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Relative abundance of the ‘western’ population of southern right whales (*Eubalaena australis*) from an aerial survey off southern Australia

Report on 2023 survey

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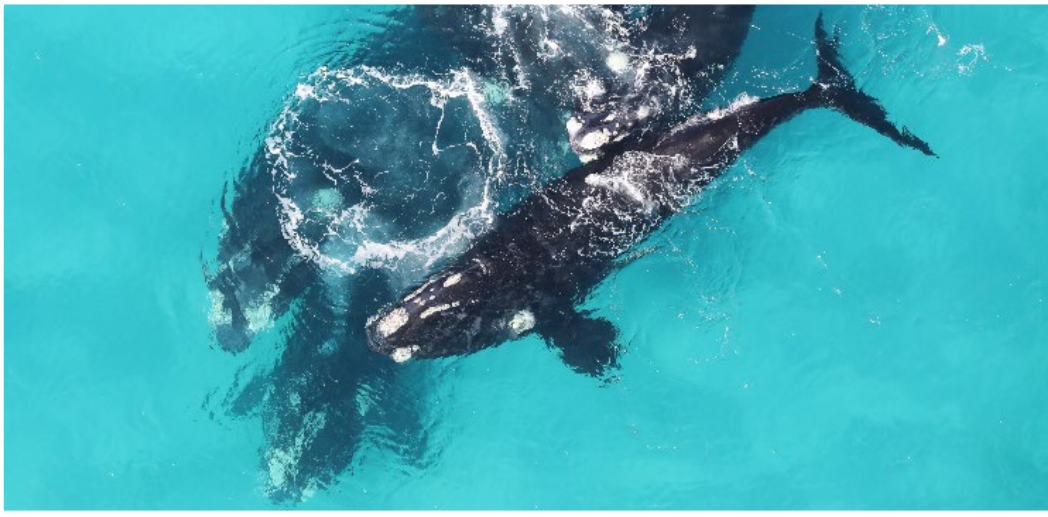

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We greatly acknowledge the late John Bannister and his past initiation, leadership and long-term dedication to the aerial surveys of southern right whales in Australia and the long-term dataset that was established to which this project maintains and contributes. We greatly acknowledge Jenny Schmidt (Royal Aero Club of WA) as pilot for her hard work and Andrew Halsall for his skills in photography and their many years of dedication to this project over the years. The flying was undertaken under relevant permits from the Western Australian Department of Parks and Wildlife (permit no. TFA 2020-0090-2), the South Australia Department for Environment and Water (permit no. MR00060-7-R Marine Parks and U26871-5 Scientific Research) and ethical approval from Murdoch University (permit no. O3031/18).

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Cover images: Large unaccompanied (without calves) whale groups off the southern coast of Australia © Joshua Smith

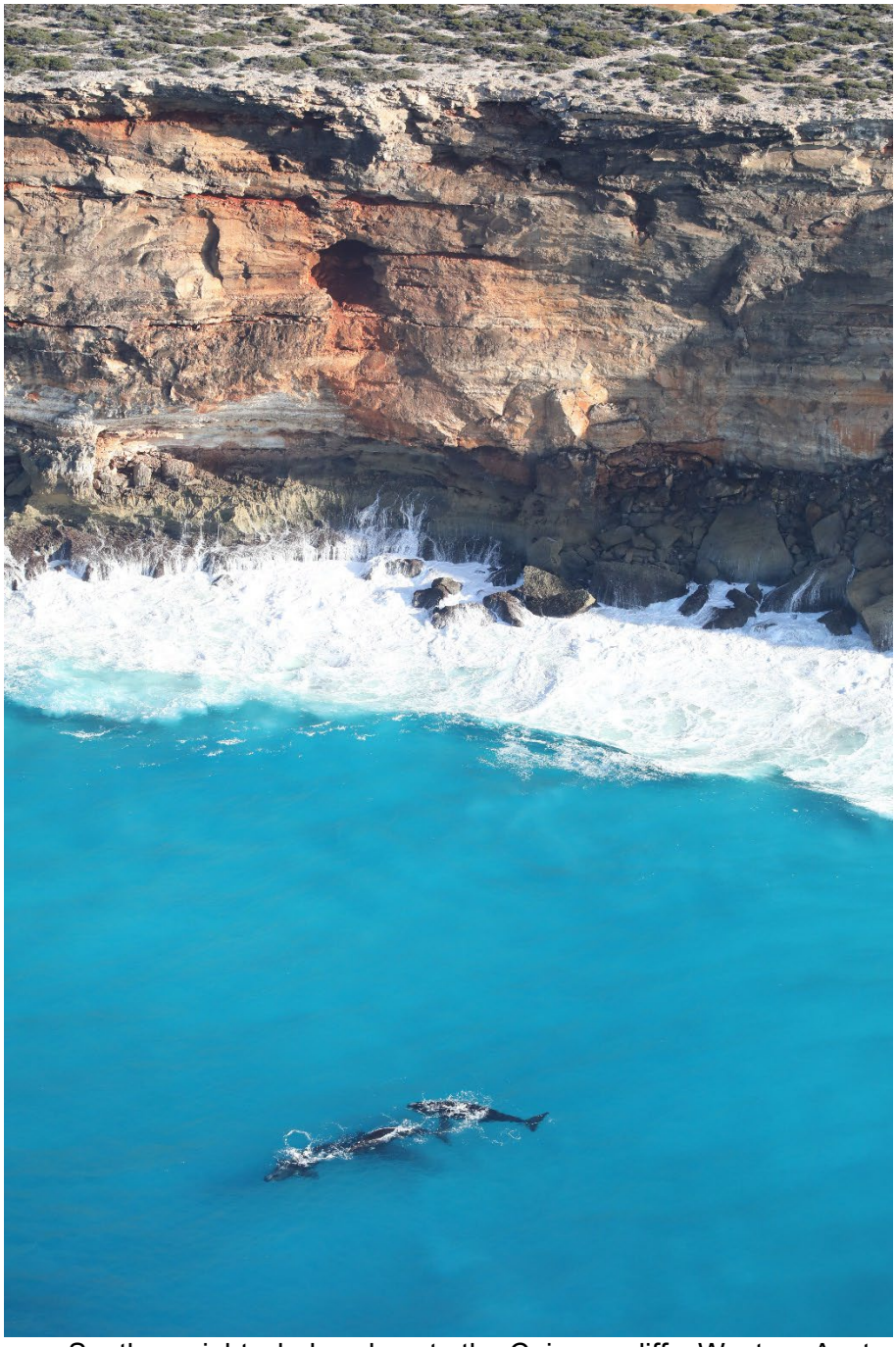

Image: Southern right whales close to the Caiguna cliffs, Western Australia

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Executive summary

An annual series of aerial surveys of southern right whales (*Eubalaena australis*) have been undertaken off the southern Australian coast since the initial signs of recovery in the mid 1970's, following extreme overexploitation from 19th and 20th Century commercial whaling. An aerial survey was undertaken over six days between 18-23 August 2023 in coastal waters from Perth (Western Australia) to Ceduna (South Australia), to monitor the recovery of this endangered species and inform the long-term population trend. The survey resulted in a total 349 whales sighted, consisting of 96 cow-calf pairs, 157 unaccompanied adults (including 2 yearlings). The 'western' population of southern right whales in Australian waters is increasing in size (~4.5% per year based on female/calf pairs and a population estimate of 2,439 whales) based on the long-term population trend data from the annual aerial surveys, which represents the majority of the Australian population given the very low numbers in the 'eastern' population. However, there is also evidence over the past 17 years that the rate of growth in female/calf pairs is slowing (8.1% in 2006 compared to 4.5% in 2023).

