunistically using a Nikon 5200 Camera fitted with a Nikon 300 mm lens. Photos of the left, right and front of the head including perspectives from the left and right posterior and anterior of each animal were obtained when possible. In addition to callosity patterns, dorsal blazes and notable scars were also used as identifiable features when present.

Processing of photo-ID images was undertaken by sorting images into folders with individuals photographed daily, and matched against individuals photographed that season. Quality of images was controlled by grading images and selecting the best images for future matching. All photo-ID images from aerial and vessel surveys were compared and a catalogue was established consisting of folders for each individual whale

sighted at FB between 1993 and 2016. If an individual was sighted across multiple years, then the photo-ID folder for that individual included multiple date folders.

6.3.3 Cross matching exercise

Photo-ID images of individual SRWs sighted and photographed at FB between 1993 and 2016 were compared with available photo-ID catalogues in Australia: WAM (Bannister, 2017), HoB (Charlton, 2017 – Chapter 3) and South ‘eastern’ Australia (SEA) (Watson *et al.*, 2013). Sightings history available from the HoB and WAM catalogues also includes matching completed with the Auckland and Campbell Islands in sub-Antarctic NZ between 1995 and 1998 (Patenaupe *et al.*, 2001, Pirzl *et al.*, 2009). Each individual match was completed by a small team of researchers experienced in SRW photo-ID, and verified by at least two different individuals.

The WAM photo-ID catalogue includes over 10,000 images of ~2,500 different non-calf individuals. As a part of the annual aerial survey, images collected at FB were matched to the WAM catalogue by J. Bannister. Sighting histories of all whales photographed at FB were contributed to this study. At the time of the analysis, internal matching of the WAM photo-ID catalogue was up to date to 2012. Sighting histories from the WAM catalogue were not available for individuals photographed at FB post 2012, however aerial images were provided by J. Bannister for cross matching of those individuals (post 2012) with other catalogues.

The HoB photo-ID catalogue contains 10,877 images of 1,186 unique non-calf individuals and an additional 362 calves of the year, collected at HoB between 1991 and 2016. Images of all individuals’ photo-ID’d at FB were systematically matched manually against the HoB catalogue using a computer-aided feature-coding system (BigFish v4.1) custom developed for the HoB catalogue (Pirzl *et al.*, 2007). Sighting histories available through the HoB dataset includes contribution of opportunistic sightings from the mid-1970s.

The SEA catalogue includes approximately 6,000 images of 355 whales including 60 females recorded with a calf, of which 12 were sighted greater than once with a calf. Data was collected in the SE between 1993 and 2016 (Watson *pers. comms.*). Images of 12 calving females that displayed site fidelity to the SE from the SEA catalogue were provided by M. Watson and cross matched manually to all individuals’ photo-ID’d at FB (1993-2016). No matching was completed for unaccompanied adults (adults not accompanied by a calf of the year) from the SEA catalogue. The subset of calving females that displayed fidelity to SE Australia was selected for cross matching to assess if individuals had

reselected preferred calving grounds from the SE to FB. Cross matching of the other calving females in the SEA catalogue is planned for 2017 and 2018.

There are three photo-ID catalogues in NZ including: the Auckland Islands containing 786 individuals photographed between 2006 and 2013 (Will Rayment pers. comm. 2017); the Campbell Island with 55 individuals photographed in 2014 (Torres *et al.*, 2017), and the mainland NZ with 33 individuals photographed between 1976 and 2010 (Patenaude 2003, Carroll *et al.* 2014). Cross matching completed between 1995 and 1998 (Patenaude *et al.*, 2001, Pirzl *et al.*, 2009) between Australia and the Auckland and Campbell Islands catalogues is included in this assessment. The Pirzl *et al.*, (2009) cross matching included only a subset of individuals. Therefore, the sighting histories available for matches made between sub-Antarctic NZ and Australia are considered an underestimate of true potential matches. Catalogues that were not examined in full include all three catalogues in NZ, Tasmania and, unaccompanied adults and calving females sighted only once from SEA. Photo ID images from the Victor Harbor/Encounter Bay in SA area are currently not catalogued and were not examined in this exercise.

6.3.4 Data Analysis

Data do not account for observer bias and variation in effort between the WAM aerial flights, HoB cliff based population monitoring, vessel based surveys at FB, or opportunistic surveys and photo-ID collection in the SE.

Cross matching to the WAM catalogue was not completed for the 13 individuals photo-ID'd at FB during 2012-2016, but was completed for the HoB and 12 individuals in the SEA catalogues. Therefore, individuals photographed at FB between 2012 and 2016 are excluded from the assessment of origin. The assessment of site fidelity, shifts in calving habitat, and within and across seasonal movements includes sighting histories from WAM and HoB catalogues before 2012 and only the HoB catalogue after 2012.

Unless stated otherwise, a sighting of an individual whale is only counted once, per site, per year. For the assessment of the origin of calving females photo-ID'd at FB, the location of first sighting of a female with a calf is considered the origin of the calving female. The site fidelity of calving females seen only once at FB and not sighted elsewhere was deemed indeterminable (Burnell, 2001). Therefore, the assessment of site fidelity included only individuals that were sighted more than once. A shift in calving habitat was recorded each time a calving female was sighted with a calf of that year, in a different location in a different year (i.e. a female sighted with a calf at FB, then sighted twice with a calf at HoB in different years, and then again at FB, has two recorded shifts in habitat). Assessment

of within and across season movements include calving females and unaccompanied adults, while the assessment of site fidelity and shifts in selected calving habitat include calving females only. Distances between sites were calculated as the shortest possible great circle distance by sea using the MATLAB (The Mathworks) Mapping Toolbox.

6.4 Results

At FB, a total of 204 sightings, including 65 female and calf pairs and 74 unaccompanied adults, were recorded during annual aerial surveys undertaken from 1993 to 2016 (Table 6-1, Figure 6-2). Of the total sightings recorded during aerial surveys at FB, 98 unique individuals were photo-ID'd from either aerial surveys during 1993-2016 or vessel surveys during 2014-2016. Of the 98 unique individuals photo-ID'd, 40 were females accompanied by a calf and 59 were unaccompanied adults. Therefore, the photo-ID success, when compared to annual sightings was 59% for unique female and calf pairs and 61% for unique unaccompanied adults. Photo-ID success is defined as the number of individuals photographed divided by the maximum daily count of individuals recorded on a single day each year. The first SRW was observed at FB in 1983 as an unaccompanied adult and contributed to this dataset as an anecdotal sighting and photograph. The first whale observed during an aerial survey was a female and calf pair in 1993.

Table 6-1: Number of total individual southern right whales counted at Fowlers Bay, South Australia during annual aerial surveys undertaken through the Western Australian Museum between 1993 and 2016, the number of unique individuals successfully photo-ID'd during aerial surveys and vessel surveys combined, and the total number of photo-ID matches to existing photo-ID datasets. The number of total individuals' photo-ID'd that were sighted outside of Fowlers Bay is also recorded.

Class	Total Count	photo-ID	photo-ID Match	Matched to WAM catalogue	Matched to HoB catalogue	Matched to SE catalogue
Female-calf pair	65	40	33	26	26	0
Unaccompanied adults	74	59	46	37	21	NA

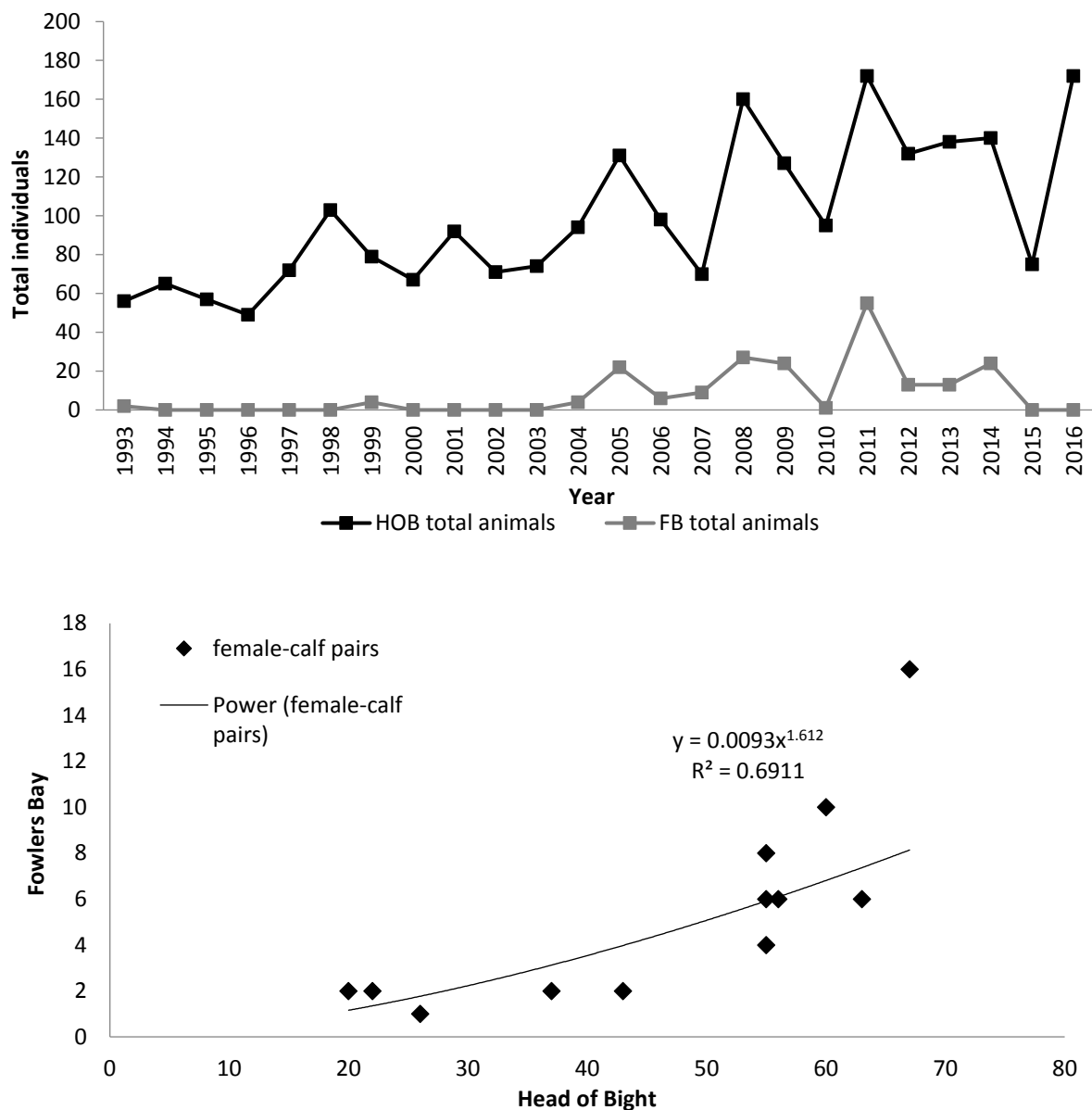


Figure 6-2: Southern right whale abundance count data for total individuals recorded from annual aerial surveys undertaken at Head of Bight and Fowlers Bay aggregation areas, South Australia from 1993 to 2016 (top), and the abundance trend of southern right whales sighted at Fowlers Bay (y-axis) compared with maximum annual counts at Head of Bight (x-axis), fitted with a power curve and excluding zero values (bottom).

