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

Final report on 2022 survey

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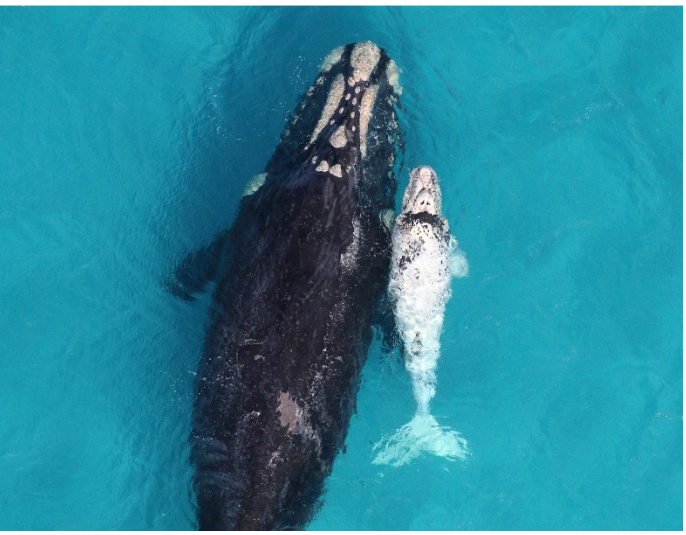

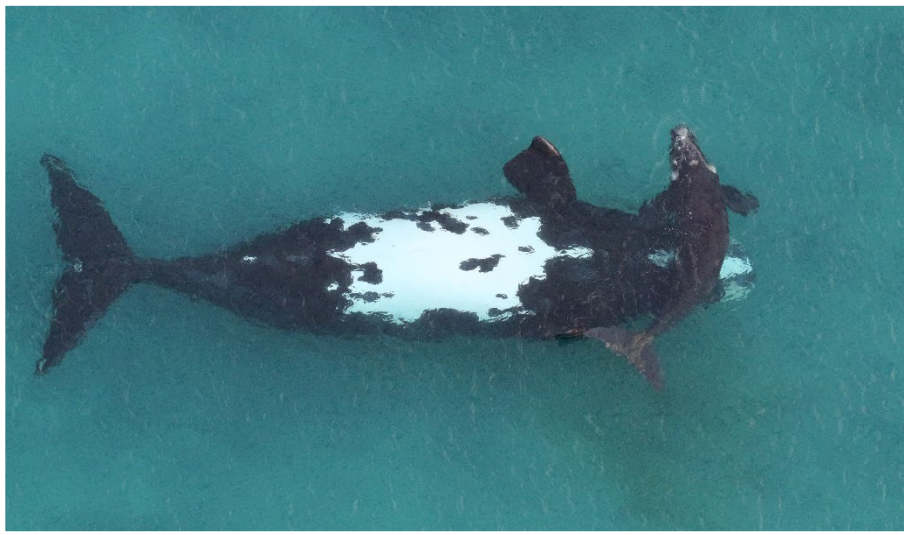

Murdoch University

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Cover images: Two Southern Right Whale mother and calf pairs off the southern coast of Australia © Joshua Smith

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Executive summary

Aerial surveys of southern right whales (*Eubalaena australis*) were undertaken off the southern Australian coast to monitor the recovery of this endangered species following extreme 19th and 20th Century commercial whaling. The aerial survey was undertaken in the coastal waters from Perth (Western Australia) to Ceduna (South Australia) between 12-19 August 2022, to maintain the annual series of population surveys and inform the long-term population trend.

The survey resulted in a total 526 whales sighted, consisting of 247 cow-calf pairs, 31 unaccompanied adults and 1 yearling. The 'western' population of southern right whales in Australian waters is increasing in size (~5.3% per year based on female/calf pairs and a population estimate of 2675 whales) based on the long-term population trend data from the annual aerial surveys. This represents the majority of the Australian population given the very low numbers in the 'eastern' population, estimated to comprise 268 (CI: 146 – 650) breeding females (Stamation et al. 2020).

While there is an increasing trend in population abundance, there is also evidence of a potential slowing down in the rate of increase of cow/calf pairs over the past 13 years (7.5% in 2009 compared to 5.3% in 2022) and there continues to be highly fluctuating annual variation in abundance and associated fluctuations in cohort structure. The inter-annual variation in sightings of cow/calf pairs is related to their breeding cycle (typically a 3-year cycle), which can also be affected by environmental factors on their foraging grounds.

The 2022 surveys recorded the lowest number of unaccompanied animals (i.e. males and females without a calf) ever throughout the time-series of the annual aerial surveys since 1993 when survey coverage between Cape Leeuwin and Ceduna first began. Across this time series, there is a particularly notable decline in sightings of unaccompanied animals over the past five years. 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. Lower than expected counts in the long-term data may provide evidence of a slowing population growth rate, which can only be assessed by continued annual population surveys to assess 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 Southern Right Whale Recovery Plan (Conservation Management Plan) 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 Australia's south-east (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 protocols from previous aerial surveys since 1993, using a high wing, single engine aircraft (Cessna 172 and Cessna 182) crewed by a pilot/observer, photographer/observer and data scribe. Aerial surveys were conducted along the southern coast of Australia between Perth (Western Australia) and Ceduna (South Australia) (Figure 1) during August, when peak whale abundance is expected given the known calving period between May and October. 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 flown at an altitude of 1000 feet and photographs of the individual markings (i.e. callosity patterns) of the whales are taken at 500 feet.

