Marine Mammal Science

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Decadal Shifts in Southern Right Whale (*Eubalaena australis*) Recovery in South Australian Waters: Implications for Conservation and Management

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ABSTRACT

Southern right whales (*Eubalaena australis*) have shown population recovery since protection from commercial whaling and are considered a flagship species for successful conservation management. However, recovery remains incomplete, with recent evidence suggesting slowed growth and variability in reproductive success. This project used 30 years of count data in Australia (1992–2022) to investigate long-term trends in relative abundance at three key reproductive areas in South Australia. Varied rates of increase were observed, while recovery trends have moderated at the major aggregation area of Head of Bight (3.34%/year, 95% CI: 2.24, 4.44); higher growth rates were observed at Fowlers Bay, where recolonization has occurred (15.29%/year, 95% CI: 7.54, 24.33). Results support that recovery trends for the Australian population are dynamic and variable across decades. Drivers of variability may include saturation of certain areas, reoccupation of suitable habitats, spatio-temporal disturbance, and changes to factors driving migration, including body condition, prey availability, and climate change. Decadal shifts in relative abundance indicate an expanding habitat range, highlighting the importance of suitable habitat and connective migration corridors, which are increasingly important during critical life stages. Adaptive conservation management and effective threat mitigation are essential to secure recovery of this threatened species in Australia.

1 | Introduction

Southern right whales (SRWs) (*Eubalaena australis*) are recovering from near global extinction caused by commercial whaling in the 19th and 20th centuries. Despite gaining full protection under the International Convention for the Regulation of Whaling in 1935 (Dawbin 1986), sightings in their historic breeding grounds remained scarce until the 1970s (Tormosov et al. 1998). SRWs are a long-lived, slow-reproducing, migratory species with circumpolar distribution, migrating from higher latitude feeding grounds in the subantarctic to lower latitude winter breeding grounds along the southern coast of Southern Hemisphere continents for critical life functions including calving, nursing, mating, and resting (Bannister 2001; Dawbin 1986; Tormosov et al. 1998; Zerbini et al. 2016). Distribution records and genetic studies have identified genetically distinct populations in wintering grounds across Australia, New Zealand, South Africa, and South America (Argentina/Brazil and Chile/Peru) (Carroll et al. 2020; Patenaude et al. 2007; Rosenbaum et al. 2000). The global population growth rate for SRWs was

FIGURE 1 | Spatial distribution of southern right whales (*Eubalaena australis*) in Australian waters, showing Biologically Important Areas (migration and reproduction) within the Commonwealth Marine Area and State waters (DCCEEW 2023). The Western Australian Museum's aerial survey route is positioned further offshore to enhance its visibility in the figure.

estimated at 6% per annum (p.a.), which is close to the expected maximum biological rate for the species, with an estimated global abundance of 13,600 (International Whaling Commission [IWC] 2013).

In Australia SRWs are listed as Endangered (Environment Protection and Biodiversity Conservation Act 1999), and Vulnerable in South Australia (National Parks and Wildlife Act 1972). SRWs migrate to nearshore waters off southern Australia within their distributional range, which extends from Exmouth in Western Australia to Hervey Bay in Queensland. Biologically Important Areas (BIAs) for reproduction and migration have been identified within this range (Figure 1) (DCCEEW 2024). The reproduction BIA has been identified as habitat critical to the survival of the species because it supports known reproductive behavior (e.g., mating, calving, nursing), individual breeding females demonstrate consistent occupancy essential for long-term population maintenance, and these areas are critical for recovery.