The increased abundance at FB correlates to the abundance of female and calf pairs at HoB. When greater than 55 pairs were sighted at HoB, there is an increase in SRW female and calf pairs at FB (Figure 2). Peaks in abundance driven by pulses in calf production were observed at HoB and FB in 2005, 2011 and 2014.

Vessel based surveys at FB recorded a combined maximum daily count from 2014 to 2016 of 14 female and calf pairs and 16 unaccompanied adults. Successful photo-ID's

were collected for 15 females accompanied by a calf and 32 unaccompanied adults. During vessel surveys, a greater number of individuals was photo-ID'd (n=47) compared with combined maximum daily counts (n=30). Results display immigration and emigration of SRWs into and out of the area throughout the season, particularly for unaccompanied adults.

Matches to existing photo-ID catalogues of known individuals were achieved for a total of 81% (n= 79) of all SRW individuals photo-ID'd at FB (n= 98). Of the successful matches, 33 were known calving females and 46 were known unaccompanied adults. All successful photo-ID matches of individuals identified at FB were from the WAM or HoB catalogue with one match with the NZ catalogue. No matches were recorded for the 11 calving females cross-matched against the SEA catalogue. Of the 33 calving females that were successfully matched to other catalogues; 26 unique individuals were matched to WAM and HoB of which 19 were matched to both,, one individual was matched to NZ. Of the 46 unaccompanied adults photo-ID'd at FB that were matched to the WAM and HoB catalogues, 37 were matched to WAM, 21 to HoB and 12 to WAM and HoB.

Although no whales were sighted at FB during aerial survey in 2015 and 2016, whales were sighted during vessel surveys in those years (detailed below).

6.4.1 Origin of calving females sighted at FB

Sightings history from all photo-ID catalogues was available for individuals photographed prior to 2012 (n= 22), and therefore these individuals are available for assessment of origin. Of these 22 calving females, 40% (n= 9) had a place of origin at FB, 45% (n= 10) at HoB, and 14% (n= 3) at another location (Figure 6-3). One each was from Twilight Cove, WA, Israelite Bay, WA and Auckland Islands, NZ.

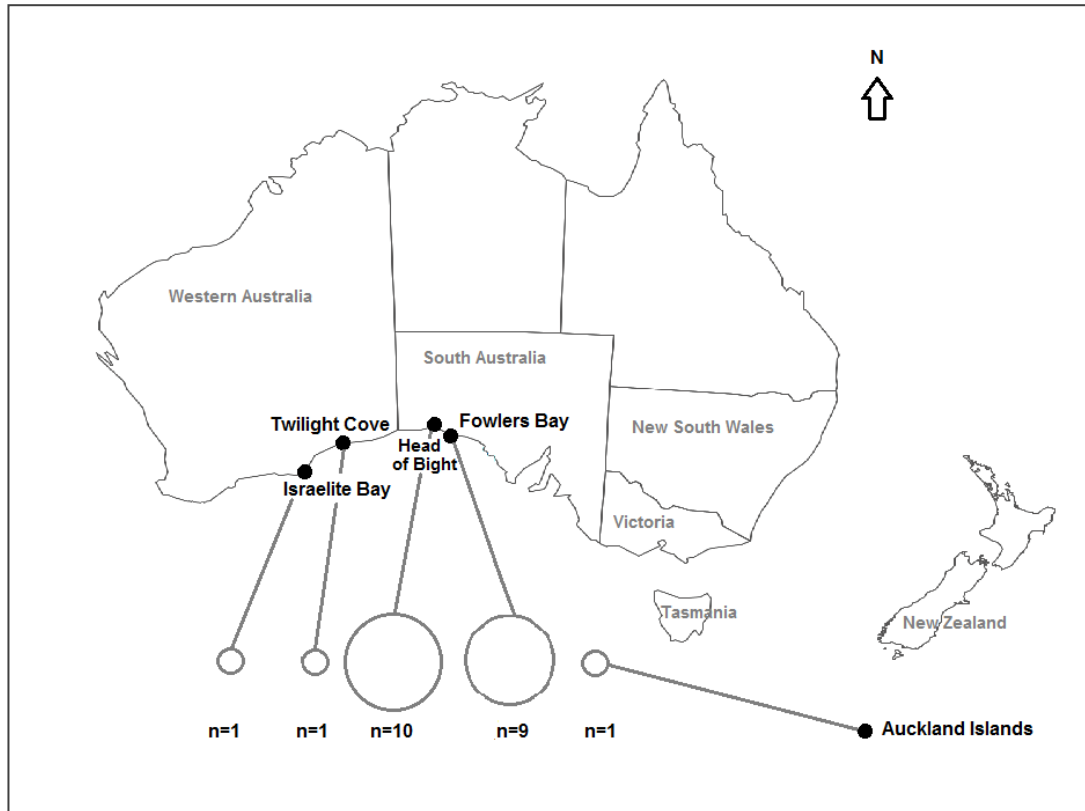


Figure 6-3: Origin (first sighting with a calf) of southern right whale calving females sighted at Fowlers Bay, South Australia 1986-2012 (n= 22).

6.4.2 Site fidelity and shifts in calving habitat of calving females

Site fidelity was displayed for five out of 24 calving females that were photo-ID'd in more than one year at FB (21%), with a maximum of three photo-ID sightings in different years of an individual female with a calf (Table 6-2). A calf was recorded in its year of birth at FB in 1996 in mid-August and was then sighted with a calf of its own at HoB in 2003 and 2006. Assuming this individual was born at or near FB, it did not display natal site fidelity to its birth place. One calving female was identified as an unaccompanied adult (or pregnant female) at FB in 2014 prior to being sighted with a calf of the year, later that season at FB.

Table 6-2: Number of times each calving female has been sighted at Fowlers Bay with a calf of that year, along with the number of times they have been sighted with a calf of that year at locations on the southern Australian coast other than Fowlers Bay (n= 37). Two individuals sighted at Fowlers Bay and another location in the same year were excluded as it is not confirmed at which location the whale resided first. One calving female was sighted at Fowlers Bay as a calf but was never sighted with a calf of her own at Fowlers Bay was also excluded.

Number of years sighted at FB	Sighted of nowhere else	Sighted elsewhere	1x Sighted elsewhere	2x Sighted elsewhere	3x Sighted elsewhere	Sighted >3x elsewhere
1	14	12	0	4	3	
2	0	1	1	0	0	
3	0	0	1	0	1	
Total (n= 37)	14	13	2	4	4	

A total of 89 calving events were recorded for the 40 unique calving females photo-ID'd at FB. Calving events for these 40 individuals were recorded at seven locations; FB (n= 46), HoB (n= 38), and one each for Israelite Bay, WA, Albany, WA, Esperance, WA, Twilight Cove, WA and the Auckland Islands, NZ. Of the 89 calving events, 52% originated (first photo-ID'd with a calf) at FB, 42.5% at HoB and 5.5% from elsewhere (inclusive of individuals who were sighted with a calf of that year at FB and another location). The mean number of photo-ID sightings recorded for calving females (unique for a site and year) is 1.15 (range 0-3, SD 0.53). The mean number of calves recorded for each calving female was 2.23 (range 1-7, SD 1.65).

Of the 40 calving females photo-ID'd at FB, 17 were also photo-ID'd elsewhere with a calf. Females sighted with a calf at FB were sighted outside FB as an unaccompanied adult in other years on two occasions and as a calf on one occasion.

Shifts in selected calving habitat were recorded for 45% (n= 17) of females accompanied by a calf in FB. The mean number of recorded shifts in selected habitat is 0.66 (n= 38, range 0-3, SD 0.85). Shifts in calving habitat were most common from HoB to FB (n= 10).

Half of the calving females that shifted selected calving habitat from HoB to FB did so in 2011 ($n=5$). Of the 10 individuals that shifted calving habitat from HoB to FB, four individuals were recorded shifting back to HoB to calve in later years. For the 10 individuals that shifted calving habitat from HoB to FB, HoB was the origin of calving for all but two individuals. One female with a calf was first sighted at Auckland Islands, NZ (3,410 km from FB) and one female with a calf was first sighted at Twilight Cove, WA, before displaying a shift in selected calving habitat to FB.

Although shifts in selected calving habitat from HoB to FB were most commonly recorded, shifts in the other direction, from FB to HoB, were also recorded. A total of five out of the 17 recorded shifts in calving habitat were recorded from FB to HoB. Of the five individuals that shifted calving habitat from FB to HoB, only one individual was recorded shifting back to FB to calve in a later year. The origin of calving females that shifted from FB to HoB was FB for four individuals and Israelite Bay, WA for the other individual. Two calving females were excluded when counting the shifts in selected habitat as they were sighted with a calf of that year at two locations in the same year, and it was uncertain which calving habitat to attribute their residence to.