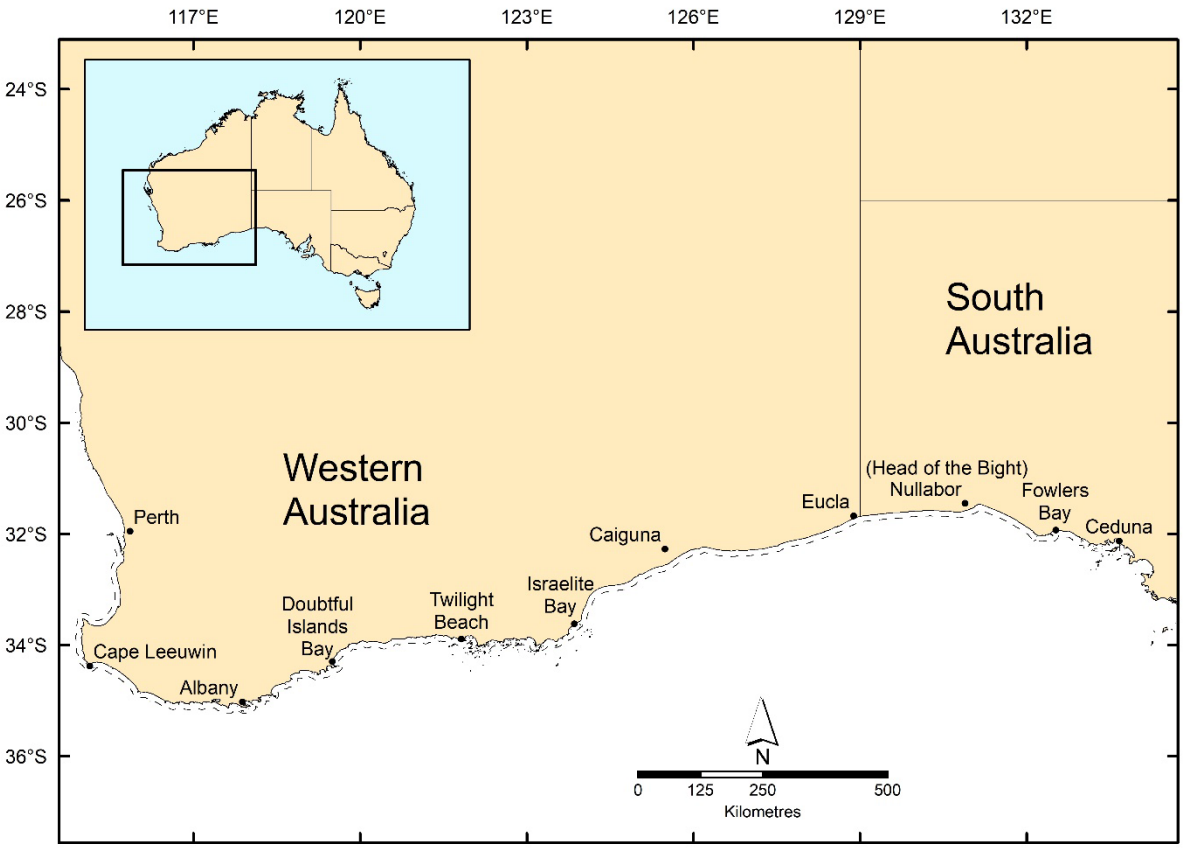

Figure 1. Approximate survey area for southern right whales off the southern coast of Australia in 2022, Perth (WA) to Ceduna (SA). Dashed line represents the approximate offshore survey area boundary.

During the 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, which is assumed to be one. When whales are sighted, a direct count of the number of whales, including presence of calves, and the GPS position are recorded. The aircraft then descends to allow photographs for individual identification to be taken, requiring clear aerial photographic images of the head callosity pattern and/or other identifying characteristics. Photo-identification images are obtained with a Canon EOS 70D and geotagged using a Canon GP-E2 GPS receiver. At the end of survey, photographs of individuals identified from their head callosity pattern are manually reviewed for quality, and images where the callosity patterns are unobstructed (e.g. from water-wash over the head) and clearly discernible are submitted to ARWPIC.

Each annual survey involves multiple 'legs' along the coast that can occur on the same day or spread across several days depending on the weather, and corresponds to sections of the coastline that can be typically covered in one or two flights. Each 'leg' is generally covered twice, once 'outwards' from Cape Leeuwin to Ceduna and once 'inwards' on the return 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 previous years 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 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 'cow/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 the data as a result of a possible under-estimate of whales during those years due to adverse weather and sighting conditions (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 eight days in total, from the 12th to 19th August 2022 over a combined 35.9 flying hours. During the entire survey, a total 982 southern right whales were recorded, consisting of 465 calves. This count incorporates likely double counts of individual whales given the majority of the survey area is surveyed twice (Albany – Ceduna and return Ceduna – Albany - Perth). There were an additional ten groups of humpback whales totalling 22 individuals, consisting of three mother and calf pairs (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, and consisted of a total 526 southern right whales sighted across the survey area, of which there were 247 cow-calf pairs and 32 unaccompanied whales including one yearling (Appendix A).

3.2 Distribution

Sightings of southern right whales during the 2022 aerial survey were consistent with previous years in the distribution of whales and areas where whales were sighted, for both cow/calf pairs and unaccompanied animals Specifically, there were higher numbers of unaccompanied whales and cow/calf pairs within three main regions of the aerial survey area; 1) Albany east to Doubtful Island Bay, 2) Israelite Bay (east to Point Culver), and 3) at the Head of Bight in South Australia (Figure 2). From 3425 images obtained on the 2022 flight, preliminary analysis has identified 186 images of 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 number of whales sighted during the 2022 aerial survey was lower (c.f. 2020) yet broadly comparable to numbers recorded throughout the time series of annual aerial surveys since 1993, noting though that there is relatively high inter-annual variability in southern right whale numbers, 2020 was a notable year of low numbers of whales sighted (Fig. 3, Appendix B). The total number of whales (N = 526) was largely due to the higher numbers of cow calf pairs sighted (N = 247) compared to 2020, with numbers in 2022 more similar to previous years (e.g. 2016 – 2019 and 2021). 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 (Fig. 3a). 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) are becoming more frequent (Fig. 3).

The overall numbers of whales sighted in 2022 was lower than most previous years, predominantly due to an extremely low number of unaccompanied whales (N = 32) sighted. This is the lowest number of unaccompanied animals ever recorded throughout the time-series of the annual aerial surveys from 1993 when survey coverage between Cape Leeuwin and Ceduna first began (Appendix B). This also resulted in the lowest ratio of the number of unaccompanied whales to cow/calf pairs at 1:7.7, which has been relatively stable during the aerial survey period since 1993, although demonstrates a declining ratio over the past three years (e.g. 2020 (1:2.17), 2021 (1:2.42), 2022 (1:7.7)).