Two populations of SRWs are described in Australia: the eastern and western populations (DSEWPaC 2012; Carroll et al. 2011, 2015), although the geographical boundary between populations remains unclear (DCCEEW 2024). The eastern population, with approximately 268 individuals, including 68 breeding females, showed no apparent increase in reproductive females between 1996 and 2017 (Stamation et al. 2020). By contrast, the western population, which had previously exhibited exponential growth at or near the species' suggested biological maximum of approximately 6% per annum, has shown signs of slowed recovery since 2017 (Grundlehner et al. 2025; IWC 2013). Recent analysis of aerial survey data from 1976 to 2024 indicate that the population size currently ranges between 2346 and 3940 individuals (16%–26% of pre-whaling levels), with declines in calf abundance since 2017—from a peak of 222 in 2016 to 200 in 2024 (Smith et al. 2024; Grundlehner et al. 2025). This plateau suggests that factors influencing SRW migration and reproductive success may now be affecting growth rates. Threats to SRWs include vessel strike, entanglement, noise disturbance, changes in prey abundance or distribution, and displacement due to habitat modification (DCCEEW 2024). The Australian SRW Recovery Plan aims to minimize threats, protect and enhance habitat, monitor species recovery, generate new knowledge to guide recovery, and increase public awareness of conservation needs.

SRWs form breeding cohorts (i.e., group of females that give birth in the same reproductive season), predominantly based on their typical 3-year calving interval (Charlton et al. 2022), where it is assumed that a calving year is followed by a rest year, and then a mating year (Cooke et al. 2001). Charlton et al. (2022) observed this pattern at HOB from 1992 to 2016, where triennial peaks in relative abundance were apparent, with the largest cohorts recorded in 2005, 2008, 2011, and 2014. However, there is some variability in this structure, as some females require an extra resting year or experience failed pregnancies, resulting in extended calving intervals and fluctuations in the cohort structure (Bannister et al. 2011; Charlton et al. 2022). Therefore, long-term monitoring on an annual basis is essential for detecting changes to population demography.

Long-term research is invaluable in assessing population dynamics and demography, including trends in relative abundance and distribution (Bannister 2001; Bannister et al. 2011; Burnell 2001; Charlton et al. 2019, 2022; Harcourt et al. 2019; IWC 2013; Smith et al. 2024). The western population of SRWs in Australia has been well studied with two long-term population monitoring programs spanning over four decades: annual aerial surveys between Perth (Western Australia) and Ceduna (South Australia), and cliff-based surveys at Head of Bight (HOB) (Figure 1) (Bannister 2001, 1990; Burnell 2001; Charlton et al. 2022; Smith et al. 2024). A 32-year continuous dataset at HOB has been used to assess relative abundance, distribution, life history parameters, residency, and site fidelity (Burnell 2001, 2008; Burnell and Bryden 1997; Charlton et al. 2019, 2022). HOB is recognized as a large reproductive area, supporting over 50 cow-calf pairs annually (DSEWPaC 2012). Reproductive females at HOB included between 21% and 48% of the western population during 1992–2016 (Charlton et al. 2022). During this period (1992–2016) trends in relative abundance at HOB showed a rate of increase of 3.2% p.a. (95% CI [1.9%–4.5%]) for all whale classes and 4.6% p.a. (95% CI [2.99%–6.3%]) for cow-calf pairs (Charlton et al. 2022). The largest breeding cohort occurred in 2016, with 81 cow-calf pairs recorded. Charlton et al. (2019) hypothesized that as the population increases, large reproductive areas such as HOB may reach saturation capacity, with density pressures driving shifts in habitat use and increasing abundance in other suitable habitats (Charlton 2017; Charlton et al. 2019, 2022).