6.4.3 Within and across season coastal movements of SRWs between FB and other aggregation areas

Movement patterns of SRW females with a calf and unaccompanied adults between FB and other southern Australian and NZ aggregation areas are displayed in Figure 6-4.

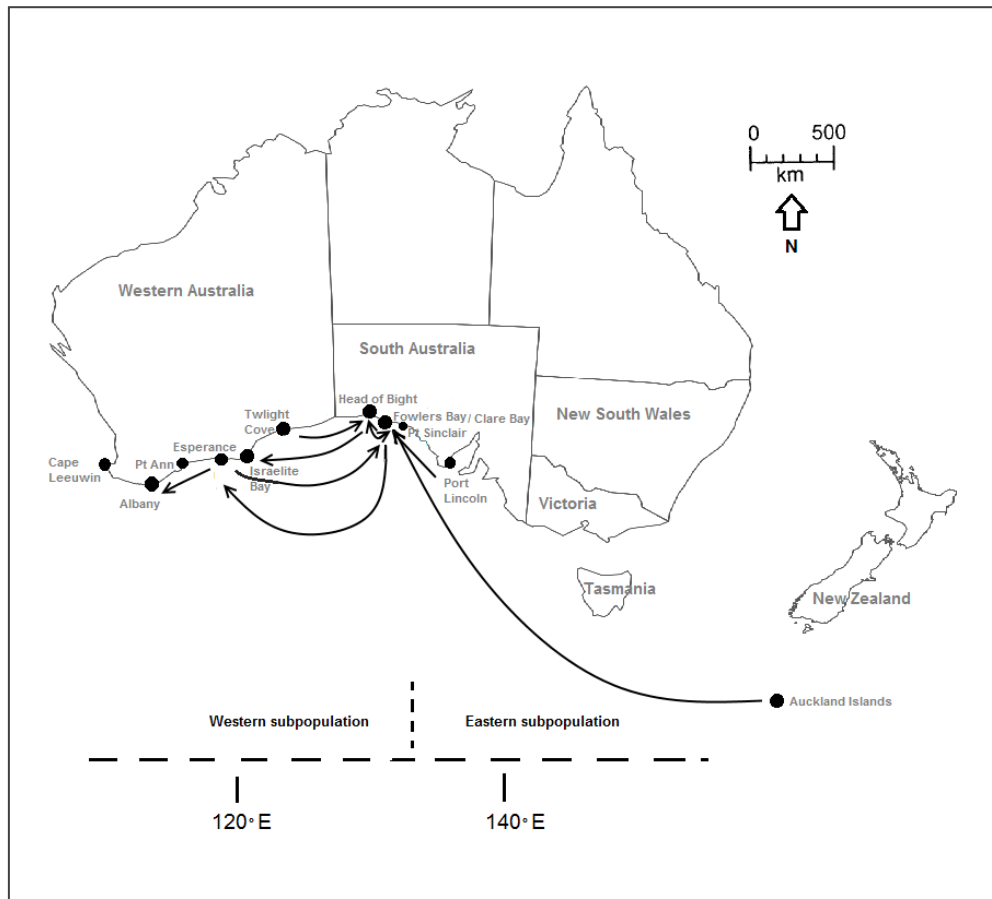


Figure 6-4: Example of movements within and across season for southern right whales from Fowlers Bay, South Australia to other coastal aggregation areas on the southern coast of Australia and the Auckland Islands, New Zealand.

Calving females

Calving females photo-ID'd at FB (n=40) were recorded a total of 118 times across all locations, of which 42% (n=46) of all sightings were recorded at FB. Individual calving females were identified at a maximum of four locations (with or without a calf of that year), including across and within season sightings. The mean number of photo-ID sighting locations was 1.925 (range 1-4, SD= 0.76). A total of 65% of all calving females identified at FB were also sighted at HoB (n= 26).

Within season coastal movements were recorded for eight (20%) calving females identified at FB. Within season movement was most common between FB and HoB, with seven out of eight calving females photo-ID'd at FB and HoB in the same year with a calf, during 2014-2016. Additionally, one within season movement of a female with a calf of that year occurred between FB and Point Ann, WA, approximately 1,310 km apart. One calving female was photo-ID'd as an unaccompanied adult (without a calf of that year) at

FB and Israelite Bay, WA in the same year, approximately 910 km apart. Females accompanied by a calf of that year displayed a westerly direction of travel for all within season coastal movements recorded between FB and HoB.

Between season movement between FB and other coastal aggregation areas was observed for all calving females with more than one photo-ID sighting ($n=23$, 58%). Calving females were photo-ID'd 71 times (each value is a unique site and year) at another location other than FB, with 69% ($n=49$) of sightings with a calf of that year and 31% ($n=22$) of sightings as unaccompanied adults. Movement between FB and HoB was observed for 91% ($n=21$) of the across season movements recorded for calving females. Across season movement was also seen between FB and West Pt Sinclair, SA, and; FB and Israelite Bay, WA, across a maximum distance of approximately 910 km apart.

Unaccompanied adults

Unaccompanied adults photo-ID'd at FB ($n=58$) were recorded a total of 108 times (each value is a unique site and year) across all locations, of which 59 (55%) of all sightings were recorded at FB. Photo-ID sightings were recorded at seven locations: FB, HoB, Point Ann, WA, Israelite Bay, WA, Point Sinclair, SA, Claire Bay, SA and Port Lincoln SA (Figure 3). Individual unaccompanied adults were sighted at up to four locations, including across and within season sightings. The mean number of sightings for each unaccompanied adult is 1.86 (range 1-14, $SD=1.99$). The mean number of photo-ID sighting locations of an unaccompanied adult photo-ID'd at FB is 1.52 (range 1-4, $SD=0.75$). A total of 36% of all unaccompanied adults photo-ID'd at FB were also photo-ID'd at HoB ($n=21$).

Within season coastal movements were recorded for 14 of the 23 unaccompanied adults photo-ID'd more than once at FB. Within season movements were most common between FB and HoB ($n=12$). Within season movement was also recorded between FB and West Point Sinclair, SA ($n=1$) and FB and Clare Bay, SA ($n=1$). The largest within season movement of unaccompanied adults photo-ID'd at FB was between FB and HoB, approximately 160 km away. Unaccompanied adults had a westerly direction of travel for 88% within season coastal movements recorded.

Between season movement between FB and other coastal aggregation areas was observed for 12 of the 23 unaccompanied adults photo-ID'd at FB more than once. Between season movement was most common between FB and HoB with 11 out of 12 of the unaccompanied adults photo-ID'd at FB moving between these adjacent aggregation areas. Between season movement was also recorded for one individual between FB and Israelite Bay, WA. The largest between season movement of an unaccompanied adult

photo-ID'd at FB was approximately 910 km between FB and Israelite Bay, WA. Calving events were recorded for six unaccompanied adults photo-ID'd at FB, of which no calving events occurred at FB, and five were recorded at HoB.

The first recorded sighting of a whale at FB was an unaccompanied adult recorded in 1983 (H9220). H9220 was first sighted in Port Lincoln, SA in 1970 and it was recorded that the whale appeared old, although no evidence is available to suggest her age because she was never seen with a calf. The sex of the animal was determined as female through visual sightings of the genital area. She was sighted a total of 12 times between 1970 and 2010 and has not been sighted since, with the last 10 sightings recorded at HoB. Of the unaccompanied adults identified at FB, nine were identified as female. Two unaccompanied adults (not identified as female) were grey-morph whales that were born as white and one had grey blazes. It has been suggested that whales born white animals were all males (Schaeff *et al.*, 1999). However, there are at least two cases from the Australian 'western' sub-population of a grey-morph adult was sighted over several years with a calf (Bannister & Charlton unpublished observations).

In summary, 98 individual SRWs (40 females with a calf and 58 unaccompanied adults) were identified in FB between 1983 and 2016. The abundance at FB correlates to the abundance of female and calf pairs at HoB: when greater than 55 pairs are sighted at HoB, there is an increase in SRW female and calf pairs at FB. Forty per cent of the females with calves were first time breeders at FB, but around a quarter (23%) of the calving females shifted in other years to other calving habitats after using FB, usually to the nearest aggregation area at HoB 160 km to the west. In total 45% of all individuals displayed shifts in calving habitat, and immigration from HoB to FB was most commonly recorded.

6.5 Discussion

SRWs off the southern coast of Australia were overexploited by the whaling industry as in other parts of the Southern Hemisphere. Peak years for catches were between 1835 and 1844 in Australian and NZ waters, but some lower level of exploitation continued until the end of the century until the mid-1930s SRWs were given international protection. After this protection, SRWs were not rediscovered on the southern coast of Australia until single female and calf pairs were observed in 1955 and 1963 off Albany, WA; in July 1967 off Leighton Beach, Fremantle, WA; and in 1968 near Port Lincoln, SA (Bannister 1994). However, around the same time as their rediscovery they were subjected to illegal Soviet pelagic hunting between 1961 and 1971 when 372 individuals were killed in the SW Pacific

Ocean on their summer feeding grounds south of Australia and NZ (Tormosov *et al.*, 1998). These individuals may have been mainly from the 'eastern' Australia sub-population.