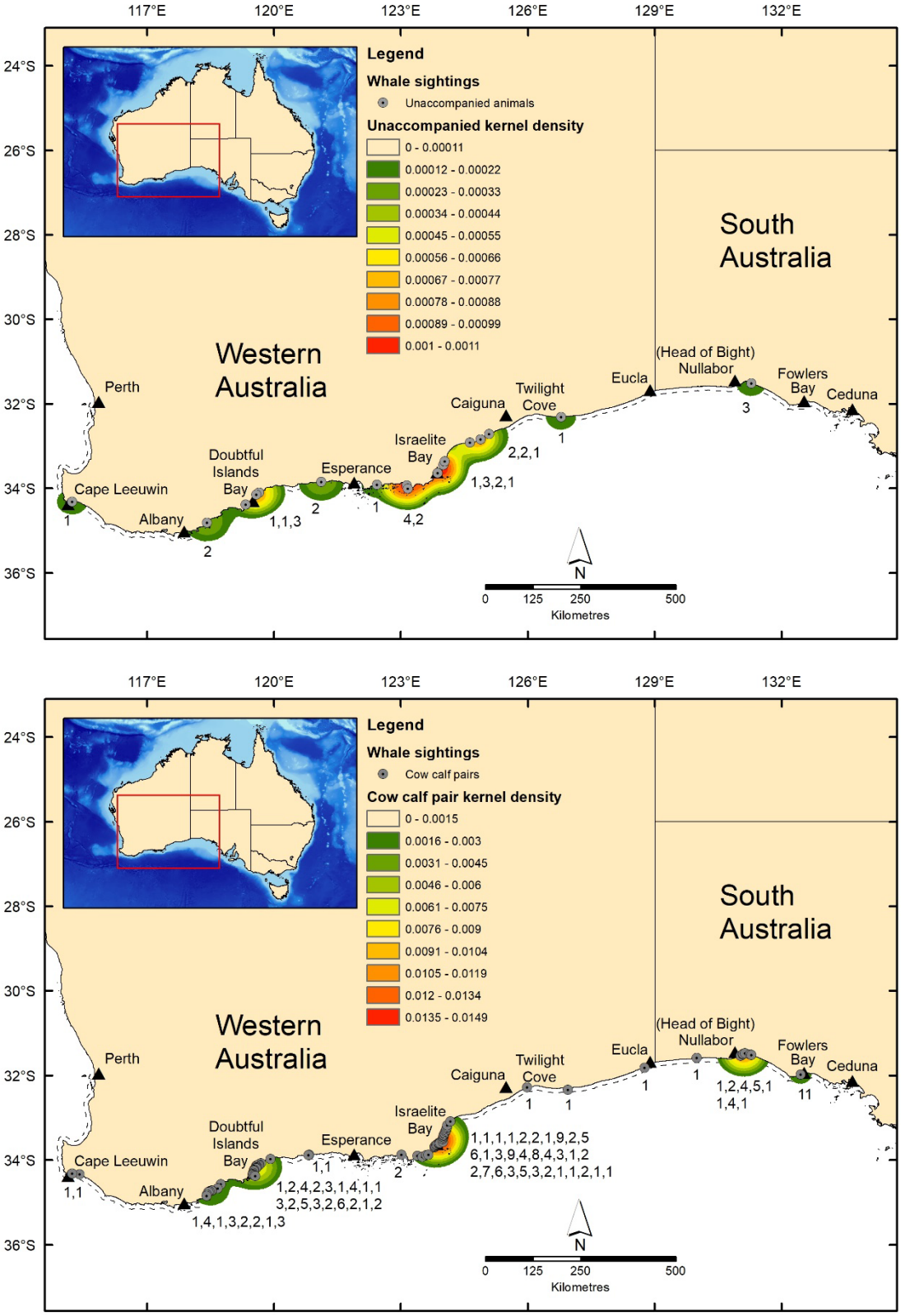

Figure 2 Survey area covered during the aerial survey undertaken in August 2022 for southern right whales. Map shows locations of southern right whale sightings, their associated group sizes and overall density probability (per km^2) for **a)** unaccompanied animals and **b)** cow / calf pairs. Note, the density probability scale is different between unaccompanied animals and cow/calf pairs.