Population growth has driven the expansion of SRW geographical ranges along the southern coast of Australia. Some historically important areas, which provided suitable reproductive habitat for SRWs, have been recolonized and show consistent use (Bannister et al. 2011; Carroll et al. 2014; Charlton et al. 2019; Kemper et al. 2022; Salgado Kent et al. 2022). Fowlers Bay (FB), located adjacent to HOB, is classified as a small reproductive area that typically supports up to 10 calves annually and was historically exploited by shore-based whaling (DSEWPaC 2012; Kemper and Samson 1999). Since the mid-2000s, an increase in SRWs in this area was observed (Bannister et al. 2011), with an estimated rate of increase of 29% p.a. for cow-calf pairs from 1993 to 2016 (Charlton et al. 2019). This estimated rate of increase exceeds the maximum rate of increase for the species, suggesting immigration from other reproductive areas. Encounter Bay (EB), located 700 km east of FB, is a small reproductive area also supporting up to 10 calves annually, with uncertainty regarding its classification as part of the eastern or western population (DCCEEW 2024; DSEWPaC 2012). High interannual variation has been observed, with an increase in cow-calf pairs in 2013, 2017, and 2018 (Kemper et al. 2022). These trends, along with site fidelity and long residency periods, suggest EB is an important reproductive area. Expansion of SRW habitat has also led to increased interactions with human activities, both within and outside marine parks and exclusion zones. Consequently, assessing trends in relative abundance and potential shifts in coastal habitat use is needed to better inform management decisions.

In this study we used sightings and count data of SRWs at three key reproductive areas in South Australia (HOB, FB, and EB), to assess: (1) the trends in their relative abundance; and (2) the relationship between the relative abundance at large and small reproductive areas. We tested the following hypotheses: (1) the rate of increase is moderating at the large reproductive area at HOB and increasing at smaller reproductive areas such as FB and EB; and (2) when the relative abundance of SRWs at HOB exceeds a density threshold based on spatial resources requirements and nearest neighbor estimates, increased relative abundance will occur at smaller reproductive areas (FB and EB). By assessing relative abundance trends at key reproductive areas (HOB, FB, and EB), this study tracks population recovery post-whaling and provides important context for overall population dynamics related to slowed growth rates or regional declines. Moreover, understanding site-specific trends allows managers to prioritize the protection of important calving and nursery areas and ensure conservation measures effectively address the species' habitat needs in Australia.

2 | Methodology

2.1 | Study Sites

This study compares trends in relative abundance of SRWs at three key reproductive areas: HOB, FB, and EB (Figure 2). Data from these areas were collected annually from 1992 to 2022 at HOB through daily land-based surveys conducted by the Great Australian Bight Right Whale Study and Curtin University, and from 2013 to 2022 at EB through systematic land-based surveys conducted by the Encounter Bay Right Whale Study and Flinders University. Data for FB were contributed by the Western Australian Museum (WAM)/Murdoch University, which provided aerial survey data for 1993 to 2022 (Table S1). Although survey methods varied, photo-identification (ID) and daily counts of SRWs were consistently collected within the reproductive areas during the peak abundance period (July–August) (Burnell 2001; Burnell and Bryden 1997; Charlton et al. 2019). At HOB, the peak abundance for all population classes was identified as July 15 to August 30, with cow-calf pairs peaking from August 15 to 30 (Burnell 2001; Burnell and Bryden 1997; Charlton et al. 2019).

HOB (31°29′ S, 131°08′ E) is located within the Far West Coast State Marine Park inside the Great Australian Bight (GAB) Commonwealth Marine Reserve, which provide sanctuary and protection for SRWs, with all vessels prohibited from