There continues to be highly fluctuating annual variation in abundance and associated fluctuations in cohort structure, with inter-annual variation in female-calf pair sightings related to their breeding cycle (typically a 3-year cycle), which can be affected by environmental factors on their foraging grounds. It is currently unclear what factors account for the decline in these sightings or may influence the variation in numbers of unaccompanied animals on the southern Australian coast. The life history traits of southern right whales make them particularly vulnerable to anthropogenic threats and consequently cumulative effects can potentially severely affect recovery of the species. Continued annual population surveys are one of the best approaches to assess recovery of the species through long-term population trend data.

1. Introduction

Southern right whales (*Eubalaena australis*) were hunted almost to extinction (~300 whales) during the 19th and 20th centuries from commercial whaling throughout the Southern Hemisphere, including off Australia. Southern right whales are currently listed as 'Endangered' under the Australian *Environmental Protection and Biodiversity and Conservation Act 1999* (EPBC Act), following unsustainable whaling. Since the mid-1970s, there have been signs of recovery for part of the population that migrates to the Australian coast each year. This recovery has been particularly evident for waters off Western Australia (WA) and western South Australia (SA), referred to as the 'western population'.

Since 1976, aerial surveys have been undertaken annually along the south-west coast of Australia to determine abundance and population trend, life history information, and obtain individual identification photographs of whales aggregating close inshore during calving and nursing. Initially, these surveys were undertaken along the WA south coast from Cape Leeuwin east to Twilight Cove and then were extended from 1993 into SA waters to Ceduna, given evidence of whale presence in key aggregations in South Australia and intra- and inter-season coastal movement. The series of surveys from 1993 were designed to provide statistically significant information on population size and trend over a fifteen-year period (to include five three-year breeding cycles; i.e. to 2007 inclusive). An anomalously low count in 2007, particularly of breeding females, led to continued aerial surveys to monitor the trend in recovery. Collection of these data is a high priority in the Australian EPBC Act National Recovery Plan for the Southern Right Whale 2024 to assess the current status of this threatened species and the effectiveness of federal and state management actions aimed to facilitate the species' recovery.

In south-east Australia (i.e. Victoria, Tasmania and New South Wales), there has been little sign of recovery in southern right whale numbers (Stamation et al. 2020) following intense commercial whaling. A working hypothesis assumes separation between the 'western' and 'eastern' populations, largely due to loss of 'cultural memory' of whales migrating to the eastern range breeding areas. Given the relative paucity of animals that visit the southern Australian coast in areas other than south-west Australia, the western population is currently considered to represent the majority of the 'Australian' southern right whale population. The count data from these aerial surveys provide data on population trend and estimates of population size for the 'western' population, and hence majority of the Australian southern right whales. The associated photo-identification data provides life history information (e.g. calving intervals) and connectivity between the 'western' and 'eastern' populations and contributes to the national southern right whale photo-id database; the Australasian Right Whale Photo-Identification Catalogue (ARWPIC). ARWPIC is an online platform and database supported by the Australian Antarctic Division and developed to manage and share images and sighting information of Australia's southern right whales.

2. Methods

2.1.1 Aerial survey count and photo-identification

Aerial surveys of southern right whales were undertaken following established survey protocols from previous aerial surveys since 1993, using a high wing, single engine aircraft (Cessna 172 and Cessna 182) and crewed by the same pilot and photographer/observer as previous surveys and a data scribe. The surveys were conducted along the southern coast of Australia between Perth (Western Australia) and Ceduna (South Australia) (Figure 1) in August when peak whale abundance is expected. Flights are conducted on days when wind speeds are less than 15 knots within *ca* one nautical mile of the coast, given the highly coastal distribution of southern right whales. Survey flights are undertaken at an altitude of 1000 feet and photographs of the individual markings (i.e. callosity patterns) of the whales at 500 feet.