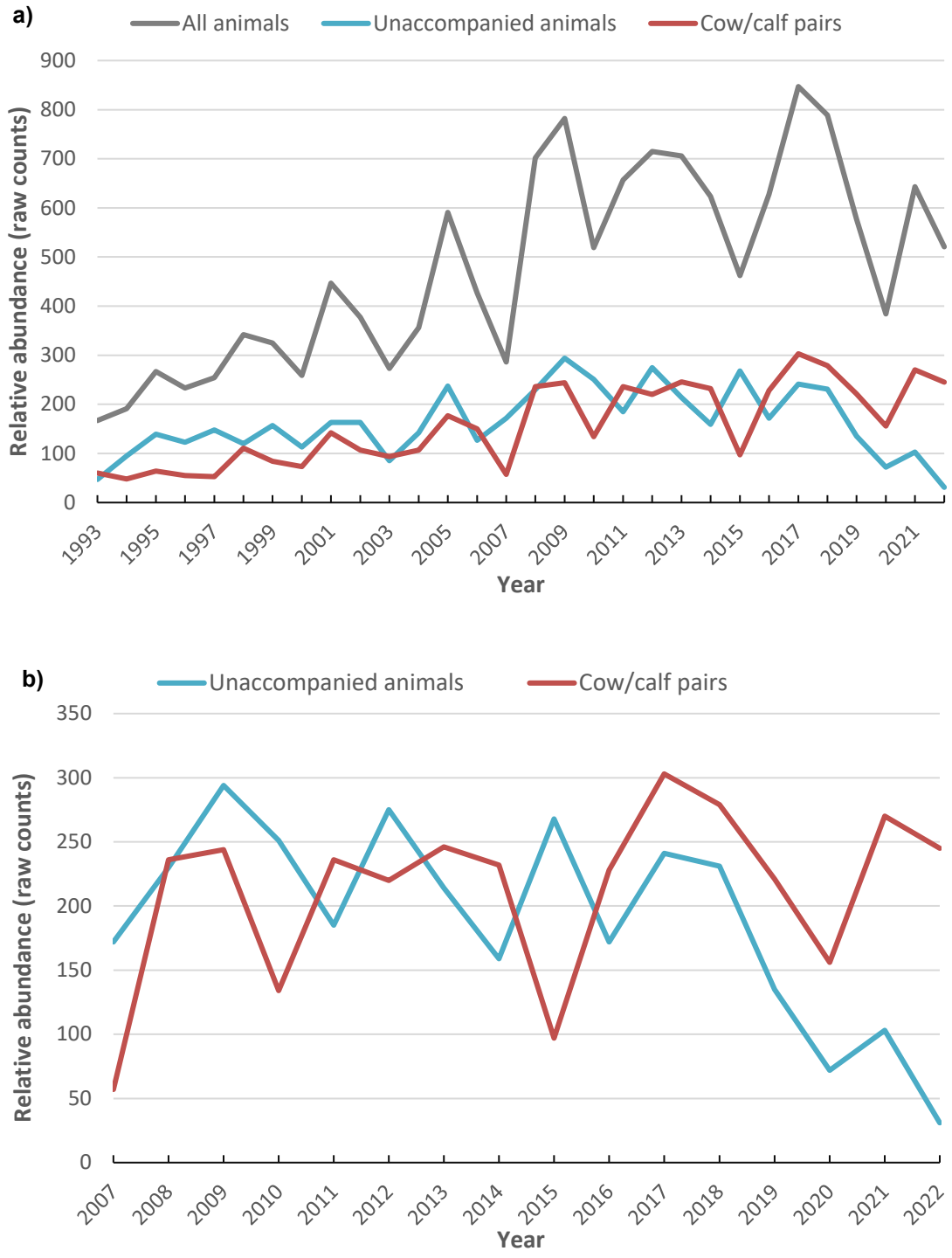

Figure 3. Graph of the relative abundance of the 'western' population of southern right whales for (a) all animals, unaccompanied animals and cow/calf pairs between 1993 and 2022 and (b) unaccompanied animals and cow/calf pairs between 2007 and 2022.

3.3.2 Population estimate

Current population sizes of southern right whales are estimated using the cow/calf count over three years (to allow for the 3-year periodicity in calving), multiplied by a factor of 3.94. For the Australian 'western' population, this results in a current breeding female population size (i.e. for the three-year rolling average period, 2020 to 2022) of 2675 whales, which is similar to estimates from the previous three years. While the population estimates are similar across the past three years, the low number of cow-calf pairs in 2020 had a large impact on these (Appendix B). The implications for future population estimates over the next two years is that if cow-calf pair counts are as high as they have been in 2021 and 2022, then the population estimate is expected to be comparable or higher to 2017/2018 (i.e. 3215, 3203). Figure 4 shows the increasing trend in the size of the 'western' population of breeding females and demonstrates the influence that increased inter-annual variation in whale counts has on the population estimates.

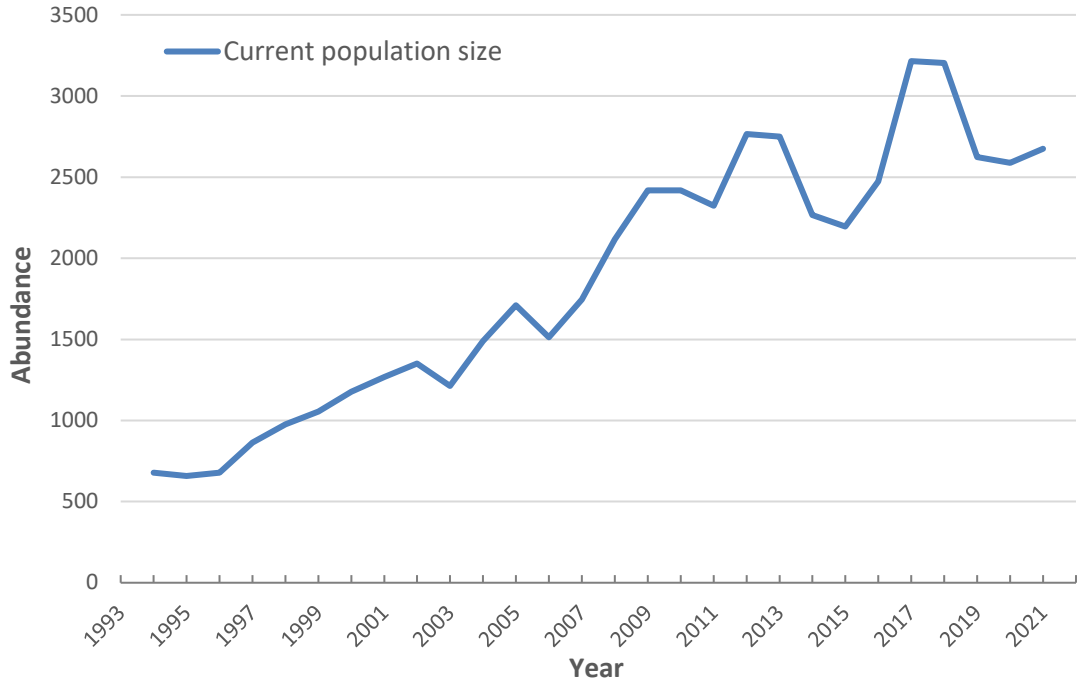

Figure 4 Current population size and population trend for the 'western' population of southern right whales.

3.4 Population trend analysis

An exponential regression analysis of the count data for 'all animals' between 1993 and 2022 (excluding 1996/97) provides an exponential rate of increase of 0.040 (95% CI 0.026, 0.053), which is equivalent to an annual increase of 4.06% (95% CI 2.6, 5.5) (Table 1, Appendix C1). The estimated exponential rate of increase based on counts of cow/calf pairs was 0.052 (95% CI 0.036, 0.068) or an annual increase of 5.31% (95% CI 3.6, 7.0) (Table 2, Appendix C2).

It is evident that there is considerable inter-annual variation in unaccompanied animals and cow/calf pairs (Fig. 3). The variation in cow/calf pairs is related to their breeding cycle (typically a 3-year cycle) and environmental factors might possibly influence that, whereas the factors that influence variation in numbers of unaccompanied animals on the southern Australian coast is less clear. Using the same regression analysis approach for a subset of the data between the years 2000 to 2022, there is less evidence of an increase in population abundance over time (Table 2). When the data is further restricted to the time period between 2007 and 2022, this relationship is not statistically significant (Table 2, Fig. 3b). There is also evidence that the rate of increase of cow/calf pairs has been slowing over the past 16 years since 2006 (8.1% in 2006 compared to 5.3% in 2022) (Fig. 5).