Female SRWs display some fidelity to calving grounds (Burnell, 2001). Long-term photo-ID studies show that females return to the same areas to calve over several decades (Payne 1986, Payne *et al.*, 1990; Rowntree *et al.*, 2001). Whilst site fidelity is displayed for SRWs in Argentina, the recognised calving area is 500-800km of coastline and dispersal within that area is recorded (Rowntree *et al.*, 2001). Dispersal is also recorded for SRW from Peninsula Valdes, Argentina, to Brazil (Best *et al.*, 1983). There is evidence that SRWs can shift selected calving habitat and display flexibility in their philopatric behaviour (Best *et al.*, 1993, Burnell, 2001; Groch *et al.*, 2005, Carroll *et al.*, 2013; Rowntree *et al.*, 2001). Site fidelity of calving females to FB was low with only five (21%) out of 24 calving females displaying site fidelity to the area with sightings histories from catalogue matching. Site fidelity of calving females at FB is low compared to HoB (67%) (Charlton, 2017 - Chapter 4). Shifts in selected calving habitat were recorded for 55% of calving females photo-ID'd at FB which may be a property of a newly established calving ground.

The rate of increase reported for SRWs at FB during 1993-2014 exceeds the maximum plausible rate of increase for the species of 6-7% (IWC, 2013). Whilst 40% of calving females sighted at FB had an origin at FB and may represent a remnant population or first time breeders selecting FB, most females are known to have calves elsewhere previously and re-selected habitat into FB.. It is possible that individuals may have calved elsewhere in other years and that a calving event was missed, therefore the sighting histories are representative of observed events only and may be biased. Of the nine calving females that were first sighted with a calf in FB, five individuals were sighted prior to 1996 and four individuals displayed site fidelity to FB, suggesting that they could possibly represent a remnant population to FB. However, earlier sighting histories are required to determine the remnant population. Of the 60% of calving females that had an alternate place of origin to FB, 45% were first sighted with a calf at HoB. All calving females identified at FB had an origin in the south-west of Australia, except for one calving female with a place of origin in Auckland Islands, NZ, which was then sighted in FB with a calf. No matches were recorded with matched calving females from the 'eastern' sub-population in the SEA catalogue. Matching was completed for a subset of individuals from the SEA and the NZ catalogues and therefore, the finding of no matches for the SEA catalogue and one match to NZ catalogue is an underestimation of true connectivity. Results show that that

immigration to the site has occurred from the 'western' sub-population, and most commonly from HoB.

Increased abundance of SRWs at FB is driven by movement of females and calves into the area since 2003. The abundance at FB correlates to the abundance of female and calf pairs at HoB and when greater than 55 pairs are sighted at HoB, there is an increase in SRW female and calf pairs at FB, with the exception of 2016. For example, peaks in abundance driven by pulses in calf production were observed at HoB and FB in 2005, 2011 and 2014. The greatest number of shifts in selected calving habitat from HoB to FB was recorded in years of high abundance at HoB. This supports that HoB may have approached a saturation capacity which resulted in dispersal of animals outside of the core aggregation area into nearby aggregation areas (Charlton, 2017 – Chapter 2). SRWs display high connectivity between FB and HoB with 65% ($n=26$) of all calving females from FB and 36% ($n=21$) of all unaccompanied adults from FB recorded at both locations. The movement of SRWs between FB and HoB within and across seasons, shows that the corridor between the two known aggregation areas is important connective habitat. Results support the view that greater abundance promotes increased linkage via connective corridors between aggregation areas. The movement of SRWs between the more densely populated large aggregation area at HoB and the small adjacent aggregation area at FB is an example of spatial density resource pressures and intra-species interactions influencing dispersal and site selection.

Increased population abundance and successful protection efforts of SRW have led to expansion of species occupancy and re-colonisation to former ranges (Groch *et al.*, 2005, Carroll *et al.*, 2014; Rowntree *et al.*, 2001). Changes in distribution of SRWs similar to those observed at FB has also been recorded for other right whale populations in Argentina and Brazil (Rowntree *et al.*, 2001; Seyboth *et al.*, 2016, Danilewicz *et al.*, 2016), South Africa (Barendse and Best, 2014) and NZ (Carroll *et al.*, 2011 and 2014). Rapid re-colonisation of SRWs to Santa Catarina in southern Brazil was reported at a rate greater than biologically plausible for the species, suggesting immigration or re-dispersal from alternate habitat, such as Peninsula Valdes (Groch *et al.*, 2005). Similarly, re-colonisation and range expansion from the main nursery area around Peninsula Valdes into historically important habitat in Patagonia was reported (Arias *et al.*, 2017). In NZ, evidence was presented of SRWs re-colonising former wintering grounds on the mainland after nearly four decades post whaling, presumably from a remnant population that persisted in the NZ subantarctic islands (Carroll *et al.*, 2014). In Australia, the expansion of SRWs into new and emerging aggregation areas has been observed here over the last two decades

since protection. Strong migration pathways between linked habitats can enhance dispersal by reducing strict philopatric affiliations (Pirzl, 2008).

Within and between season movements of SRWs on the southern Australian coastline were documented by Burnell (2001). Within year movements averaged 730 km, over 34 days. The maximum reported within season movement of an individual SRW across coastal southern Australia is 1,490 km. Of the calving females photo-ID'd at FB, one individual moved approximately 910 km within a season. Reported between year movements of SRWs were an average of 1,036 km, and up to 2,287 km (Burnell, 2001). The maximum between season movement of an individual whale photo-ID'd at FB was approximately 3,410 km between Auckland Islands and FB. Long-range movements of SRWs between Australia and subantarctic NZ aggregation areas of approximately 3,600 km across years have also been documented (Pirzl *et al.*, 2009).

6.5.1 Conclusion

This study presents evidence that the increased abundance and re-colonisation of SRWs into FB, observed since 2004, is mainly due to immigration to the site and not due to the increase in a remnant population. A total of 40% of calving females were sighted for the first time at FB indicating that they may represent a remnant population or first time breeders. However, the high degree of immigration of breeding females to and from FB and the low site fidelity to the site suggests that the increased abundance is due to immigration of whales to the site. Immigration of SRWs to FB from the 'western' sub-population and particularly from HoB was observed. The increased abundance of SRWs at FB correlates with high abundance at HoB and suggests that animals are 'spilling over' as a result of the primary habitat of Australia's largest calving aggregation ground at HoB reaching its physical saturation capacity. Whale dispersal into FB and other coastal habitats in Australia can be expected with an increasing population. Changes to the distribution of SRW has been observed in Australia with small aggregation areas emerging in the south west of Australia. Further research is needed to understand distributional shifts in right whale occupancy in Australia. This study highlights the importance of established and growing aggregations along the Australian coastline as they continue to grow, and the importance of connective corridors between aggregation areas. This information can be used to facilitate habitat protection and robust recovery planning, including management of potential anthropogenic impacts and the setting of population recovery targets.

7 General discussion

Population demographics of SRWs in the GAB were studied using long-term time series datasets from annual monitoring undertaken since 1991. This research investigated the distribution, abundance, life histories, residence and site fidelity of SRWs at the major aggregation ground at HoB during 1991-2016, and the small established aggregation area at FB during 1993-2016. Key findings of this research show that SRWs at HoB are increasing at a slightly lower yet comparable rate to the 'western' subpopulation (Bannister, 2017). Assessment of life history parameters showed that biological parameters influencing population recovery have not changed significantly over time and that the mean apparent calving interval and age at first parturition are comparable to other populations of SRWs in South Africa (Brandão *et al.*, 2011) and Argentina (Cooke *et al.*, 2003). This study showed that conservation efforts in the GAB have successfully provided sanctuary to most SRWs visiting HoB during the primary calving season, and that continued efforts are required to manage the dispersal of an increasing population of SRWs into new and emerging aggregation areas such as FB. The re-colonisation of SRWs to FB is primarily a result of whales emigrating from HoB and immigrating to FB due to density resource pressures in certain years although this fidelity to FB is variable.

To detect changes in the rates of increase and recovery of long-lived and slow to recover marine mammals, such as SRWs, long-term monitoring in the order of decades is required. Detecting changes in the rate of increase in SRWs requires annual monitoring due to their mainly three and less frequently four or five-year calving cycles (Bannister *et al.*, 2011; Charlton, 2017 – Chapter 3). To detect change on a time scale relevant for management, assessment of each breeding cohort is required (Bannister *et al.*, 2011; Burnell, 2001). The trend in abundance at HoB is highly variable, due to the cohort structured breeding cycles driven by the mean three-year calving cycles of SRWs. The rate of increase of 3.7% (± 1.3) p.a. of HoB is lower than 5.55% (± 1.9) p.a. of the 'western' sub-population and supports that HoB is an open population with movement of animals into and out of the area.

The rate of increase of reproductive females for HoB (4.9% ± 0.85 , 95% CI) is lower although not significantly different from the 'western' sub-population in Australia (6.01% ± 1.8 , 95% CI). The rate of increase for the 'western' sub-population in Australia is comparable to those elsewhere in the world. The South African population of SRWs has been increasing at an estimated rate of 6.8% ($\pm 0.4\%$) p.a. between 1979 and 2008

(Brandão *et al.*, 2011). The Argentinean population increase has declined from 6.8% during 1971-2007 (Cooke *et al.*, 2003) to 5.1% and 3.23% during 1999 to 2014 (Crespo *et al.*, 2017). The NZ population of SRW has been estimated to be increasing at a rate of 4.8% (95% CI, 2.4% to 6.4%) p.a. between 2006 and 2016 (Davidson *et al.*, 2016). The Chile-Peru population and the 'eastern' Australian sub-population (Bannister, 2017) are not increasing or are estimated to be increasing at a slower rate than other SRW populations. The difference in growth rates recorded for SRW in NZ and Chile-Peru and eastern Australia are considered to be a result of the increased historical whaling pressure being more concentrated in the South Pacific Ocean leading to the absence of a remnant stock of whales returning to the area (IWC, 2013).