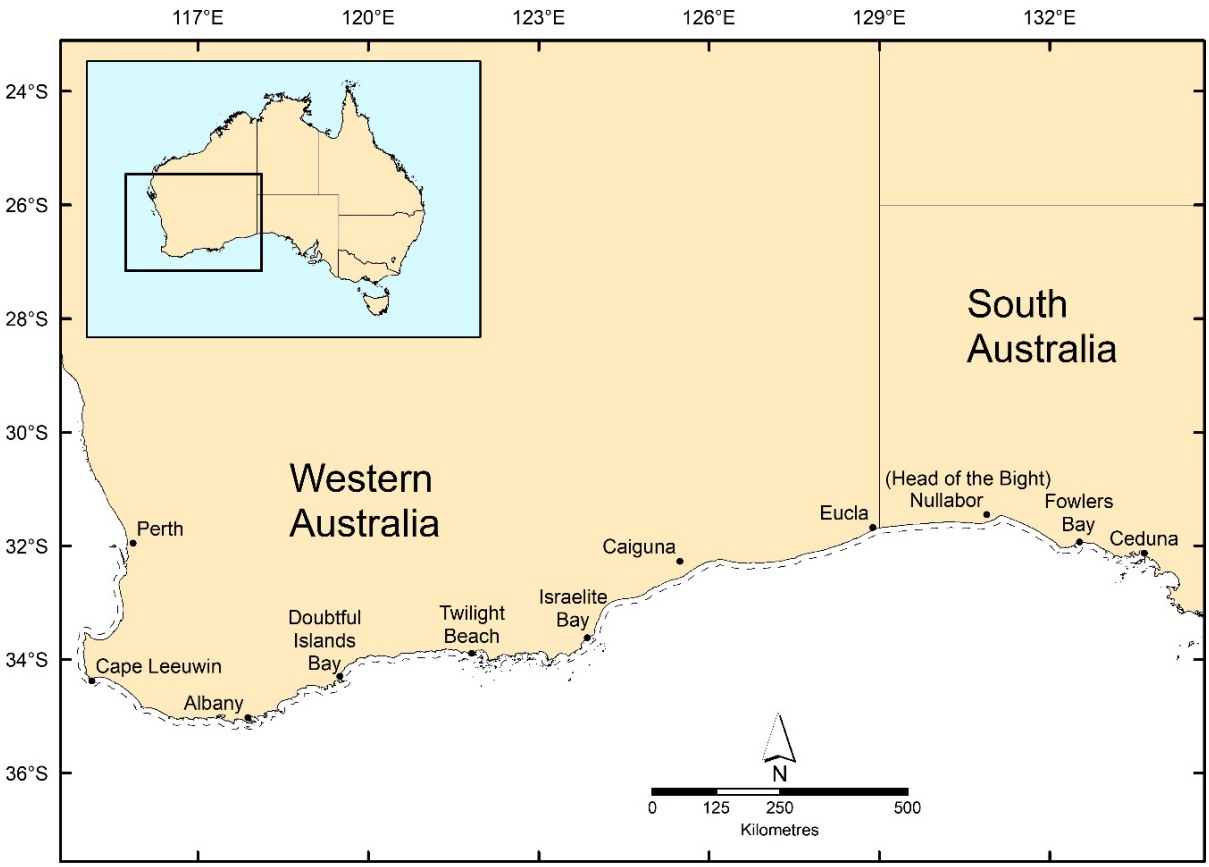

Figure 1. Approximate survey area for southern right whales off the southern coast of Australia (within *ca* one nautical mile) in 2023 between Perth (WA) and Ceduna (SA). The dashed line approximates the offshore survey area boundary.

During the aerial survey, direct counts of animals observed within the search area along the coast are undertaken. Most animals, particularly cows accompanied by calves, are easily observed in the relatively clear waters on the south coast and no corrections are made to account for detection probability of a sighting ($g(0)$) in the survey data (assumed to be one). When whales are sighted, a direct count of the number of whales (including numbers of calves) and GPS position are recorded. The aircraft then descends to allow photographs to be taken for individual identification of whales, requiring clear aerial photographic images of the head callosity pattern and/or other identifying characteristics. Photo-identification images are geotagged using a Canon EOS 5D DSLR and Canon 100-400 USMII lens. At the end of survey, photographs of individuals identified from their head callosity pattern are manually reviewed for quality and where the callosity patterns are unobstructed (e.g. from water-wash over the head) and clearly discernible, whale-IDs and images are submitted to ARWPIC.

Each annual survey involves multiple 'legs' along the coast which corresponds to sections of the coastline that can typically be covered in one or two flights within a day, dependant on weather. The survey occurs from Perth in Western Australia east to Ceduna in South Australia (i.e., outwards) and then returns from Ceduna to Perth (i.e., inwards). Consequently, each 'leg' is surveyed twice dependant on weather, on the 'outward' flights and then the return 'inward' flights. The maximum count on either the 'outward' or 'inward' flight on each 'leg' are then used to obtain estimates of both population trend and current population size, which is consistent and comparable to surveys since 1993. Given the relative low number of whales that visit the remainder of the southern Australian coast (Stamation et al. 2020), the 'western' population recorded between Cape Leeuwin and Ceduna is considered to represent the majority of the 'Australian' population.

2.1.2 Population estimate and trend analysis

The total population size estimate for the 'western' population is currently obtained using a simple model adopted at the 2011 International Right Whale Workshop (IWC, 2013) based on the numbers of cow/calf pairs (i.e. mature females) sighted, multiplied by a single applied conversion factor to convert estimates of mature females to the total number of individuals in the population. The number of mature females over three years (to allow for a 3-year calving interval) is multiplied by the conversion factor of 3.94, which is the average based on the South Africa (3.92) and southwest Atlantic (3.95) populations. Given the multiplication factor is based on a 3-year average of counts, it can be influenced by consecutive years of lower or higher annual whale counts.

A population trend analysis is undertaken using an exponential regression (i.e. a linear regression of the natural log of the count on year) of the maximum count data for 'all animals' and 'female-calf' pairs (Table 1) using aerial survey count data between Cape Leeuwin (WA) and Ceduna (SA) since 1993. It excludes data for two years (1996 and 1997), due to potential bias in count data from adverse weather and sighting conditions providing a possible under-estimation of whales (Bannister 1998, 2002).

3. Results

3.1 Aerial survey

An aerial survey of the 'western' population of Australian southern right whales was undertaken between Perth (WA) and Ceduna (SA) over six days in total, from the 18th to 23rd August 2023 over a combined 35.4 flying hours. During the entire survey, there were recorded a total 614 southern right whales, consisting of 95 calves. This count incorporates likely double counts of individual whales given the majority of the survey area is surveyed twice (due to outward and inward flights). There were an additional ten groups of humpback whales totalling 24 individuals, including five female-calf pairs between Esperance and Perth (Appendix A).

The maximum whale counts of each leg ('outwards' or 'inwards') between Cape Leeuwin and Ceduna are used to determine population size and trend for the 'western' population which totalled 342 southern right whales across the survey area, comprising of 95 female-calf pairs and 152 unaccompanied whales including one yearling (Appendix A: Southern right whale aerial survey summary data).

3.2 Distribution

Sightings of southern right whales during the 2023 aerial survey were generally consistent with previous years in whale distribution for both female/calf pairs and unaccompanied animals, within three main regions of the aerial survey area (Figure 2):

1. Albany east to Doubtful Island Bay,
2. Israelite Bay (east to Point Culver)
3. Head of Bight in South Australia

Female-calf pairs were more concentrated within the three main regions, whereas unaccompanied whales had a broader distribution particularly from Esperance to Caiguna and Eucla to Head of Bight. From 7739 photo-identification images obtained on the 2023 flight, preliminary analysis has identified 193 individual whales selected to conduct computer-assisted 'matching' with those images already available in the ARWPIC catalogue.

3.3 Population abundance

3.3.1 Population count

Overall, the total number of southern right whales sighted during the 2023 aerial survey (N=349) was the lowest number recorded in the past 16 years since 2007 (N=286) in the time series of annual aerial surveys since 1993 (Figure 3, Appendix B: Summary table of aerial survey count data), with only a slightly higher number in 2020 (N=384). The greatest influence was the low numbers of female-calf pairs observed (N=96), which was also the lowest number counted since 2007, and only moderate numbers of unaccompanied animals.

It is evident there is significant inter-annual variation in the numbers of whales sighted as a result of the non-annual breeding female cycle of typically 3 year cycles (Figure 3a). However, recent years (from 2007) are showing greater inter-annual variation in whale counts and anomalous years of pronounced low whale numbers (i.e., 2007, 2015, 2020, 2023) are becoming more frequent (Figure 3).