Table 1. Best fit regressions for maximum counts of whales in each leg of the southern right whale aerial survey for years between 1993 - 2022 (excl. 1996 & 97)

Period	**1993 - 2022**		**1993 - 2021**	
Class	All animals	Cow/calf pairs	All animals	Cow/calf pairs
Exponential increase	0.0398	0.0517	0.0430	0.0531
SE	0.007	0.008	0.007	0.008
95% CI (Lower – Upper)	0.026 – 0.053	0.036 – 0.068	0.028 – 0.056	0.035 – 0.069
p-value	< 0.001	< 0.001	< 0.001	< 0.001
R^2	0.58	0.63	0.61	0.62
Percentage annual increase	**4.06**	**5.31**	**4.39**	**5.45**
SE	0.67	0.79	0.69	0.84
95% CI (Lower – Upper)	2.64 – 5.49	3.62 – 7.01	2.92 – 5.87	3.65 – 7.28

Table 2. Best fit regressions for maximum counts of whales in each leg of the southern right whale aerial survey for years between 2000 - 2022 and 2007 - 2022 (excl. 1996 & 97)

Period	**2000 - 2022**		**2007 - 2022**	
Class	All animals	Cow/calf pairs	All animals	Cow/calf pairs
Exponential increase	0.0295	0.0447	0.0054	0.0376
SE	0.009	0.012	0.0161	0.0228
95% CI (Lower – Upper)	0.010 – 0.049	0.020 – 0.068	-0.029 – 0.040	-0.011 – 0.087
p-value	0.005	0.001	0.742	0.122
R^2	0.32	0.41	0.01	0.16
Percentage annual increase	**2.99**	**4.57**	**0.54**	**3.84**
SE	0.95	1.17	1.63	2.31
95% CI (Lower – Upper)	0.98 – 5.05	2.06 – 7.13	-2.87 – 4.08	-1.13 – 9.05

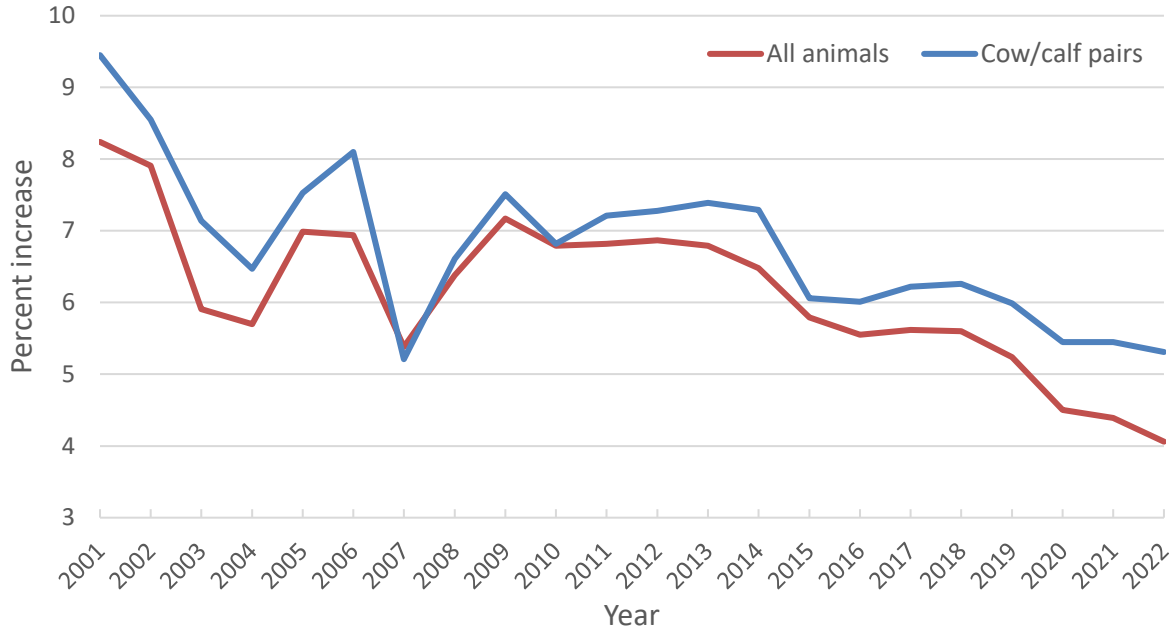

Figure 5 Rate of percent annual increase in abundance of the western population of southern right whales derived from regression analyses of annual count data since 1993 (i.e., Table 1; 2022). It should be noted that counts in beginning of program (1993-2000) are not possible or unreliable for trend analysis based on a power analysis due to low sample size and the non-annual female breeding cycle (~3 years) requiring analysis over several breeding cycles.

4. Discussion and conclusions

The overall population count from the 2022 annual aerial survey was lower than most recent years (i.e. since 2008), yet still broadly comparable to numbers recorded throughout the time series of annual aerial surveys (Appendix B). This is demonstrated in the estimated population size of the 'western' population of 2,675 whales, which is similar to the estimates from the previous three years. However, given an increasing long-term population trend in relative abundance, the population count and size should be predicted to increase and be higher than was recorded based on the assumption that the annual aerial surveys are undertaken at the time of peak abundance. Based on cow/calf pair data, the 'western' population of southern right whales in Australian waters is estimated to be increasing in size at ~5.31%, yet there are also indications of a potential slowing down in the rate of increase of cow/calf pairs over the past 13 years (Fig. 5; e.g. 7.5% in 2009 compared to 5.3% in 2022), and there continues to be highly fluctuating annual variation in abundance and associated fluctuations in cohort structure. Relatively high annual variability in numbers of southern right whales that occur on the Australian coast is a significant characteristic in the southern right whale population trend data. Within the population time-series data there are years of substantially low numbers of whales sighted on the coast, which are likely to be real signals in the data rather than potential anomalous years.

Inter-annual variation of cow/calf pairs is largely attributed to the non-annual breeding female cycle (i.e. typically 3-year cycles). This can become pronounced and lead to unpredictable fluctuations in the cohort structure if females that are 'due' to breed in a particular year avoid breeding ('skip-breed') until the subsequent year, and/or if there is an extension of the breeding cycle to 4 or 5 years (Charlton et al. 2022). Furthermore, southern right whale breeding success as exemplified by cohort strength from year to year, has been correlated to environmental conditions on foraging grounds with high sea surface temperatures related to El Niño events affecting conception rates and consequently pregnancy rates in the following year (Leaper et al. 2006). Other possible explanations for a potential decline in the rate of population increase is a greater overwintering of whales on foraging grounds and/or potentially greater offshore distribution away from the near-shore coastline in recent years. It is possible several, or all, of these factors may influence the recent patterns in distribution and abundance being observed, although it is unclear to what extent.