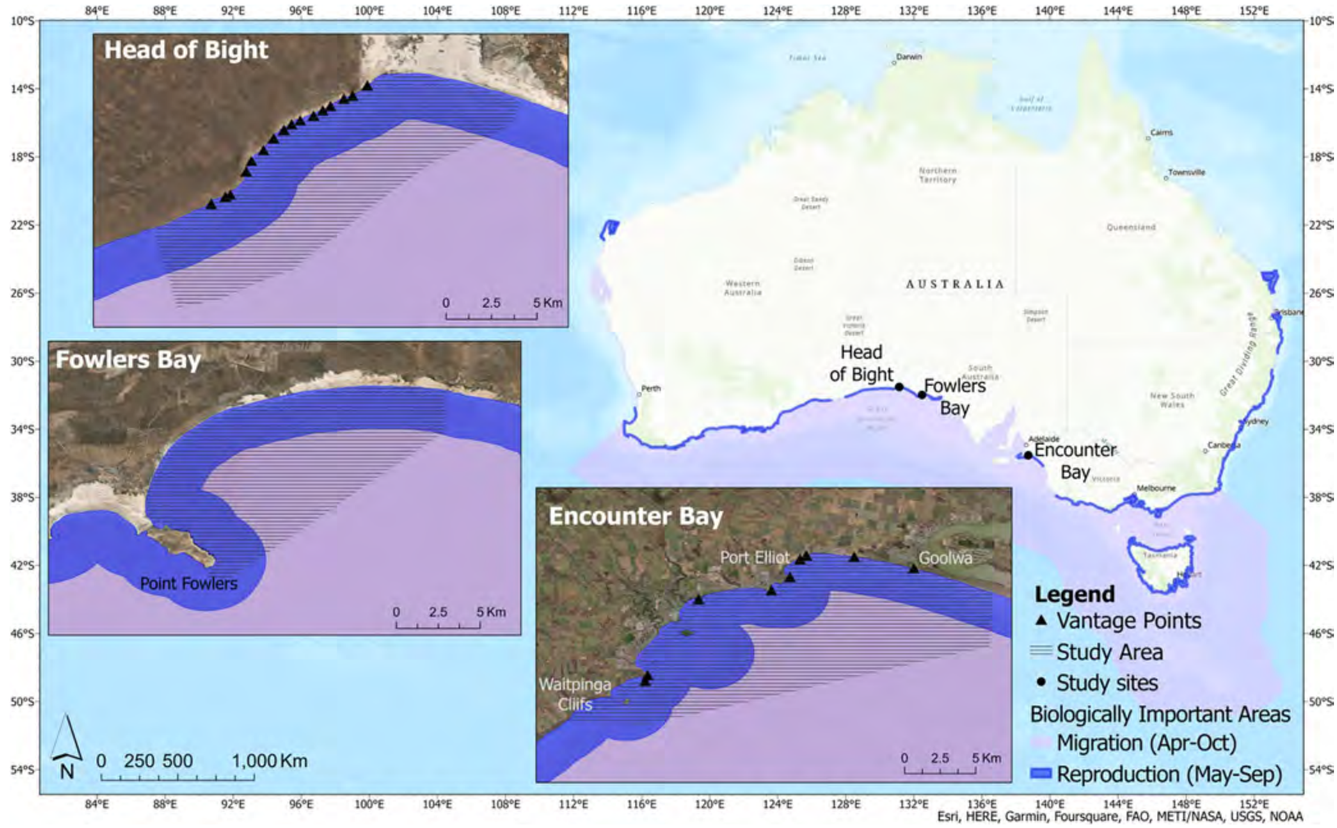

FIGURE 2 | Location of South Australian reproductive areas for southern right whales (*Eubalaena australis*) including Head of Bight, Fowlers Bay, and Encounter Bay. The map also shows overlapping migration and reproductive Biologically Important Areas (DCCEEW 2023).

entering the area from May 1 to October 29 in place since 1995 (Figure 2). Situated on Yalata Aboriginal land, HOB is characterized by 30–55 m high Bunda Cliffs to the west and a sandy bay to the east, with a sloping shelf reaching depths of 50 m within 2 km of the shoreline. FB (32°0′ S, 132°31′ E) is located approximately 170 km southeast of HOB, within the Far West Coast State Marine Park (Figure 2). Whales are typically distributed 1–6 km east of the FB jetty, within 1 km of the shore (Charlton et al. 2019). The habitat includes a protected sandy bay, with depths up to 20 m within 5 km of the shore. EB (35°56′ S, 138°63′ E) lies 700 km east of FB and is currently considered part of the eastern population (Figure 2). Located within the Encounter Marine Park, the study site spans 35 km from Waitpinga Cliffs to Goolwa Beach, with reefs, islands, and headlands in the west and a long sandy beach in the east (Figure 2). Protection measures at FB and EB are limited, with no formal vessel restrictions; however, South Australian regulations under the National Parks and Wildlife (Protected Animals—Marine Mammals) Regulations 2010 prohibit vessels from approaching closer than 100 m at FB and 300 m inside the Encounter Marine Park.