In this study, temporal shifts in the peak abundance period for total animals and females and calf pairs at HoB were observed, however, the maximum daily count was consistently recorded between August 15th and 30th. Seasonal variability in abundance occurs at HoB as SRWs arrive to the site between May and early-July, peak in abundance during mid-July to late-August, and depart the site between September and October. Results provide information on timing and arrival of SRWs to the HoB coastal aggregation area, which is required for species management in Australian waters and risk minimisation. Considering the proportion of the breeding population recorded at HoB in mid-June (mean=16%, range=8-28%), and the percentage of breeding females at HoB remaining in late-September (mean=27%, range=13-61%), SRWs and their newborn calves may be sensitive to potential human disturbance during their migration to and from the coast in the broader GAB area between May and October. Within season abundance results from this study confirmed that the GAB Commonwealth Marine Reserve MMPZ restricted access period from May 1 to October 31 is effective at providing sanctuary to most whales that visit the HoB aggregation area. The timing and duration of the calving season for SRWs varies among the global populations. In the GAB, the season is shorter than in South Africa and Argentina with an earlier peak abundance period. In South Africa SRWs can be sighted all year round with calves sighted between June and December, and peak numbers recorded in September (Best and Scott, 1993) and in Peninsula Valdes, Argentina, the calving season is between May and December, with the maximum number of whales reached from August to September (Crespo *et al.*, 2017; Rowntree *et al.*, 2001; Payne 1986).

The mean two-week period of peak abundance for female and calf pairs across the study period was July 17 to August 3 and the mean date of calving observed was July 23. Peak abundance periods highlighted in this study will inform future monitoring planning. To

achieve the objective of photographing all females accompanied by a calf to inform mark recapture assessments of life history parameters and population recovery, a six-week field season between July 15 and August 30 is recommended. The recommended study period covers the peak abundance period (July 17- August 3) and the consistent sampling period surveyed annually at HoB (August 15-30) across all survey years. Given the mean residency period of 40 days for females accompanied by a calf at HoB, the proposed study period would provide coverage and exposure to females and their calves that arrive at the site in May/June and may have departed the site before the August 15-30 study period. Considering the mean date of calving recorded at HoB (July 23th), it can be assumed that the proposed survey period of July 15 - August 30 will enable assessment of whale reproductive status. The likelihood of calves being present along the cliff line and having callosities developed enough for future identification is increased in late August. The use of drone technology improves efficient data collection by providing access to areas previously inaccessible for photo-ID and improved image quality.

The change in the relative proportion of SRWs at HoB compared with the annual counts for the 'western' sub-population indicates that movement of individuals into and out of the area is increasing as the population expands. Therefore, the percentage of the annual counts for the 'western' sub-population of SRWs that HoB represents is showing a decreasing trend with time. For example, in the early 1990's, SRWs at HoB represented up to 48% of the total annual count for the 'western' subpopulation, and in 2016 the SRWs at HoB represented 25%. Results suggest that immigration and emigration of whales into and out of the site has increased in recent years as the population uses more of its former habitat range along the southern Australian coast. Furthermore, the number of new individuals' photo-ID'd at HoB, relative to the number of individuals matched to known individuals in the photo-ID'd catalogue, showed a trend towards increasing across years. This increased percentage of new breeding females to HoB relative to individuals sighted previously at HoB with a calf is attributed to increasing emigration of females that had already calved previously, or immigration of calving females into the study area, along with population growth. New calving females not previously sighted at HoB grew from a mean of 15% of all female and calf pair sightings (1995-1999), to a mean of 48% (2012-2016). Further modelling is required to compare the expected recruitment of first time breeders versus the immigration and emigration of calving females to and from the study area. To test whether the increase in newly sighted calving females at HoB is likely due to immigration and emigration of whales moving in and out of the study area or attributed

to population growth, an Australian-wide comparison of SRW photo-ID's from other available catalogues is needed.

Distribution of 95% of all SRW sightings recorded between 2014 and 2016 at the HoB aggregation area occurred within an area 10.16 km wide from east to west and within 0.19 km from shore, and within the 20m depth contour. Research into the nearest neighbour suggests minimum spatial distance of 150-200 m between adults at HoB (Pirzl, 2008). Based on the spacing distance between whales of 150 m, the area occupied by 95% of all whales sighted would reach capacity at 68 female and calf pairs, assuming a perfect packing density. Conservatively, when a minimum spatial requirement of 100 m is tolerated by SRWs at HoB, the area occupied by 95% of whales sighted would reach capacity at 155 female and calf pairs, assuming a perfect packing density. Results suggest that the primary habitat for SRW at HoB may have already reached capacity with a maximum of 172 individuals including 81 female and calf pairs sighted one day in 2016. Helicopter surveys completed by SARDI in 2014 of the broader region between the WA border in the west and FB in the east showed that up to 17% of whale sightings occurred outside of the HoB cliff based study area. Density resource pressures (space) will cause SRW to disperse outside of the desired habitat in the primary aggregation area of HoB. It can be expected that habitat dispersal outside of HoB will occur with an increasing population.

Daily counts provide a snap-shot of SRW distribution and abundance on a given day within the study area. Therefore, the maximum daily count is an underestimation of the true maximum number of individuals using the HoB and FB aggregation areas during the season. Photo-ID mark recapture shows that the number of individuals photographed often exceeds the maximum daily count, indicating immigration and emigration across a season, particularly for unaccompanied adults (Burnell, 2001; Charlton, 2017- Chapter 3). Individuals that are outside of the visual detection range of 5 km from the cliff based observation stations at HoB are not detected during daily counts. Helicopter surveys showed that in July of 2014, up to 17% of SRWs sighted in the HoB area were recorded outside of the HoB cliff based study area (Mackay *et al.*, 2015). Counts completed simultaneously between the WAM aerial survey and the cliff based count team resulted in comparable counts. For example, in 2016 the WAM aerial survey counted 66 female and calf pairs and 11 unaccompanied adults at HoB and the count team sighted 66 female and calf pairs and 10 unaccompanied adults. Whilst it is acknowledged that the HoB cliff counts have limitations in counting individuals outside of the visual detection range, the cliff based counts have compared favourably to the WAM aerial survey counts across

years and the cliff surveys give greater precision in establishing a seasonal maximum daily count used as a long-term trend metric. The minimum two-week survey period at HoB allows for most residing SRW individuals to be captured through photo-ID because they move around the study site within that period.

Long-term trends in abundance and life history parameters provide critical information for population recovery assessment and monitoring of changes to a population over time. This study reports on the long-term trends in abundance and life history parameters including apparent mean calving interval and age at first parturition of SRWs at the major aggregation area at HoB. The estimates of the life history parameters presented in this analysis update those previously reported for this population for the years 1991 to 2007 (Burnell, 2001 and 2008). A total of 26 years of data were included in this assessment compared to 17 years reported by Burnell (2008), thus nine additional years are analysed and presented in this study. Estimated demographics parameters including mean calving interval and age at first parturition compare favorably with previous research completed for this population (Burnell, 2001 and 2008), and with research completed for other SRW populations around the world (Payne *et al.*, 1990; Cooke *et al.*, 2003; Brandão *et al.*, 2011; IWC 2013). The mean apparent calving interval for 1991-2007 was 3.4 years \pm 95% CI 3.29 - 3.46 years (Burnell, 2008) and was 3.3 years (SD=0.8, \pm 0.3, 95% CI) between 1991 and 2016. Variability in mean apparent calving intervals has increased at HoB since 2011 with a lower proportion of females displaying a three-year calving cycles compared to a four-year interval and higher. The occurrence of four year mean calving intervals in 2015 and 2016 warrants monitoring into the future to assess if a change to the mean interval is occurring. The mean observed calving interval for the 'western' sub-population in Australia is comparable with estimates for the SRW population in South Africa of 3.16 years (\pm 3.13-3.19, 95% CI) (Brandão *et al.*, 2011) and the SRW in Argentina of 3.42 years (S.E. 0.11) (Cooke *et al.*, 2003).

Apparent age at first parturition indicate that sexual maturity can be reached by age five, at least in some individuals. The median age of 9.5 years and mean age of 9.3 years (SD=2.1, \pm 0.9, 95% CI, n=22) for first parturition are consistent with the earlier calculation of a median age at first parturition of 9 years and a mean of 9.1 years (\pm 0.48, 95% CI) by Burnell (2008). A mean age at first parturition of 8.6 years was recorded off South Africa (Brandão *et al.*, 2011), and a mean age of 9.1 years (SE 0.4) was recorded off Argentina (Cooke *et al.*, 2003).

The estimates presented here are for the largest calving aggregation area on the Australian coastline. This is not a closed population and the estimates were confounded to some extent by movements in and out of this site and from other coastal aggregation areas outside of the HoB, primarily from other parts of the 'western' sub-population. A national assessment is needed using all photo-ID datasets available in Australia and NZ to better understand life history parameters, coastal movements and the degree of connectivity between the 'western' and 'eastern' sub-populations of SRWs in Australia.

Drivers of variation in population demographics are expected to be influenced by forcing factors impacting changes to calving intervals (Pirzl *et al.*, 2009). Links between sea surface temperature in feeding areas and the calving success of SRWs were documented for SRWs in Argentina (Leaper *et al.*, 2006). Inter-annual variability observed in the Australian SRW population was related to Southern Ocean climate factors (Pirzl *et al.*, 2009) and SRW reproductive success was linked to krill density and climate for SRW in Brazil (Seyboth *et al.*, 2016). Depression in calving intervals and population growth of critically endangered North Atlantic right whales was related to climate associated changes in prey availability (Meyer-Gutbrod *et al.*, 2015). Prey availability affects body condition and poor body condition was linked to reproductive success for North Atlantic right whales (Miller *et al.*, 2011 and 2012) and 'western' gray whales (Bradford *et al.*, 2008). Foraging and distribution patterns of SRWs in the Southern Ocean are poorly understood, making the correlation between prey abundance, climate factors and demographics parameters difficult to understand. Further assessment is required to identify correlations between climate, prey availability, body condition and reproduction for right whale populations globally.