Generally, the overall number of whales sighted in 2022 was lower than most previous years over the past decade (except 2020), which was predominantly due to an extremely low number of unaccompanied whales (N = 32) sighted. This is the lowest number of unaccompanied animals ever recorded throughout the time-series of the annual aerial surveys since 1993 when survey coverage between Cape Leeuwin and Ceduna first began (Appendix B). Across this time series, there is a particularly notable decline in sightings of unaccompanied animals over the past five years. This is lower than the number of unaccompanied animals observed in 2020 (N = 72), which had previously been the lowest number sighted since 1993 (N = 47). The low number of unaccompanied animals in 2022 also resulted in the lowest ratio of the number of unaccompanied whales to cow/calf pairs at 1:7.7, which has been relatively stable during the aerial survey period since 1993, although demonstrates a declining ratio over the past three years (e.g. 2020 (1:2.17), 2021 (1:2.42), 2022 (1:7.7)). While the variation in cow/calf pairs is related to their breeding cycle and potential influences from environmental factors, it is currently unclear what factors influence

the extreme variability in numbers of unaccompanied animals on the southern Australian coast.

4.1 Future considerations and data needs

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 time 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. A series of lower than expected counts in the long-term data may provide evidence of a slowing population growth rate. 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 periods of time.

Substantial variation in counts from year to year in combination with the non-annual female breeding cycle results in considerable noise in the data, making it difficult to extricate effects on abundance due to the sampling approach and real biological effects (including any environmental effects on reproductive success). Future considerations require evaluation of the appropriateness of continued regression analysis of the count data and assessment of improved analysis methods, including time-series analyses. A re-evaluation of the appropriateness of applying the abundance correction factor to the Australian population to get a total population abundance estimate (of all animals) is also required given it has been derived based on other population data (i.e. South Africa, southwest Atlantic). Finally, to inform national and international species recovery assessments using life history data, efficient processing of photo-identification data is crucial and improved machine learning artificial intelligence software and resources for data curation is needed to improve data curation for the large aerial survey photo-identification dataset.

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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	12-08-22	1&2 Albany-Esperance	69	60	0	129	7	2	9	100 / 05	4.8
	13-08-22	3&4 Esperance-Caiguna *	122	103	0	225	0	0	0	040 / 10	5.6
	14-08-22	5&6 Caiguna-Nullarbor * (excl HoB)	11	10	0	21	0	0	0	N / 10	3.9
	14-08-22	6&7 Nullarbor-Ceduna * (incl HoB)	69	68	0	137	0	0	0	N / 15	2.1
Total Outward		**1-7 Albany-Ceduna**	**271**	**241**	**0**	**512**	**7**	**2**	**9**		**16.4**
Inward legs Ceduna to Albany	15-08-22	8 Ceduna-Nullarbor (incl HoB)	56	55	0	111	0	0	0	270 / 10-20	2.6
	15-08-21	9&10 Nullarbor-Caiguna (excl HoB)	6	3	0	9	2	0	2	225 / 15	3.8
	18-08-22	11 Caiguna-Esperance	108	99	0	207	0	0	0	225 / 10	4.0
	18-08-22	12&13 Esperance-Albany *	73	64	1	138	0	0	0	315 / 10	4.2
Total Inward		**3-5 Ceduna-Albany**	**243**	**221**	**1**	**465**	**2**	**0**	**2**		**14.5**
Additional leg	19-08-22	14 Albany-Perth	3	2	0	5	10	1	11	270 / 10	4.9
Total	**6 days**	**14 flights**	**517**	**464**	**1**	**982**	**19**	**3**	**22**		**35.9**

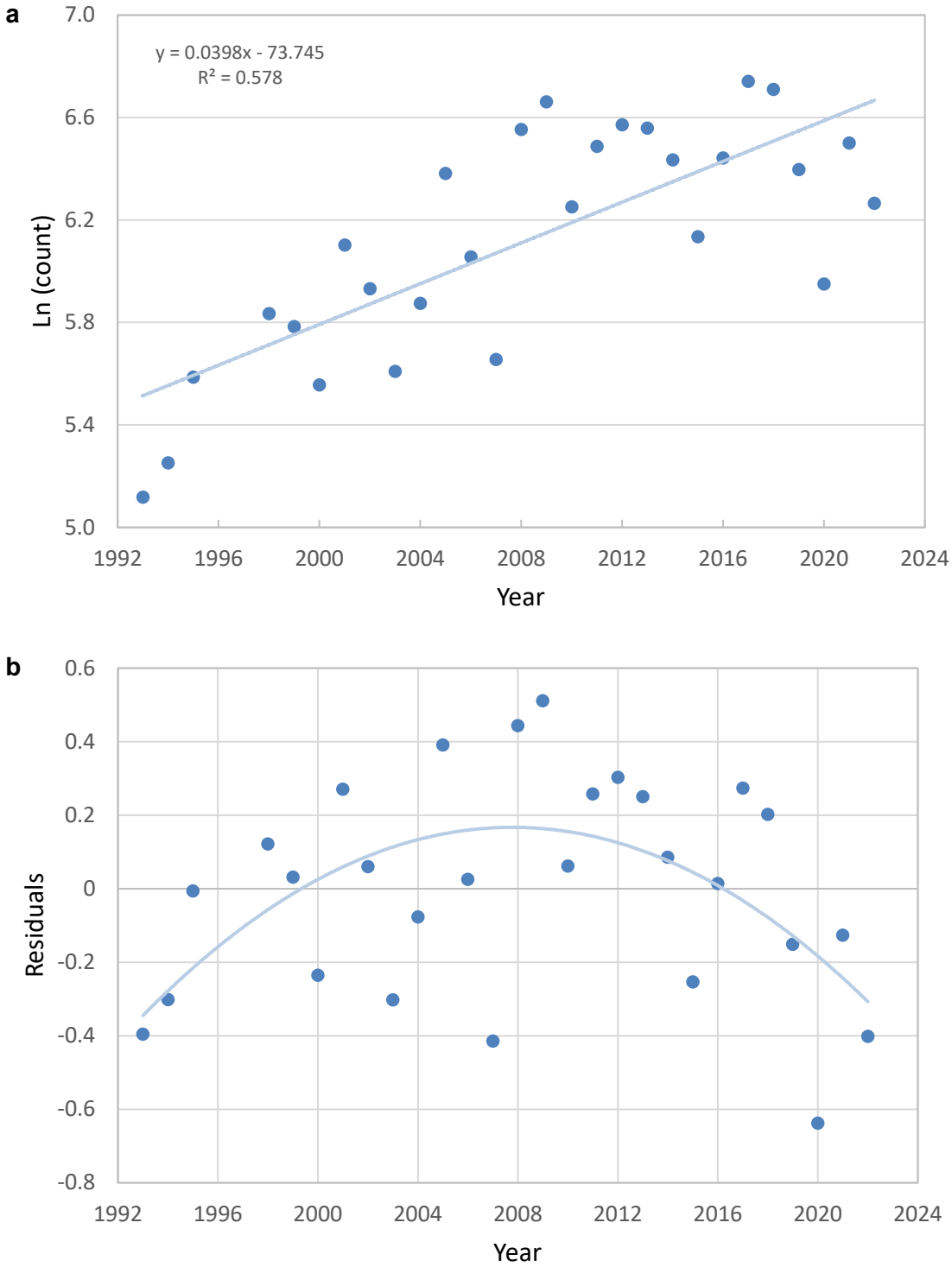
[1] direction of wind/wind speed (knots)
[2] all humpback whales; no other large whales recorded
[3] A = adult, C = calf, Y = 'yearling', T = total
* survey legs with maximum numbers of whales used for mapping and calculating trend (i.e. in Table 2)