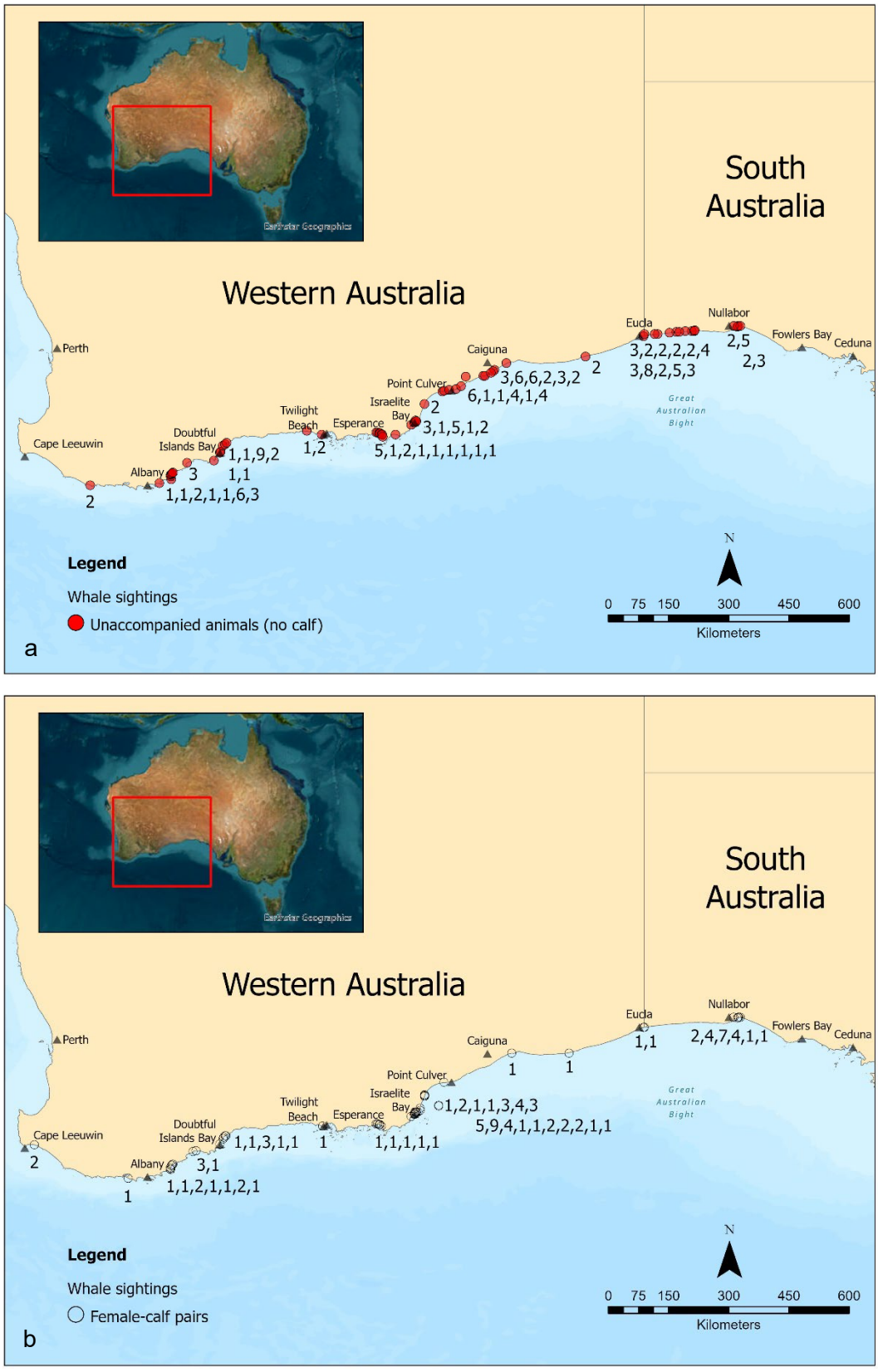

Figure 2 Survey area covered during the aerial survey undertaken in August 2023 for southern right whales. Map shows locations of southern right whale sightings for **a)** unaccompanied animals and **b)** cow / calf pairs.

Figure 3. Graph of the relative abundance of the 'western' population of southern right whales for **a)** all animals, unaccompanied animals and cow/calf pairs between 1993 and 2023 and **b)** unaccompanied animals and cow/calf pairs between 2007 and 2023.

The overall numbers of whales sighted in 2023 was lower than most previous years, predominantly due to low numbers of female-calf pairs (N = 96), but also low numbers of unaccompanied animals. This is the lowest number of female-calf pairs since 2007 (N = 57) (Appendix B).

3.3.2 Population estimate

Current estimated population sizes of the 'western' population of southern right whales use the female-calf count over three years (to allow for the 3-year periodicity in calving) multiplied by a factor of 3.94. This results in a current breeding female population size (i.e. for the three-year rolling average period, 2021 to 2023) of 2,439 whales. This is similar to estimates from the previous four years, with no apparent increase in change over this period.

Figure 4 shows an overall increasing trend in the size of the 'western' population of breeding females, although also demonstrates with Fig. 3 a more recent change in population growth with substantially greater variability since 2007.

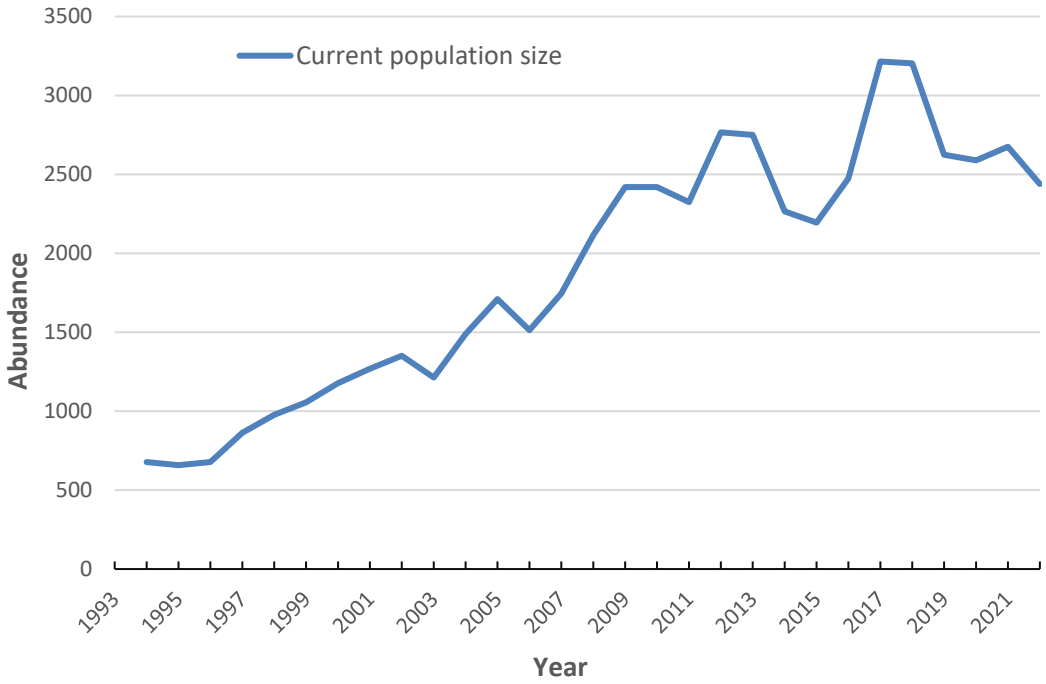

Figure 4 Current population size and population trend for the 'western' population of southern right whales.