Increased abundance and re-colonisation of SRWs into FB, observed since 2004, is due to immigration to the site and is not due to a rapid increase from a remnant population. The abundance of SRWs at FB has increased since 2004 and the mean annual rate of increase in SRWs (38.8% p.a. SE=29.7) vastly exceeded the maximum biological rate of increase between 2004 and 2014. SRW occupancy at FB was reported between July and September with shorter residency periods for female and calf pairs and unaccompanied adults than recorded at HoB. For example, at FB mean residency periods recorded were 23 days for females accompanied by a calf and two days for unaccompanied adults, compared with residency periods at HoB of 40 days for females accompanied by a calf and 15 days for unaccompanied adults. The increase in SRWs at FB is attributed to immigration to the site from elsewhere and in particular from HoB. Shifts in selected calving habitat were recorded for almost half (45%) of the females accompanied by a calf

identified at FB. Shifts occurred in selected calving habitat across three aggregation areas in Australia and NZ and most commonly between HoB and FB, particularly evident in years of high abundance at HoB. Results suggest that density factors (space) are an influencing driver for females to display malleable philopatry and shift selected calving and nursing habitat. It is possible that increases abundance at FB is also attributed to females calving 'on their' way to HoB and then selecting FB as a suitable nearby habitat. Habitat dispersal driven by location of calving has occurred for the growing population of humpback whales in Western Australia and may be expected for SRW into the future.

Increased population abundance and successful conservation effort has allowed the SRWs to recolonise different locations within their former range (Groch *et al.*, 2005, Carroll *et al.*, 2014). Changes in the distribution of SRWs like those observed at FB has also been recorded for other right whale populations in Argentina and Brazil (Rowntree *et al.*, 2001; Seyboth *et al.*, 2015, Danilewicz *et al.*, 2016), South Africa (Barendse and Best, 2014) and NZ (Carroll *et al.*, 2011 and 2014). Rapid re-colonisation of SRWs to Santa Catarina in southern Brazil was reported at a rate greater than biological plausible for the species, suggesting immigration or re-dispersal from alternate habitat, such as Peninsula Valdes (Groch *et al.*, 2005). Similarly, re-colonisation and range expansion from the main nursery area around Peninsula Valdes into historically important habitat in Patagonia was reported (Arias *et al.*, 2015). In NZ, evidence was presented of SRWs re-colonising former wintering grounds on the mainland after nearly four decades post whaling, presumably from a remnant population that persisted in the NZ subantarctic islands of Auckland and Campbell (Carroll *et al.*, 2014). In Australia, the expansion of SRWs into new and emerging aggregation areas has been observed over the last two decades. Strong migration pathways between linked habitats, such as the connective habitat between HoB and FB, can enhance dispersal by reducing strict philopatric affiliations (Pirzl, 2008).

Evidence of the re-establishment of SRWs into an important historical calving and nursing area at FB, SA is presented. This research addresses the objective in the Commonwealth SRW Conservation Management Plan to better understand population dynamics in small or emerging aggregation areas. The occurrence of SRWs at FB since 2004 highlights the increasing significance of the area as a calving and nursing ground. The decline in SRW numbers recorded through aerial surveys in 2015 and 2016 of the 'western' sub-population and the high variability in annual abundance suggests that re-establishment to FB is not consistent across years. Therefore, it is important to minimise the risk of disturbance to the re-established population of SRWs in areas outside of the GAB Commonwealth Marine Reserve MMPZ to promote population growth.

7.1.1 Conclusion

Long-term trends in abundance and life history parameters for SRWs were assessed at HoB and FB in the GAB using 26 and 23 consecutive years of photo-ID mark recapture data, respectively. This research directly addresses key priorities and objectives in the Commonwealth SRW Conservation Management Plan to understand life history parameters and to measure population growth. This research improves our understanding of seasonal trends in distribution and abundance of SRWs at the major aggregation area at HoB (1991-2016). Information provided by this research will inform marine park management, management of human activities outside of the marine reserve. Specifically, the research improves current understanding of the timing of arrival and departure of whales to and from the site, and peak abundance periods in abundance. Baseline data are provided for detection of population changes over time and to enable before and after assessment of impacts associated with marine based activities proposed for the area. Information provided by this study informs population status and recovery assessment, linkages to health and climate factors, and global comparative studies of SRW populations. SRW in the south west of Australia are increasing at or near the maximum biological rate of increase. The increase in abundance has led to habitat dispersal into former ranges and distribution shifts along the Australian coastline.

Management applications of this research include: i) Great Australian Bight Marine Reserve, Marine Mammal Protection Zone is successfully protecting the largest aggregation of SRW in Australia; 2) there is a need to manage SRW habitat outside of the Marine Protected Area, particularly as the population increases and habitat range expand, and; 3) information is now available for managers and industry for before and after risk assessment for marine based activities proposed. Long term annual population monitoring programs including long range aerial surveys of the Australian coast and dedicated research in important aggregation areas are critical to the assessment of population demographics and species recovery over time.

Future monitoring and research should consider the full distribution of SRWs in Australia and connectivity between all the coastal wintering grounds in Australia and NZ, to ensure the protection of the population and continued recovery of the species. Future research priorities to inform recovery planning and management of SRW in Australia include:

- Integration of existing major photo ID datasets and mark recapture analysis update abundance estimates and assess coastal movements and connectivity;

- Understanding the two-population model and drivers for the absence of SRW increased abundance in the eastern sub-population
- Understand offshore distribution, migration pathways and foraging habitat
- Collaborative studies with other right whale populations around the world to compare life history parameters, recovery trajectories and possible mixing of populations
- Understanding anthropogenic disturbances to SRW in Australia
- Investigation of linkages between health, reproduction and climate factors.

References

- Arias. M., Coscarella, M., Svendsen, G., Romero, M., Curcio, N., Sueyro, N., Crespo, E., González, R. 2017. Changes in the distribution and abundance of Southern Right Whale *Eubalaena australis* in San Matías Gulf (Patagonia, Argentina). *International Whaling Commission document* SC\67A\06.
- Baker, C. S., Patenaude, N. J., Bannister, J. L., Robins, J., Kato, H. 1999. Distribution and diversity of mtDNA lineages among southern right whales (*Eubalaena australis*) from Australia and New Zealand. *Marine Biology* 134: 1–7.
- Bannister J. L. 1986 Southern right whales: status off Australia from twentieth century incidental sightings and aerial survey. *International Whaling Commission document* (Special Issue 10): 153-158.
- Bannister, J. L. 1990 Southern right whales off Western Australia. *International Whaling Commission document* (Special Issue 12):279-288.
- Bannister, J. L. 1994. Report on aerial survey for southern right whales off southern Australia, 1994. *Unpublished report to the Australian Nature Conservatory Agency*. 16pp.
- Bannister, J. L. 2001 Status of southern right whales (*Eubalaena australis*) off Australia. *Journal of Cetacean Research and Management (Special Issue)* 2: 103–110.
- Bannister J. L. 2010 Southern right whale aerial survey, southern Australian coast, August 2010 *Final Report to The Australian Marine Mammal Centre*. 11pp.
- Bannister, J. L., 2017. Project A7- Monitoring Population Dynamics of ‘Western’ Right Whales off Southern Australia 2015-2018. *Final report to National Environment Science Program, Australian Commonwealth Government*.
- Bannister, J. L., Burnell, S.R., Burton, C. and Kato. H. 1997. Right whales off southern Australia: direct evidence for a link between onshore breeding grounds and offshore probable feeding grounds. *International Whaling Commission document* 47: 441-444.
- Bannister, J. L., Hedley, S.L., Bravington, M.V. & Burnell, S.R. 2011. Monitoring population dynamics of right whales off southern Australia Project 2009/41: *Final Report to The Australian Marine Mammal Centre*. 23pp.

- Bannister, J. L., Pastene, L.A. and Burnell, S.R. 1999. First record of southern right whale movement between warm water breeding grounds and the Antarctic Ocean, south of 60°S. *Marine Mammal Science* 15(4): 1337–1342.
- Barendse, J. and Best, P. B. 2014. Shore-based observations of seasonality, movements, and group behaviour of southern right whales in a non-nursery area on the South African west coast. *Marine Mammal Science* 30(4): 1358-1382 Doi: 10.1111/mms.12116.
- Best P. B. 1993. Increase rates in severely depleted stocks of baleen whales. *ICES Journal of Marine Science*. 50(2):169–186.
- Best, P. B, R. Payne, V. Rowntree, J. Palazzo and M. Do Carmo Both. 1993. Long-range movements of South Atlantic right whales, *Eubalaena australis*. *Marine Mammal Science* 9:227–234.
- Best, P. B; A. Brandao, D. Butterworth. 2001. Demographic parameters of southern right whales off South Africa. *Journal of Cetacean Research and Management* pp.161-169.
- Best, P. B., Brandão, A. and Butterworth, D. S. 2005. Updated estimates of demographic parameters for southern right whales off South Africa. *International Whaling Commission document SC/57/BRG2*, 1-17.
- Best, P.B. 2012. Sex ratios in southern right whale calves. Appendix 4 of Annex F of the Report of the Scientific Committee, Panama City.
- Best P. B. 1994. Seasonality of reproduction and the length of gestation in southern right whales *Eubalaena australis*. *Journal of Zoology* 232:175-189.
- Best P. B. and Scott H.A. 1993. The distribution, seasonality and trends in abundance of southern right whales, *Eubalaena australis*, off De Hoop Nature Reserve, South Africa. *South African Journal of Marine Science* 13:175-186.
- Bradford, A.L., D.W. Weller, P.R. Wade, A.M. Burdin and R.L. Brownell, JR. 2008. Population abundance and growth rate of western gray whales *Eschrichtius robustus*. *Endangered Species Research*: 16:1–14.
- Brandão, A, Best, P. B. and Butterworth, D. S. 2011. Monitoring the recovery of the southern right whale in South African waters. *International Whaling Commission document SC/S11/RW18*.