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.

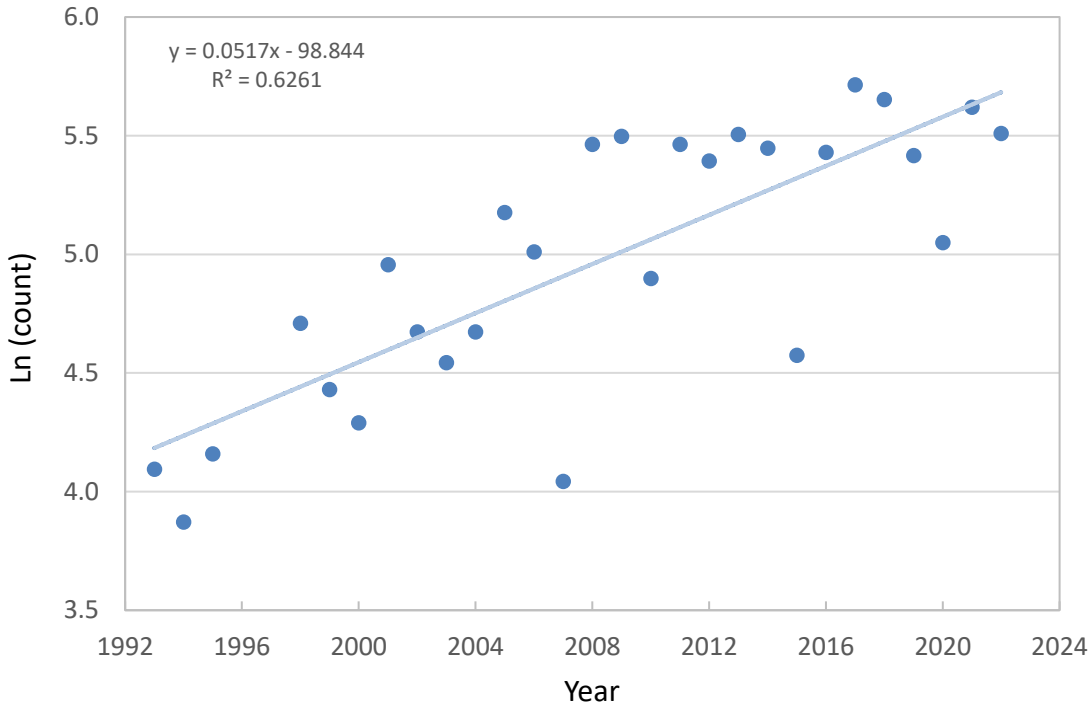
Year	All animals	Unaccompanied animals	Cow/calf pairs
1993	167	47	60
1994	191	95	48
1995	267	139	64
1996	233	123	55
1997	254	148	53
1998	342	120	111
1999	325	157	84
2000	259	113	73
2001	447	163	142
2002	377	163	107
2003	273	85	94
2004	356	142	107
2005	591	237	177
2006	427	127	150
2007	286	172	57
2008	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

Appendix C: Linear regression analyses of whale trend data

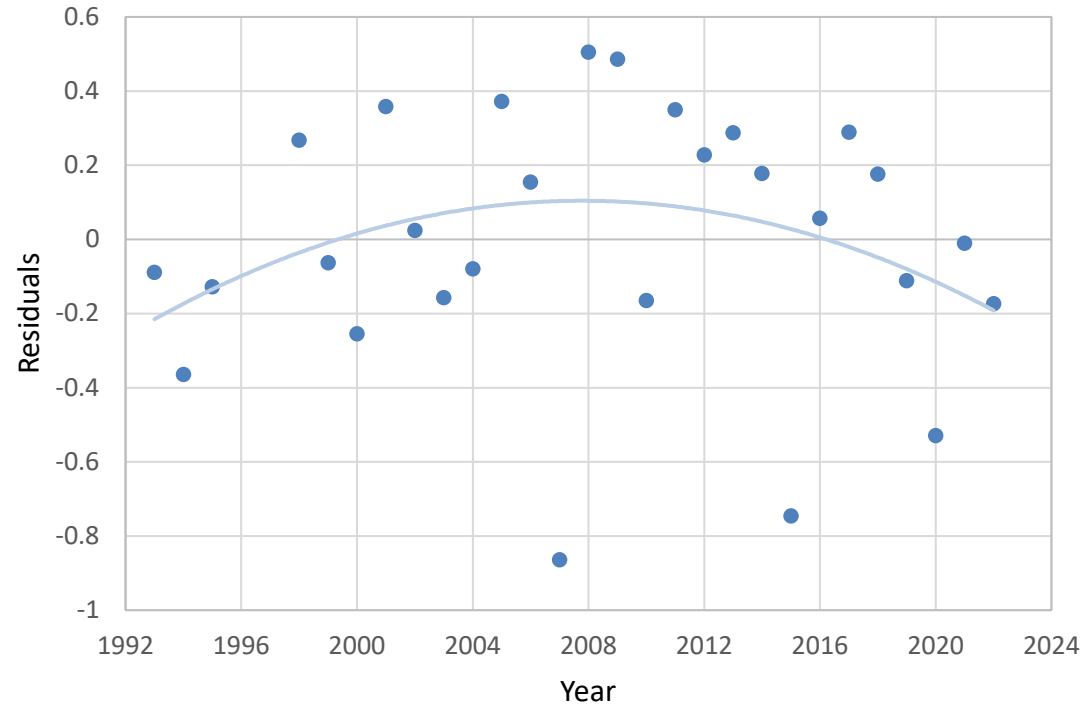


Appendix C1. Plots for *All animals* of the fitted (a) linear regression and (b) residuals for the maximum counts of whales in each leg of aerial surveys undertaken between 1993-2022 (excluding 1996/1997).