3.4 Population trend analysis

The exponential regression analysis of the whale count data for 'all animals' between 1993 and 2023 (excluding 1996/97) suggests an exponential rate of increase of 0.03 (95% CI 0.020 - 0.049), which is equivalent to an annual percentage increase of 3.49% (95% CI 2.0 - 5.0) (Table 1, Appendix C: Linear regression analyses of whale trend data). The estimated exponential rate of increase based on counts of cow/calf pairs was 0.044 (95% CI 0.027 - 0.062) and an annual percentage increase of 4.51% (95% CI 2.7 - 6.4) (Table 2, Appendix C: Linear regression analyses of whale trend data2).

There is evidence that the rate of increase of cow/calf pairs has been slowing over the past 17 years (i.e., ~5-6 breeding cycles) since 2006 (8.1% in 2006 compared to 4.51% in 2022) (Figure 5). A regression analysis of a subset of the count data between 2000 and 2023 (i.e., ~ seven breeding cycles) demonstrates a non-significant relationship in the trend count data over time, which also occurs in the more recent count data between 2007 and 2023 (Table 2, Figure 3b).

Table 1. Best fit regressions for maximum counts of whales in each leg of the southern right whale aerial survey for years between 1993 - 2023 (excl. 1996 & 97)

Period	**1993 - 2023**		**1993 - 2022**	
Class	All animals	Cow/calf pairs	All animals	Cow/calf pairs
Exponential increase	0.0343	0.0441	0.0398	0.0517
SE	0.007	0.009	0.007	0.008
95% CI (Lower – Upper)	0.020 – 0.049	0.027 – 0.062	0.026 – 0.053	0.036 – 0.068
p-value	< 0.001	< 0.001	< 0.001	< 0.001
R^2	0.47	0.49	0.58	0.63
Percentage annual increase	**3.49**	**4.51**	**4.06**	**5.31**
SE	0.71	0.86	0.67	0.79
95% CI (Lower – Upper)	2.00 – 4.99	2.69 – 6.37	2.64 – 5.49	3.62 – 7.01

Table 2. Best fit regressions for maximum counts of whales in each leg of the southern right whale aerial survey for years between 2000 - 2023 and 2007 - 2023 (excl. 1996 & 97)

Period	**2000 - 2023**		**2007 - 2023**	
Class	All animals	Cow/calf pairs	All animals	Cow/calf pairs
Exponential increase	0.0220	0.0336	-0.0061	0.0171
SE	0.010	0.012	0.016	0.023
95% CI (Lower – Upper)	0.002 – 0.042	0.008 – 0.059	-0.040 – 0.027	-0.033 – 0.067
p-value	0.034	0.012	0.7	0.476
R^2	0.19	0.25	0.01	0.03
Percentage annual increase	**2.22**	**3.42**	**-0.61**	**1.72**
SE	0.98	1.25	1.58	2.37
95% CI (Lower – Upper)	0.17 – 4.30	0.79 – 6.12	-3.87 – 2.78	-3.22 – 6.92

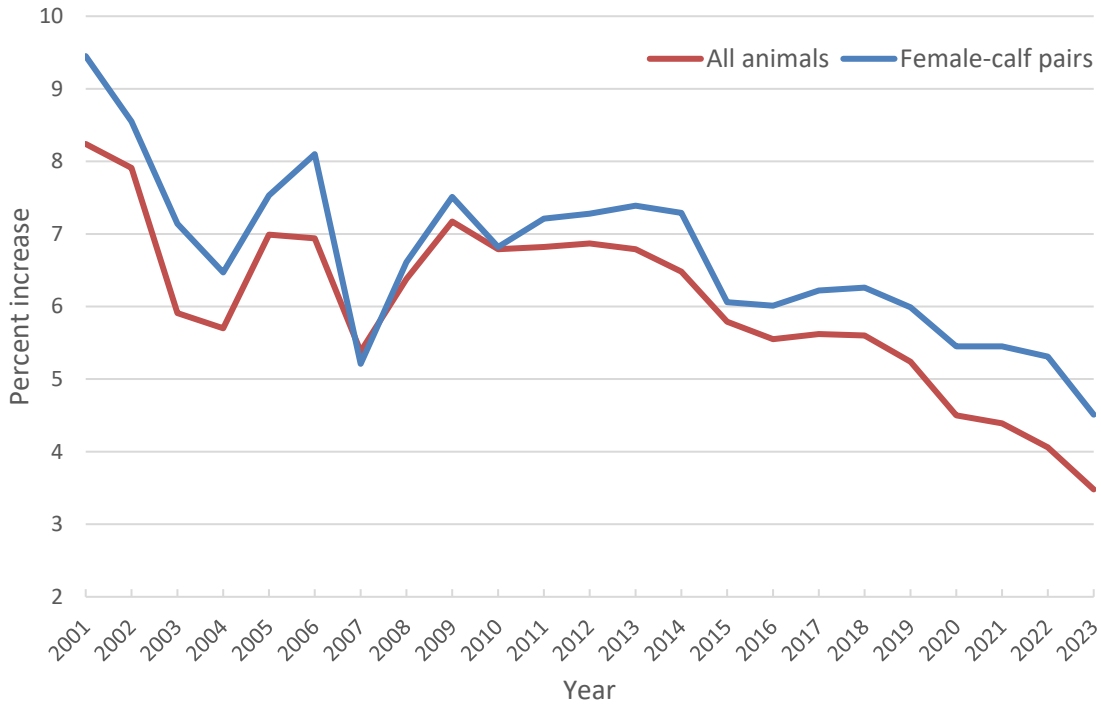

Figure 5 Rate of percent annual increase in abundance of the western population of southern right whales based on regression analyses of annual count data since 1993 (i.e., Table 1; 2023). Note, counts early in the program (1993-2000) are not included due to either low sample size and/or lack of data to cover a minimum 3 years breeding cycle, resulting in a trend analysis being either not possible or unreliable.

4. Discussion and conclusions

The overall count of 349 whales (maximum count per leg) from the 2023 annual aerial survey, while lower than most recent years (i.e. since 2008), is still broadly comparable to numbers recorded throughout the time series of annual aerial surveys (Appendix B). A prominent trend in the aerial survey count data is considerable annual variability since 2007, where there is an overall increase in population trend, although substantial low counts in periodic years of every 3-5 years (Figure 4, Figure 5). The population size of the 'western' population inclusive of the 2023 survey data is an estimated 2,439 whales, which is similar, or lower, to estimates over the previous fifteen years. However, given an increasing long-term population trend in relative abundance, the population count and subsequent population size should be higher than was recorded. This is based on the assumption of comparative annual count data given the long-term consistency in the methodology and that the annual aerial surveys are undertaken at a time of peak abundance. Since 2001, the population trend data for both unaccompanied animals and female-calf pairs indicates a slowing in the rate of increase, with two evident significant declines in 2004 and 2007 (Figure 5). For example, the rate of increase of female-calf pairs has decreased over the past 14 years from 7.51% in 2009 to 4.51% in 2023. Consequently, the population size of southern right whales in Australian waters is approximately less than 20% of pre-whaling abundance estimates given the eastern population is estimated at only 268 individuals (Stamation, Watson et al. 2020) and recovery of the species is slowing.