2.2 | Data Collection

2.2.1 | Aerial Surveys

Long-term monitoring of the western population has operated annually through aerial surveys, which began in 1976 (Bannister 2001, 1990, 2017; Smith et al. 2024). Surveys were extended in 1993 to include the current SRW distribution range of the western population, from Cape Leeuwin, Western Australia to Ceduna, South Australia (Figure 1). Conducted between mid-August and early September, the surveys record SRW sightings and photo-ID, detailed methodology can be found in Bannister (2017). Flights cover multiple "legs" along the coast, flown twice (outward and inward), with the maximum count from either flight used to estimate population trends. Both HOB and FB are within the SRW distributional range in the western population and included in the annual surveys. Count data from FB, collected through annual aerial surveys of the western population (1993–2022) were used in the analysis.

2.2.2 | Land-Based Surveys

Annual land-based surveys at HOB were conducted from 1992 to 2022 during the peak abundance period (August 15–30). Field methodology was replicated for consistency across years, as detailed in Charlton et al. (2019). SRW counts were conducted along 16 vantage points (VPs) along a 15 km stretch, with visual detection estimated up to 5 km from shore.

At EB, land-based surveys were conducted within the Encounter Marine Park (except Waitpinga Cliffs). Ad hoc SRW land-based monitoring programs have occurred since the 1990s (Kemper et al. 2022), with increased citizen scientists participation from May to November starting in 2013. Data collected prior to 2013 were not used because they were likely to be underestimations of relative abundance. Systematic surveys, using similar methodology to HOB, were conducted from 2019, except for 2020, in collaboration with Flinders and Curtin University researchers and citizen scientists (Gilmore 2022; Marsh 2020). Surveys included 10 VPs across a 30 km stretch of coastline between Waitpinga Cliffs and Goolwa Beach, with visual detection estimated up to 2 km from shore.

Surveys were conducted in Beaufort Sea State 3 or less, with minimal rain and fog, and weather conditions monitored throughout the survey. Two to four trained observers spent a minimum of 10 min at each VP scanning the area with Bushnell 10 × 50 binoculars. For each whale sighting, the recorded variables included: date, time (Australian Central Standard Time, UTC + 9.5 h), VP location, whale location (bearing, reticules/range), classification (either cow-calf pair, unaccompanied adult or unknown), number of whales in group, and behavior. Photo-ID was collected using various single-lens-reflex cameras and an Unmanned Aerial Vehicle (DJI Phantom 4 Pro V2.0 or Mavic Pro) (Charlton et al. 2019; Christiansen et al. 2018). Environmental data, including Beaufort Sea State, swell, cloud cover, wind speed, and direction, were recorded at the start and end of each survey.

While detection ranges varied and were not explicitly accounted for across sites, spatial distribution assessments in coastal reproductive areas indicated that 95% of whales were within 1 km of the shore (Charlton et al. 2019; Smith et al. 2024).