- Burnell, S. R., and Bryden, M.M. 1997. Coastal residence periods and reproductive timing in southern right whales, *Eubalaena australis*. *Journal of Zoology, London* 241:613-621
- Burnell, S. R. 2001. Aspects of the reproductive biology, movements and site fidelity of right whales off Australia, *Journal of Cetacean Research and Management (Special Issue)* 2: 89–102
- Burnell, S. R. 1999. The population biology of southern right whales in southern Australian waters. *PhD thesis*, University of Sydney, Sydney
- Burnell S.R. 2008. Estimates of demographic parameters of southern right whales off Australia. *International Whaling Commission document*. SC/60/BRG12
- Camara, I. G, Palazzo, J. T. 1985 New information on the presence of *Eubalaena australis* in the south of Brazil. *Primera Reunion de Trabajo de Expertos Mamferos acuaticos America del Sur*. Buenos Aires, June 1984: p. 13
- Carroll, E., Patenaude, N., Alexander, A., Steel, D., Harcourt, R., Childerhouse, S., Smith, S., Bannister, J., Constantine, R. & Baker, C.S. 2011. Population structure and individual movement of southern right whales around New Zealand and Australia *Marine Ecology Progress Series* 432: 257–268
- Carroll, E. L., Rayment, W. J., Alexander, A. M., Baker, C. S., Patenaude, N. J., Steel, D., Constantine, R., Cole, R., Boren, L. J., Childerhouse, S. 2014. Reestablishment of former wintering grounds by New Zealand southern right whales. *Marine Mammal Science* 30: 206–220
- Carroll E.L., Childerhouse S.J., Fewster S.J., Patenaude N.J., Steel D., Dunshea G., Boren L., Baker C.S. 2013. Accounting for female reproductive cycles in a superpopulation capture–recapture framework: application to southern right whales. *Ecology Application*, 23:1677–1690, Doi:10.1890/12-1657.1
- Carroll, E. L., Baker, C. S., Watson, M., Alderman, R., Bannister, J., Gaggiotti, O. E., Gröcke, D. R., Patenaude, N., Harcourt, R. 2015. Cultural traditions across a migratory network shape the genetic structure of southern right whales around Australia and New Zealand, *Scientific Reports*. 5:16182 Doi: 10.1038/srep16182
- Charlton C.M., Guggenheimer, S.N., Burnell, S.R. 2014. Long-term Southern Right Whale Population Monitoring at the Head of the Great Australian Bight, South Australia

- (1991-2013). *Final report to the Department of Environment*, Australian Antarctic Division- Australian Marine Mammal Centre. 32pp.
- Charlton C.M., Burnell, S.R. 2011. Southern right whales- 2010 Population Census and Photo Identification at the HoB, South Australia. *Final Report to Great Australian Bight Marine Park*. 14pp
- Childerhouse, S., Double, M. and Gales, N. 2010. Satellite tracking of southern right whales (*Eubalaena australis*) at the Auckland Islands, New Zealand. *International Whaling Commission document SC/62/BRG19*
- Christiansen, F., Dujon, A.M., Sprogis, K.R., Arnould, J.P.Y. and Bejder, L. 2016. Non-invasive Unmanned Aerial Vehicle provides estimates of the energetic cost of reproduction in humpback whales. *Ecosphere*. Doi: 10.1002/ecs2.1468
- Clarke, C.W., Ellison, W.T., Southall, B.L., Hatch, L., Van Parijs, S.M., Frankel, A. and Ponirakis, D. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication, *Marine Ecology Progress Series*, 395: 201 – 222, Doi: 10.3354/meps08402
- Cooke, J. G., Rowntree, V. J., Payne, R. 2001. Estimates of demographic parameters for southern right whales (*Eubalaena australis*) observed off Peninsula Valdes, Argentina. *Journal of Cetacean Research and Management* (Special Issue) 2:125-132
- Cooke, J., Rowntree, V., Payne, R. 2003. Analysis of inter-annual variation in reproductive success of South Atlantic right whales (*Eubalaena australis*) from photo-identifications of calving females observed off Peninsula Valdes, Argentina, during 1971-2000. *International Whaling Commission document SC/55/O23*.
- Crespo, E.A., Coscarella, M.A., Pedraza, S.N., Dans, S.L., Svendsen, G.M., Degradi, M. 2017. Southern right whales *Eubalaena australis* still growing but at a decelerated speed. *International Whaling Commission document SC/67A/CMP/01*
- Dakin, W.J. 1938. *Whalemen Adventurers* revised edition. Angus and Robertson, Sydney. Reprinted by Sirius Books in 1963
- Danilewicz D., Moreno I. B., Tavares M., Sucunza F. 2016. Southern right whales (*Eubalaena australis*) off Torres, Brazil: group characteristics, movements, and

- insights into the role of the Brazilian-Uruguayan wintering ground. *Mammalia*.
Doi: 10.1515/mammalia-2015-0096
- Davidson A., Rayment, W., Slooten, E. 2016. Population dynamics of New Zealand southern right whale (*Eubalaena australis*) *International Whaling Commission document*. SC/67A/SH/08
- Dawbin, W.H. 1986. Right whales caught in waters around south eastern Australia and New Zealand during the nineteenth and early twentieth centuries. *International Whaling Commission document (Special Issue)* 10: 261-67.
- Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC). 2012. Conservation Management Plan for the Southern Right Whale: A Recovery Plan under the Environment Protection and Biodiversity Conservation Act 1999 (2011–2021), Available at:
<http://www.environment.gov.au/system/files/resources/4b8c7f35-e132-401c-85be-6a34c61471dc/files/e-australis-2011-2021.pdf>
- Galletti Vernazzani, B., Cabrera, E., and Brownell, R. L. Jr. 2014. Eastern South Pacific southern right whale photo-identification catalog reveals behavior and habitat use patterns. *Marine Mammal Science* 30: 389–398. Doi:10.1111/mms.12030.
- Groch, K. R., Palazzo, Jr., J. T. Flores, P. A. C., Adler, F. R., Fabian, M. E. 2005. Recent rapid increases in the right whale (*Eubalaena australis*) population off southern Brazil. *Latin American Journal of Aquatic Mammals* 4: 41-47
- Hamilton, P. K., Knowlton, A. R., Marx, M. K., Kraus, S. D. 1998. Age structure and longevity in North Atlantic right whales *Eubalaena glacialis* and their relation to reproduction. *Marine Ecology Progress Series*. 171: 285-292.
- International Whaling Commission (IWC). 2013. Report of the workshop on southern right whales. *International Whaling Commission document*. SC/65A/Rep05
- Jackson J.A., Carroll E.L., Smith, T.D., Zerbini A.N., Patenaude N.J., Baker C.S. 2016. An integrated approach to historical population assessment of the great whales: case of the New Zealand southern right whale. *Royal Society Open Science*. 3: 150669. <http://dx.doi.org/10.1098/rsos.150669>
- Keane, M., J. Semeiks., A. Webb, Y. Li., V. Quesada., T. Craig., L.B. Madsen., S. Van dam., D. Brawand., P. Marques., P. Michalak., L. Kang., J. Bhak., H. Yim., N. Grishin., N. Nielsen., M. Heide-Jørgensen., E. Oziolor., C. Matson., G. Church.,

- G. Stuart., J. Patton., C. George., R. Suydam., K. Larsen., C. López-Otín., M. O'connell., J. Bickham., B. Thomsen., J. De magalhães. 2015. Insights into the Evolution of Longevity from the Bowhead Whale Genome. *Cell Reports*, Vol.10(1), pp.112-122
- Kemper, C.M., Samson C.R. 1999. Southern right whale remains from the 19th century whaling at Fowler Bay, South Australia. *Records of the South Australian Museum*, 32(2): 155-172
- Kraus, S. D., Moore, M. J., Price, C. A., Crone, M., Watkins, W., Winn, H. and Prescott, J. H. 1986. The use of photographs to identify individual North Atlantic right whales (*Eubalaena glacialis*). *International Whaling Commission document*. (Special Issue) 10:145–151
- Leaper, R., Cooke, J., Trathan, P., Reid, K. and Rowntree, V. 2006. Global climate change drives southern right whales (*Eubalaena australis*) population dynamics. *Biology Letters* 2: 289-92.
- Lockyer, C. 1981. Growth and energy budgets of large baleen whales from the southern hemisphere. *Mammals in the seas* 3:379-487. *FAO Fisheries Series* 5. FAO, Rome.
- Mace GM, Lande R. 1991. Assessing extinction threats: toward a re-evaluation of IUCN threatened species categories. *Conservation Biology* 5:148–157
- Mackay, A. I., Bailleul, F., Childerhouse, S., Donnelly, D., Harcourt, R., Parra G.J., Goldsworthy, S.D. 2015. Offshore migratory movement of southern right whales: addressing critical conservation and management needs. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000526-1. *SARDI Research Report Series* No. 859. 40pp
- Mate, B.R., Best, P.B., Lagerquist, B.A. and Winsor, M.H. 2011. Coastal, offshore and migratory movements of South African right whales revealed by satellite telemetry. *Marine Mammal Science* 27(3): 455-76.
- Meyer-Gutbrod, E.L., Greene, C.H., Sullivan, P.J., Pershing, A.J. 2015. Climate-associated changes in prey availability drive reproductive dynamics of the North Atlantic right whale population. *Marine Ecology Progress Series* 535:243-258. <https://doi.org/10.3354/meps11372>