Highly fluctuating annual variation in abundance is a prominent characteristic of the Australian southern right whale population trend data (Figure 3). Inter-annual variation of female-calf pairs is largely due to the non-annual breeding female cycle (i.e. typically 3-year cycles), which results in a cohort structure within the data based on females returning to the Australian coast every 3-years on average. Pronounced inter-annual variability and unpredictable fluctuations in the cohort structure may occur if females 'due' to breed in a particular year avoid breeding ('skip-breed') in a particular year until the subsequent year. This could also occur if there is an extension of the breeding cycle to 4 or 5 years, as seen on a majoring calving ground at Head of Bight where the mean calving interval for breeding females during 2015-2021 has increased from three to four years (Charlton et al. 2022). The factors associated with 'skip-breeding' and/or increase in mean calving intervals are currently unknown but may be influenced by factors such as climate change (Pirzl 2008). Southern right whale breeding success from Argentina, as exemplified by cohort strength from year to year, has been inversely correlated to sea surface temperature (SST) anomalies on foraging grounds and high sea surface temperatures related to El Niño events affecting conception rates and consequently pregnancy rates in the following year (Leaper et al. 2006). Thus, more extreme climate events on the foraging and/or calving grounds could negatively influence the female breeding cycle and potentially explain a slowing in the rate of population increase. Other possible explanations for a potential decline in the rate of population increase is a greater overwintering of whales on foraging grounds or temporal/spatial changes in distribution on the calving grounds, such as a potentially greater offshore distribution away from the near-shore coastline calving areas in recent years. Currently, the reasons for the high annual variability in whale counts and increased mean calving interval are unknown.

4.1 Implications for species conservation management

To evaluate the recovery of the southern right whale population, it will be critical to understand potential causes of annual variability in whale numbers related to the non-annual female breeding cycle and seasonal distribution and abundance of unaccompanied whales. Considerable inter-annual variation in whale numbers makes it difficult to detect consistent and reliable changes in abundance from one year to the next (and over longer periods), and inhibits our ability to identify immediate threats to the population. This includes identifying possible influences from short-term climate dynamics, longer-term climate change and/or potential impacts from anthropogenic threats. Importantly, there are several natural and anthropogenic threats that affect southern right whales that are likely to interact, and their cumulative effects may severely affect recovery of the species. Given some threats operate over longer time scales (e.g., climate change), there should be a focus on managing threats that can be reduced in the short term (e.g., anthropogenic underwater noise, vessel strike, entanglement). Continued annual population aerial surveys to inform long-term population trend data from the western population will be the best approach to assess any potential slowing of the population growth rate and still represent the best frequency for detecting change over longer time scales.

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Appendix A: Southern right whale aerial survey summary data

Flight	Date	Leg / flights	Whale sightings							Weather[1]	Flying hrs
			Right whales				Other large whales[2]				
			A[3]	C	Y	T	A	C	T		
Outward legs Albany to Ceduna	19-08-23	2&3 Albany-Esperance *	58	21	1	80	5	2	7	250/10	5.0
	20-08-23	4&5 Esperance-Caiguna *	103	49	1	153	0	0	0	320/09	4.5
	21-08-23	6&7 Caiguna-Nullarbor (excl HoB)	11	1	0	12	0	0	0	260/20	3.8
	21-08-23	8 Nullarbor-Ceduna * (incl HoB)	48	19	0	67	0	0	0	270/20	1.5
Total Outward		**2-8 Albany-Ceduna**	**220**	**90**	**2**	**312**	**5**	**2**	**7**		**14.8**
Inward legs Ceduna to Albany	22-08-23	9 Ceduna-Nullarbor (incl HoB)	28	17	0	45	0	0	0	240/06	2.3
	22-08-23	10&11 Nullarbor-Caiguna * (excl HoB)	38	4	0	42	0	0	0	150/08	3.7
	23-08-23	12&13 Caiguna-Esperance	105	44	0	149	0	0	0	260/15	4.2
	23-08-23	14&15 Esperance-Albany	54	19	0	73	9	1	10	270/06	3.6
Total Inward		**9-15 Ceduna-Albany**	**225**	**84**	**0**	**309**	**9**	1	**10**		**13.8**
Additional leg	18-08-23	1 Perth-Albany	4	3	0	7	4	1	5	090/calm	4.5
Total	**6 days**	**15 flights**									**33.1**

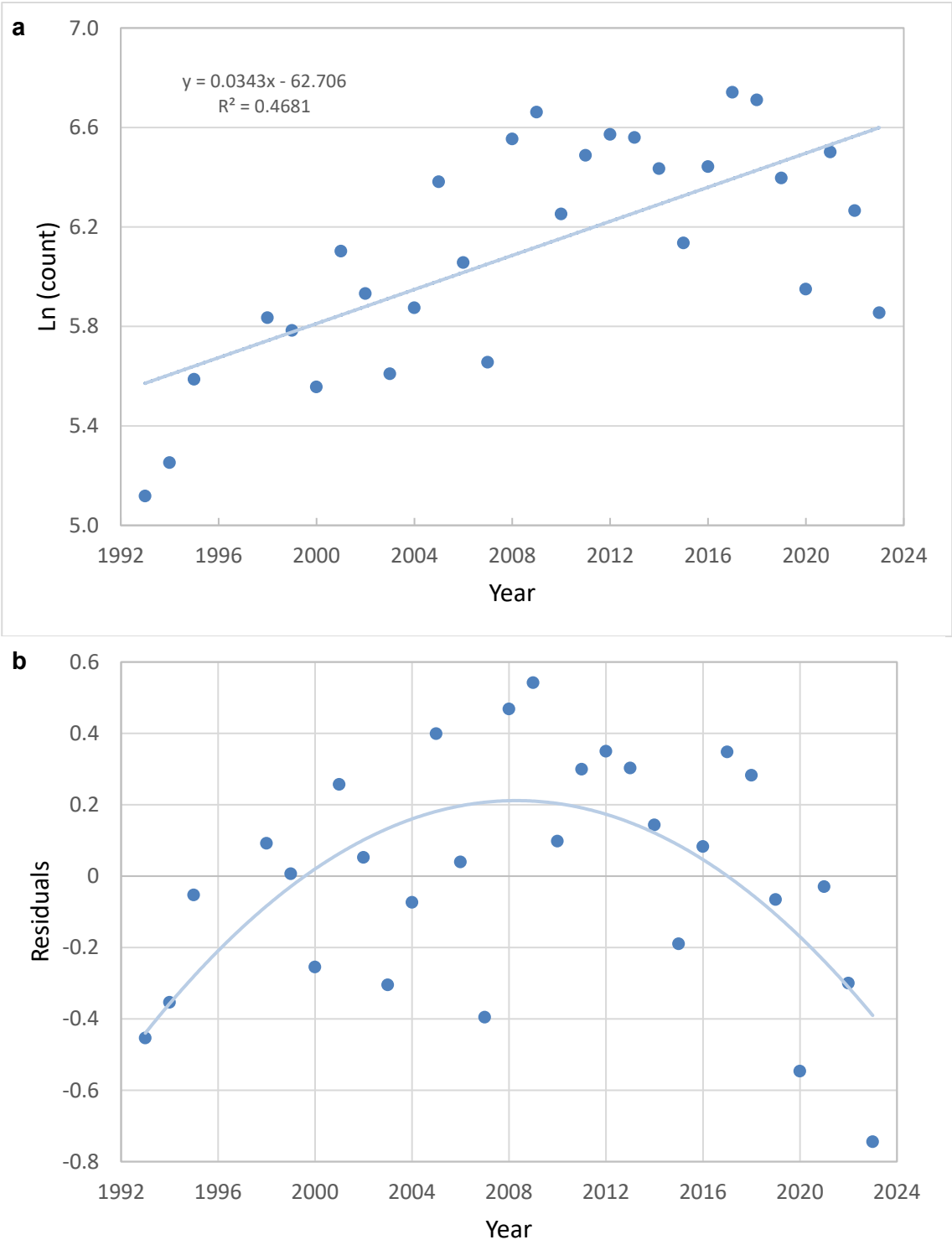
[1] direction of wind/wind speed (knots)
[2] all humpback whales; no other large whales recorded
[3] A = adult, C = calf, Y = 'yearling', T = total
* survey legs with maximum numbers of whales used for mapping and calculating trend (i.e. in Table 2)