2.3 | Data Processing

Daily counts represent the number of individuals sighted within the reproductive area on a given day, providing a snapshot of relative abundance. However, because SRWs are highly mobile and their numbers fluctuate throughout the season, daily counts likely underestimate the actual number of individuals using these areas, as they do not account for immigration and emigration. To reduce detection bias, the maximum daily count (including cow-calf pairs and unaccompanied adults) for each year at each location was selected as the yearly relative abundance. Mean or median counts can be highly sensitive to variation in survey effort (e.g., weather conditions affect visibility, different numbers of surveys per year). Maximum counts, in contrast, reduce the influence of low-count days that might not accurately represent whale presence. Many long-term datasets on right whales (e.g., including the HOB) have used maximum counts, allowing for comparisons over time (Charlton et al. 2022, 2019; Kemper et al. 2022). Changing metrics could make trend comparisons more difficult or introduce artifacts. Photo-ID mark-recapture data show that individual counts often exceed the maximum daily count, particularly for unaccompanied adults, highlighting seasonal movement (Burnell 2001; Charlton et al. 2022). While whales may move between sites, the maximum count method ensures that all individuals using a given location are counted at some point, reducing the risk of underestimating the population.

Simultaneous counts between the WAM aerial survey and the cliff-based count team at HOB have been comparable. Cliff counts have consistently aligned with WAM aerial surveys and provide greater precision in establishing seasonal maximum daily counts as a long-term trend metric (Charlton 2017), validating that the visual range successfully encapsulates the primary breeding ground.

Daily counts were collated, and the maximum daily count for each population class and year was extracted. Population class was defined as cow-calf pair (breeding female with a calf of that year), unaccompanied adults (adult, sub-adult, or yearling), and all individuals including maximum counts of individuals (cow-calf pairs and unaccompanied adults) on a given day.

2.4 | Statistical Analyses

2.4.1 | Trends in Relative Abundance of SRWs in South Australian Reproductive Areas

Linear regressions of the annual maximum count data of SRWs (all individuals and cow-calf pairs) at HOB (1992–2022), FB (1993–2022), and EB (2013–2022) were used to assess long-term trends in the relative abundance across the three sites. The natural logarithm of count data were used, and data were presented as linear regression of the natural logarithm of maximum count data for all individuals and cow-calf pairs (Young 2017). All three sites were analyzed separately with year as the independent variable and count data as the dependent variable. Linear regressions of the natural logarithm were used to allow for comparisons with past analyses at HOB (1992–2016) and the western population 1993–2023 (Burnell 2008; Charlton et al. 2022; Smith et al. 2024). A polynomial regression analysis was also explored given the apparent non-linear changes and the hypothesis that HOB may have reached saturation capacity. Although a polynomial regression does not yield a single rate of increase across the entire period, it was useful for visually assessing the trends and understanding the changes.

For count data that did not meet the assumptions of a linear regression of the natural logarithm, generalized linear models (GLM) with Poisson or negative binomial distribution and log link function were used to determine the relationship between maximum number of whales (all individuals and cow-calf pairs) and year. A negative binomial model has successfully been applied in ecological studies and allows the variance to be greater than the mean (Hilbe 1994; Zuur et al. 2009), such as in Península Valdés to assess SRW rates of increase using count data (Crespo et al. 2019).

2.4.2 | Comparisons of Trends in Relative Abundance of SRWs Across Reproductive Areas

To measure the strength and direction of the relationship between trends in relative abundance of SRW cow-calf pairs and unaccompanied adults at HOB, FB, and EB, Pearson or Spearman correlation tests were performed and displayed as a correlation matrix. To test for density-driven shifts in relative abundance across reproductive areas, a two-sample means test was performed to assess whether relative abundance at small reproductive areas differed in years of high and low abundance at HOB.

TABLE 1 | Summary of the annual maximum number of all individuals, cow-calf pairs, and unaccompanied adults of southern right whales (*Eubalaena australis*) counted at Head of Bight (1992–2022), Fowlers Bay (1993–2022), and Encounter Bay (2013–2022), South Australia.