- Miller, D. 2011. Sustainable Management in the Southern Ocean: CCAMLR Science. *Science Diplomacy: Antarctica, Science, and the Governance of International Spaces*. Washington, Smithsonian Inst Scholarly Press: 103–121.
- Patenaude, N. J. 2003. Sightings of southern right whales around ‘mainland’ New Zealand. *Science for Conservation* 225:1–37.
- Patenaude, N.J., Portway, V.A., Schaeff, C.M. Bannister, J.L., Best, P.B., Payne, R.S., Rowntree, V.J., Rivarola, M., Baker, C.S. 2007. Mitochondrial DNA diversity and population structure among southern right whales (*Eubalaena australis*) *Journal of Heredity* 98(2): 147–157
- Patenaude, N.J., Todd, B., Stewart, R. 2001. A note on movements of southern right whales between the sub-Antarctic Auckland and Campbell Islands, New Zealand. *Journal of Cetacean Research and Management* (Special Issue) 2:121–123.
- Payne, R. 1984. Reproductive rates and breeding area occupancy in the southern right whale, *Eubalaena australis*. *International Whaling Commission document* (Special Issue) 6: 482.
- Payne, R. 1986. Long term behavioral studies of the southern right whale (*Eubalaena australis*). *International Whaling Commission document* (Special Issue) 10: 161-67.
- Payne, R., Brazier, O., Dorsey, E., Perkins, J., Rowntree, V., Titus, A. 1983. External features in southern right whales (*Eubalaena australis*) and their use in identifying individuals in Communication and behaviour of whales. *Westview Press: Boulder, Colorado*, pp 371–445
- Payne, R., Rowntree, V., Perkins, J.S., Cooke, J.G. and Lankester, K. 1990. Population size, trends and reproductive parameters of right whales (*Eubalaena australis*) off Peninsula Valdes, Argentina. *International Whaling Commission document* (Special Issue) 12: 271-78.
- Pirzl, R. 2008. Spatial ecology of *Eubalaena australis*: habitat selection at multiple scales Ph.D. thesis, *School of Life and Environmental Sciences*, Deakin University, Melbourne

- Pirzl, R., Patenaude, N. J., Burnell, S. and Bannister, J. 2009. Movements of southern right whales (*Eubalaena australis*) between Australian and subantarctic New Zealand populations. *Marine Mammal Science* 25: 455-461
- Pirzl, R., Lawton, K., Murdoch, G. 2007. Development of a data management system for southern right whale monitoring at Head of Bight, South Australia *Final Report to South Australian Department for Environment and Heritage*, Adelaide (unpublished)
- Portway, V. A., Schaeff, C. M., Best, P. B., Rowntree, V. J., Payne, R., Moore, M. J., Hamilton, P. J. 1998. Genetic population structure of South Atlantic right whales (*Eubalaena australis*). *Proceedings of International Whaling Commission Special Meeting of the Scientific Committee towards a Comprehensive Assessment of Right Whales Worldwide*. Cape Town, South Africa.
- Rice, A. N., Tielens, J. T., Estabrook, B. J., Muirhead, C. A., Rahaman, A., Guerra, M & Clark, C. W. 2014. Variations of ocean acoustic environments along the Western North Atlantic Coast: A case study in context of the Right Whale migration route. *Ecological Informatics*, Doi: 10.1016/j.ecoinf.2014.01.005
- Rosenbaum, H. C., Brownell, Jr R. L., Brown, M. W., Shaeff, C., Portway, V., White, B. N., Malik, S., Pastene, L. A., Patenaude, N. J., Baker, C. S., Goto, M., Best, P.B., Clapham, P. J., Hamilton, P., Moore, M., Payne, R., Rowntree, V J., Tynan, C.T., Bannister, J.L., DeSalle, R. 2000. World-wide genetic differentiation of *Eubalaena*: questioning the number of right whale species. *Molecular Ecology* 9:1793- 1802.
- Rowntree, V.J., Payne, R. and Schell, D.M. 2001. Changing patterns of habitat use by southern right whales (*Eubalaena australis*) on their nursery ground at Península Valdés, Argentina, and in their long-range movements. *Journal of Cetacean Research and Management (Special Issue)* 2: 133-43.
- Roux, J.-P., Braby, R. J. and Best, P. B. 2015. Does disappearance mean extirpation? The case of right whales off Namibia. *Marine Mammal Science* 31: 1132–1152
- Schaeff, C. M., Best, P. B., Rowntree, V. J., Payne, R., Jarvis, C. and Portway, V. A. 1999. Dorsal skin color patterns among southern right whales (*Eubalaena australis*): genetic basis and evolutionary significance. *The American Genetic Association* 90: 464-471

- Seyboth, E., Groch, K. R., Rosa, L. D., Reid, K., Flores, P. A. C., Secchi, E. R. 2016. Southern Right Whale (*Eubalaena australis*) Reproductive Success is Influenced by Krill (*Euphausia superba*) Density and Climate, *Scientific Reports* 6:28205; Doi: 10.1038/srep28205
- Simoës-Lopes, P. C., Palazzo, J. T., Both, M. de C., Ximenez, A. 1992. Identificação, movimentos e aspectos biológicos da baleia franca austral (*Eubalaena australis*) na costa sul do Brasil, *Anales de Tercero Reunión de Trabajo de Especialistas Mamíferos Acuáticos de América del Sur*, Montevideo, July 1988. Valdivia; Universidad Austral de Chile: 62-66.
- Skalski J.R., Ryding K.E., Millspaugh J. 2005. Wildlife demography: analysis of sex, age and count data. *Elsevier Academic Press*, 656 pp
- Thomas, P. O., and S. M. Taber. 1984. Mother-infant interaction and behavioral development in southern right whales, *Eubalaena australis*. *Behaviour* 88:42–60
- Torres L.G., W. Rayment., C Olavarriá., D.R. Thompson., B. Graham., S Baker., N. Patenaude., S.J. Bury., L. Boren., G. Parker., E.L. Carroll. 2017. Demography and ecology of southern right whales *Eubalaena australis* wintering at sub-Antarctic Campbell Island, New Zealand. *Polar Biology* 40:95–106
- Townsend, C.H. 1935. The distribution of certain whales as shown by logbook records of American whaleships. *Zoologica* (NY) 19(1-2): 1-50+6 maps.
- Tormosov, D.D., Mikhalev, Y.A., Best, P.B., Zemsky, V.A., Sekiguchi, K. and Brownell Jr, R.L. 1998. Soviet catches of southern right whales, *Eubalaena australis*, 1951-1971; biological data and conservation implications. *Biology Conservation*. 86(2):185-97
- Watson M, Westhorpe I, Bannister J, Hedley S, Harcourt R. 2013 Final report on the assessment of numbers and distribution of southern right whales in Southeast Australia. *Report to the Australian Marine Mammal Centre*.
- Whitehead, H., Payne, P. M. and Payne, R. 2000. Population estimate for the right whales off Peninsula Valdes, Argentina, 1971-1976. *International Whaling Commission document (Special Issue)* 10: 169-171
- Whiteway, T. 2009. Australian Bathymetry and Topography Grid, June 2009. Scale 1:5000000. Geoscience Australia, Canberra. Doi 10.4225/25

Zerbini, A.N., Clapham, P.J. & Wade, P.R. 2010. Assessing plausible rates of population growth in humpback whales from life-history data, *Marine Biology* 157: 1225.

Zerbini, A., Mendez, M., Rosenbaum, H., Sucunza, F., Andriolo, A., Harris, G., Clapham, P., Sironi, M. and Uhartm, M. 2015. Tracking southern right whales through the southwest Atlantic: New insights into migratory routes and feeding grounds. *International Whaling Commission document SC/66a/BRG/22*

"Every reasonable effort has been made to acknowledge the owners of copyright material. I would be pleased to hear from any copyright owner who has been omitted or incorrectly acknowledged."

Appendix 1: Copyright Permission Statement

From: John Bannister <bannisj@bigpond.com>
Sent: Thursday, 7 September 2017 11:33 AM
To: 'Claire Charlton'
Subject: RE: Written permission to include your data in my PhD Thesis

Dear Claire

I'm happy to agree to your using my data in your thesis.

Good luck!

Regards

John

From: Claire Charlton [mailto:claire.charlton@live.com.au]
Sent: Thursday, 7 September 2017 10:20 AM
To: john bannister <bannisj@bigpond.com>
Subject: Written permission to include your data in my PhD Thesis
Importance: High

Dear John,

I would like to ask for your email confirmation of your approval for inclusion of your data in my PhD thesis. With your permission, the data that I have used and included in my thesis includes: Southern right whale count and photo-ID sightings data collected during annual aerial surveys of the 'western' sub-population from 1993-2016. Specifically, data from Head of Bight and Fowlers Bay were used. When published and documented results are referred to, your work is referenced accordingly.

I confirm that you have been acknowledged and included as a co-author when your data and intellectual property has been used. I also confirm that you have been given the opportunity to review my thesis in full and that your review feedback has been incorporated.

If you are happy with the above, could you please reply to this email with your approval? I need to provide written confirmation as an appendix to my thesis.

Many thanks,

Claire

Claire Charlton
PhD Candidate | Centre for Marine Science and Technology
Curtin University
Mobile | +61 474 854 454

Email | claire.charlton@live.com.au

Project Web | www.gabrightwhales.com

From: steve burnell <steveburnell@gmail.com>

Sent: Thursday, 7 September 2017 1:09 PM

To: Claire Charlton

Subject: Re: Written permission to include your data/IP in my PhD Thesis

Dear Claire,

You have my approval and full support to include my data and related intellectual property in your PhD thesis.

Best regards,
Steve Burnell

On Wed, Sep 6, 2017 at 7:23 PM Claire Charlton <claire.charlton@live.com.au> wrote:

Dear Steve,

I would like to ask for your email confirmation of your approval for inclusion of your data and intellectual property in my PhD thesis. With your permission, the data that I have used and included in my thesis includes: Southern right whale count and photo-ID sightings data collected during annual cliff based surveys at Head of Bight, 1991-2016. The IP of the data is joined by you, Steve Burnell of Eubalaena Pty. Ltd. and myself, Claire Charlton. When published and documented results are referred to in the thesis, your work is referenced accordingly.

I confirm that you have been acknowledged and included as a co-author when your data and intellectual property has been used. I also confirm that you have been given the opportunity to review my thesis in full and that your review feedback has been incorporated.

If you are happy with the above, could you please reply to this email with your approval? I need to provide written confirmation as an appendix to my thesis.

Many thanks,

Claire

Claire Charlton

PhD Candidate | Centre for Marine Science and Technology

Curtin University

Mobile | +61 474 854 454

Email | claire.charlton@live.com.au

Project Web | www.gabrightwhales.com