Appendix B: Summary table of aerial survey count data

Total comparable maximum counts of southern right whales from annual aerial surveys undertaken between Cape Leeuwin (WA) and Ceduna (SA) since 1993.

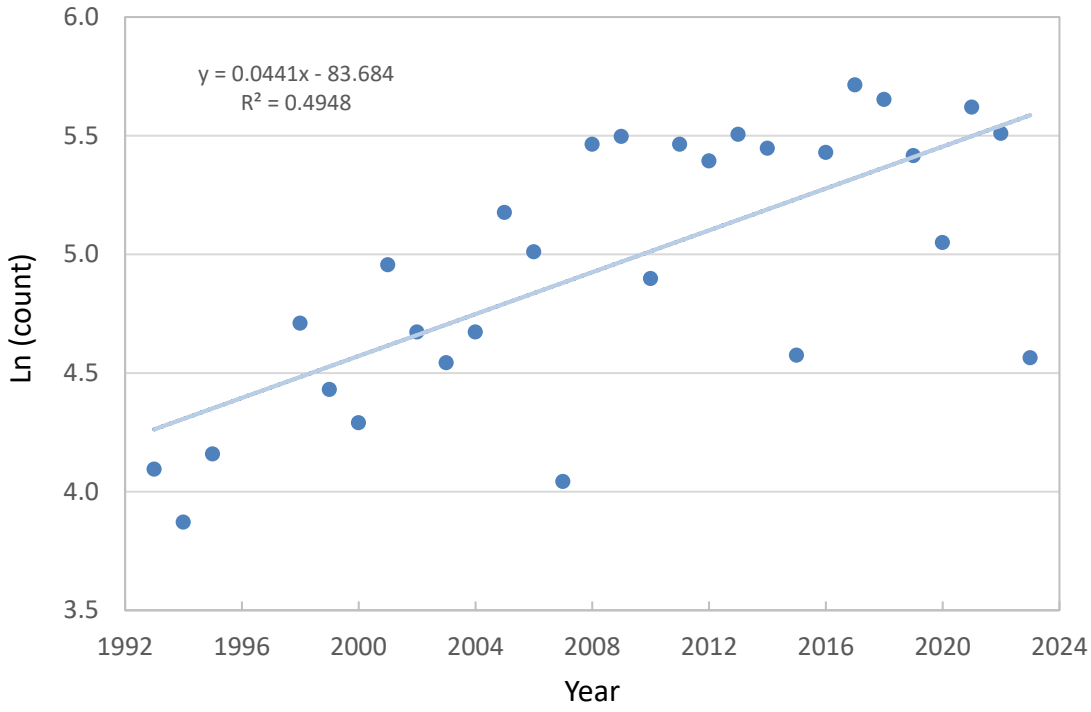
Year	All animals	Unaccompanied animals	Cow/calf pairs
1993	167	47	60
1994	191	95	48
1995	267	139	64
1996	233	123	55
1997	254	148	53
1998	342	120	111
1999	325	157	84
2000	259	113	73
2001	447	163	142
2002	377	163	107
2003	273	85	94
2004	356	142	107
2005	591	237	177
2006	427	127	150
2007	286	172	57
2008	702	230	236
2009	782	294	244
2010	519	251	134
2011	657	185	236
2012	715	275	220
2013	706	214	246
2014	623	159	232
2015	462	268	97
2016	628	172	228
2017	847	241	303
2018	821	251	285
2019	600	150	225
2020	384	72	156
2021	666	114	276
2022	526	32	247
2023	349	155	96

Appendix C: Linear regression analyses of whale trend data

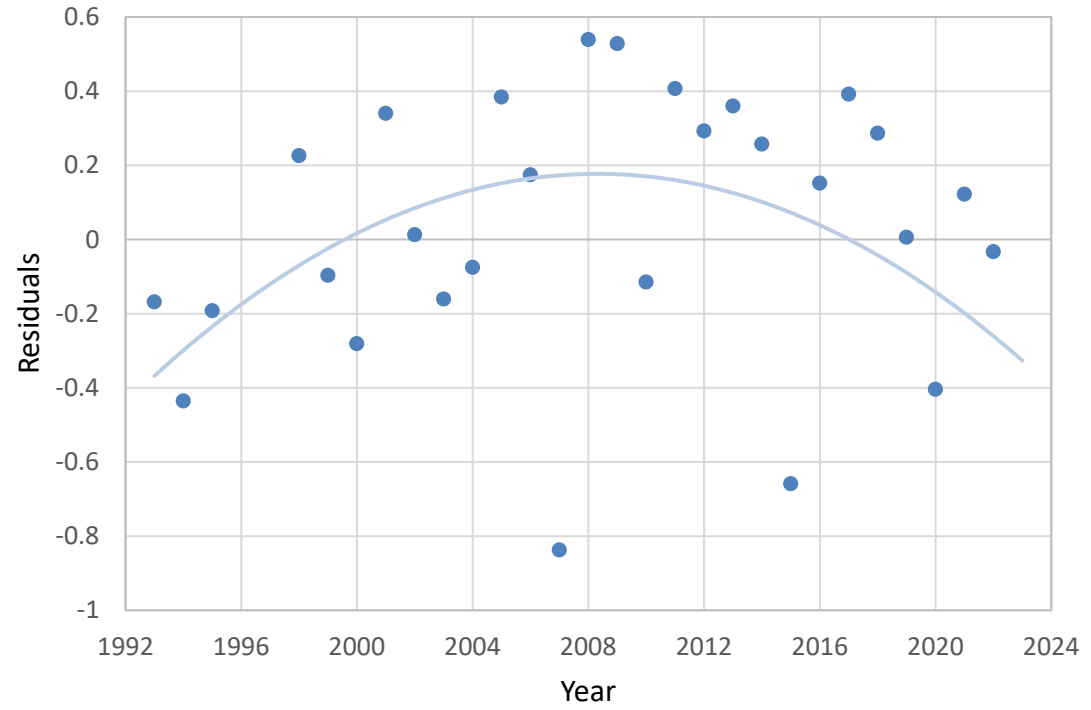


Appendix C1. Plots for *All animals* of the fitted (a) linear regression and (b) residuals for the maximum counts of whales in each leg of aerial surveys undertaken between 1993-2022 (excluding 1996/1997).