	All individuals			Cow-calf pairs			Unaccompanied adults		
	Head of Bight	Fowlers Bay	Encounter Bay	Head of Bight	Fowlers Bay	Encounter Bay	Head of Bight	Fowlers Bay	Encounter Bay
Number of years available	31	30	10	31	30	10	31	30	10
Minimum number of individuals	43	0	2	18	0	1	7	0	1
Maximum number of individuals	172	55	14	81	18	6	35	23	8
Mean	103.35	11.37	7.2	42.94	4.23	2.9	22.55	3	4.3
Median	98	4	6.5	42	2	2	23	0	4

Charlton et al. (2019) suggested that the primary HOB nursery area ($10.16 \times 1.04\,km^2$) may have reached saturation capacity with a minimum packing density of 55 cow-calf pairs or 110 total individuals based on nearest neighbor preferences of approximately 200 m between cow-calf pairs (Pirzl 2008). SRWs at HOB can tolerate neighbor preferences of 150 m, allowing for a maximum packing density of 68 cow-calf pairs or 136 total individuals (Charlton et al. 2019). The lower density threshold was used in this study as an indicator of a trigger point for shifts in proportion of the population using the site.

Therefore, the maximum daily count of cow-calf pairs at HOB from 1993 to 2022 was classified into two categories: low (< 55 cow-calf pairs) or high (≥ 55 cow-calf pairs). Corresponding years of cow-calf pairs and unaccompanied adults at FB and EB were also categorized, and a two-sample means test was conducted. Cohen's d standardized effect size was used for comparison (Pallant 2020), with an effect size of greater than 0.5 considered a large effect (Cohen 1988). Relative abundance values were plotted with HOB as the independent variable and smaller reproductive areas as the dependent variable for cow-calf pairs and unaccompanied adults separately. All statistical analyses of this study were conducted using R Studio 2023.03.1 (R Core Team 2022).

3 | Results

3.1 | Trends in Relative Abundance of SRWs in South Australian Reproductive Areas

Annual maximum counts varied across sites, with HOB consistently supporting the highest numbers of whales and EB showing the lowest in South Australia. At HOB, counts exhibited high inter-annual variation, ranging from 43 individuals in 1992 to a peak of 172 in 2016, with a similar pattern observed for cow-calf pairs (18 in 1992–81 in 2016) (Table 1; Figures 3 and 4). Unaccompanied adult counts peaked at 35 in 2011 but have remained low since 2019 (Table 1; Figures 3 and 4). The proportion of reproductive females at HOB compared to the total western population declined over time. From 1993 to 2022, HOB accounted for an average of 30.49% (SD = 7.31%) of the western population's reproductive females, peaking at 47.92% in 1994 and decreasing to 19.84% by 2022 (Figure 3).

At FB, sightings were sporadic before 2004, after which counts increased, peaking at 55 individuals in 2011. Cow-calf pairs reached a maximum of 18 in 2021, while unaccompanied adults peaked at 23 in 2011 (Table 1; Figures 3 and 4). From 1993 to 2022, FB accounted for a smaller proportion of the western population's reproductive females, averaging 2.09% (SD = 2.08%), with a maximum of 6.78% in 2021 (Figure 3). EB had the lowest counts, ranging from 2 individuals in 2014 to a maximum of 14 in 2013 (Table 1; Figures 3 and 4).

3.1.1 | Rates of Change in Maximum Counts of SRWs in South Australian Reproductive Areas

The annual maximum count of all individuals at HOB increased at an average annual rate of 3.34% per year during 1992–2022 (Table 2; Figure 5) and the annual maximum count of cow-calf pairs increased at an average annual rate of 3.93% (Table 2; Figure 5). Since 2016, a non-linear trend appears to be occurring for all individuals and cow-calf pairs (Figure 5). A polynomial regression using a cubic model yielded a smaller estimated error and a higher correlation for all individuals (SE = 0.23, $R^2 = 0.65$), and cow-calf pairs (SE = 0.28, $R^2 = 0.65$) (Figure 5). The regression model shows that the rate of change at HOB appears to be moderating.