a

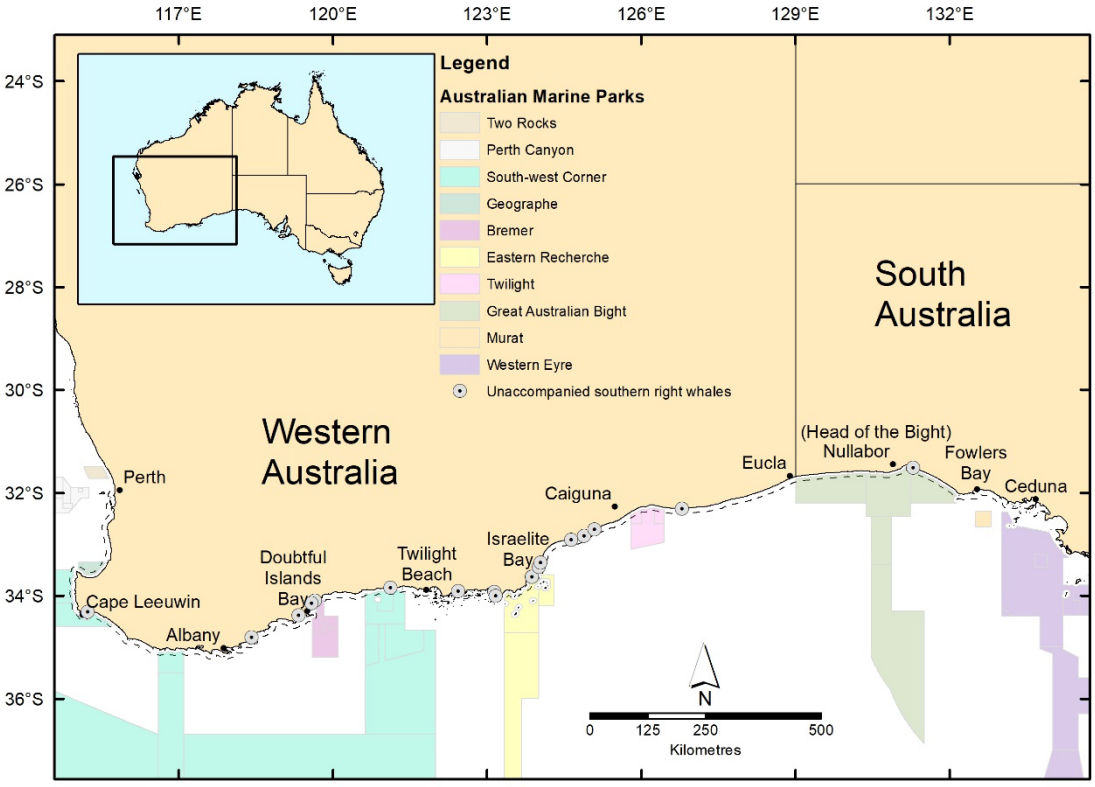


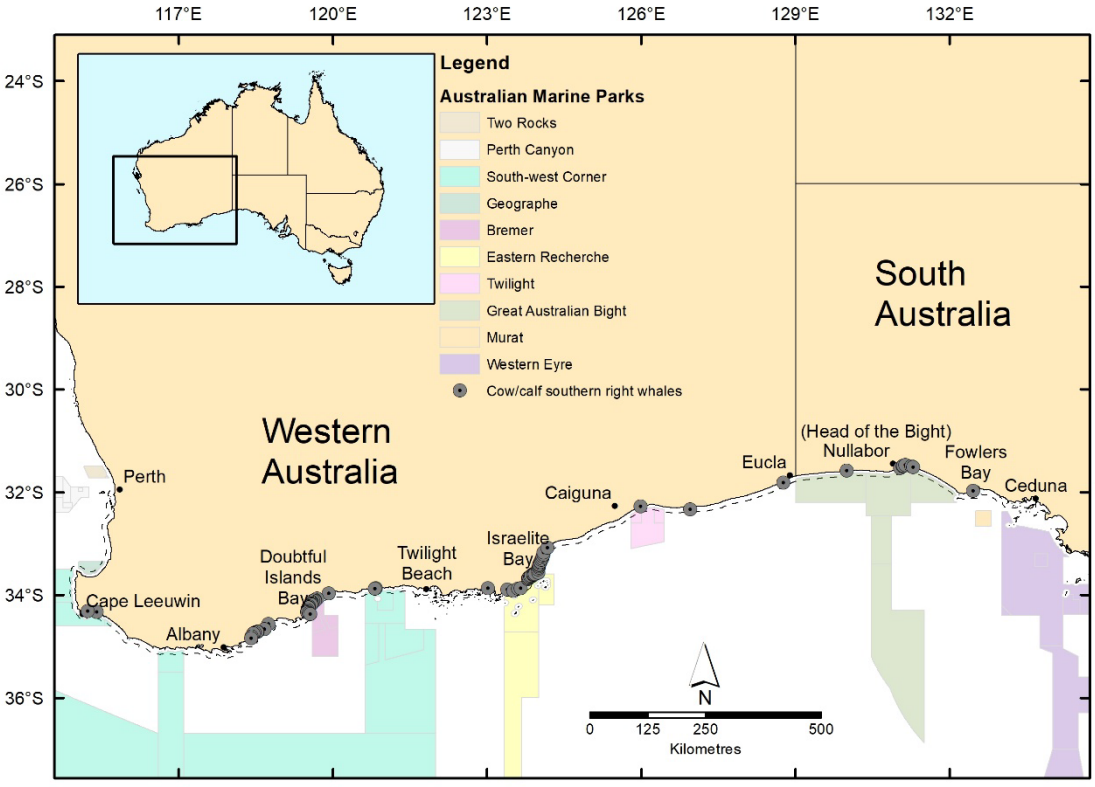
b



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





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