a

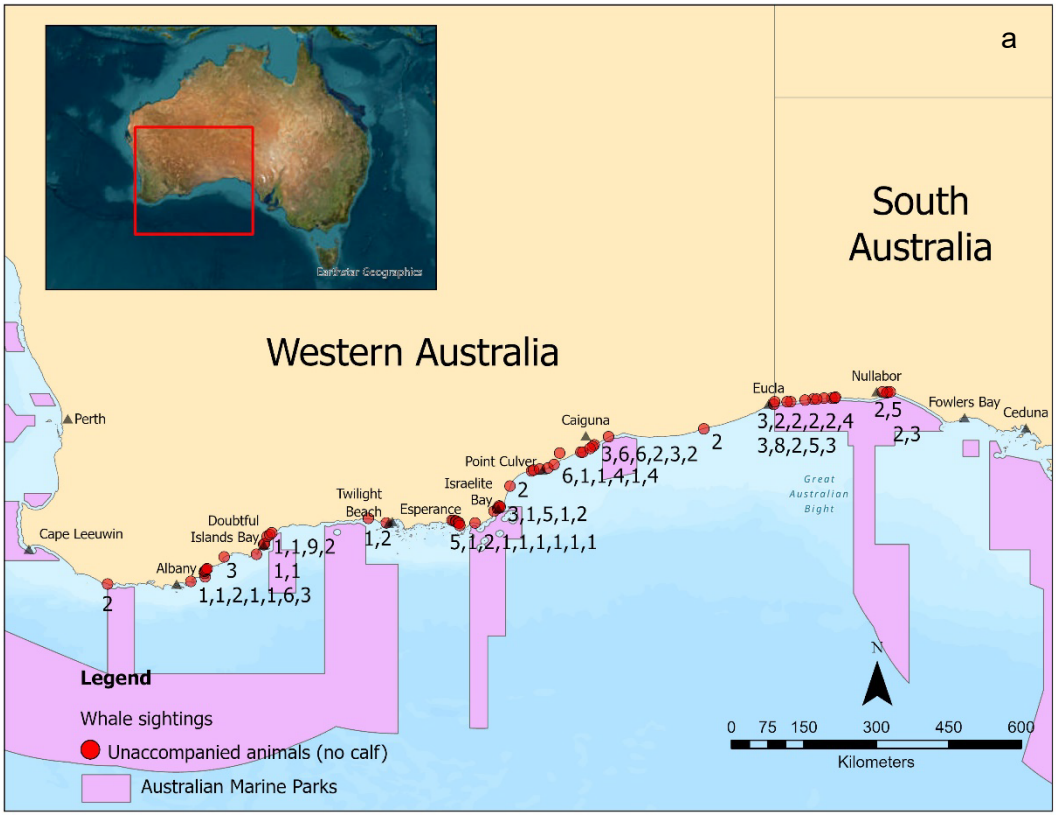


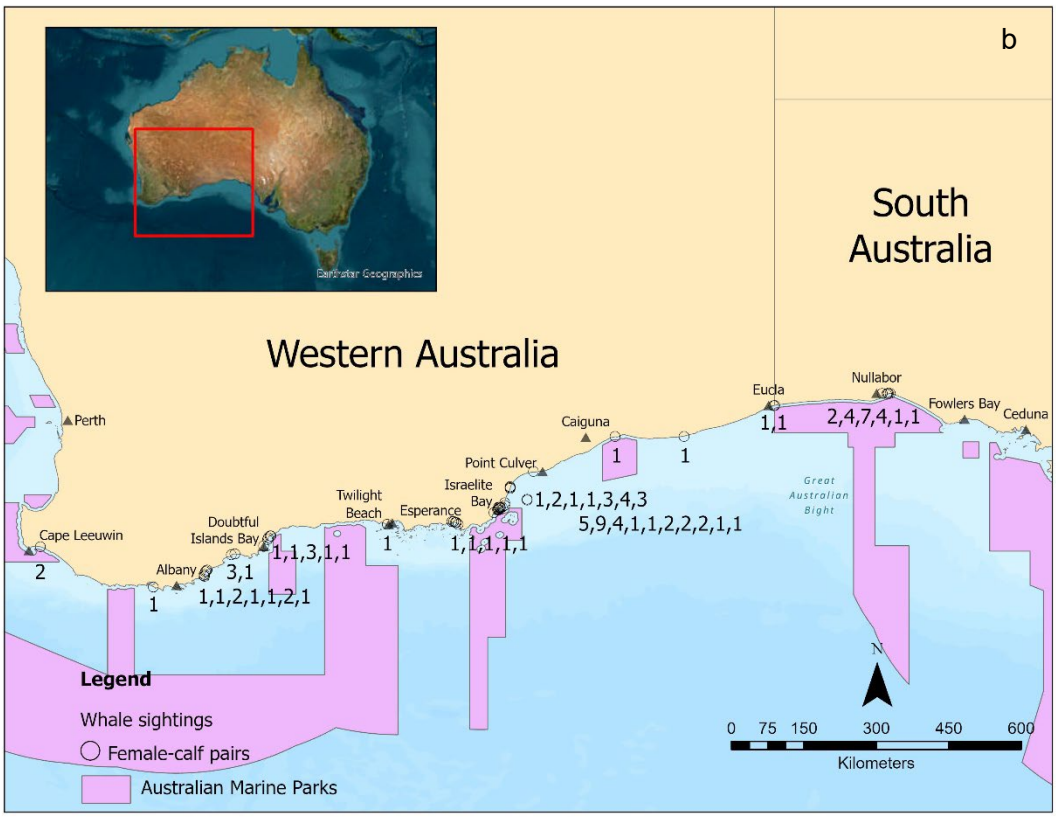
b



Appendix C2. Plots for *Cow / calf pairs* of the fitted (a) linear regression and (b) residuals for the maximum counts of whales in each leg of aerial surveys undertaken between 1993-2022 (excluding 1996 / 1997).

Appendix D: Sightings maps and Marine Parks





Appendix D1 Southern right whale sightings maps of **a)** unaccompanied animals and **b)** female-calf pairs

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