Annual maximum counts of all individuals and cow-calf pairs increased significantly at FB. The annual rate of increase for all individuals was 15.29% p.a., and for cow-calf pairs was 14.4% p.a. from 1993 to 2022 (Table 2; Figure 6). Linear, Poisson, and polynomial regression were also explored for FB, but the models were a poor fit due to high variability.

High variability and small sample size from EB made it difficult to assess the rate of change using count data (2013–2022).

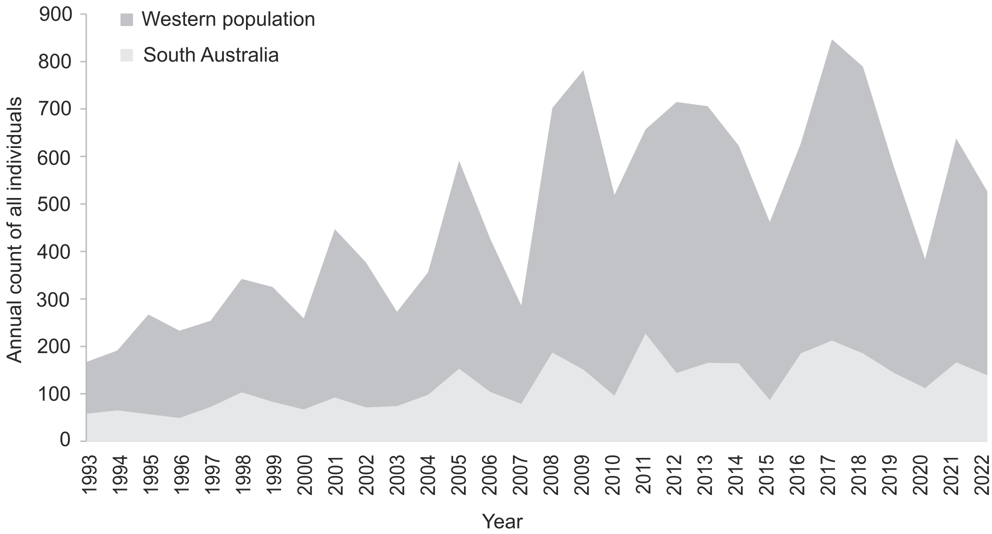

FIGURE 3 | Relative abundance of southern right whales (*Eubalaena australis*) in South Australian reproductive areas compared to the overall western population. Annual maximum number of all individuals counted from 1993 to 2022 in South Australian reproductive areas (Head of Bight, Fowlers Bay, and Encounter Bay) shown in light gray, stacked with the Western Australian Museum annual aerial survey count data in dark gray (Smith et al. 2024).

Linear, polynomial regression, and GLM models (negative binomial and Poisson) showed poor fits for count data, with no significant trends observed in the annual maximum counts of all individuals or cow-calf pairs (Table 2).

3.2 | Comparison of Trends in Relative Abundance Across Three Key SRW Reproductive Areas in South Australia

In years of high relative abundance at HOB (1993–2022), FB also showed increased relative abundance. Annual maximum counts of cow-calf pairs at HOB and FB were strongly positively correlated (Table 3). A significant positive correlation was also observed between cow-calf pairs at HOB and unaccompanied adults at FB. The correlation for unaccompanied adults at HOB and FB was slightly positive but not significant. No significant relationships were found for cow-calf pairs and unaccompanied adults across remaining sites ($p > 0.3$) (Table 3).

3.2.1 | Density-Driven Shifts in Relative Abundance Across Reproductive Areas

Variation in relative abundance trends was observed for different aggregation areas, with years of high relative abundance at HOB often corresponding with high relative abundance at FB (1993–2022). Cow-calf pair counts at FB were significantly higher in years of high relative abundance at HOB (Mann–Whitney U tests: $U = 182$, $z = 3.49$, $p < 0.001$, $r = 0.64$), with higher mean ranks yielded in high years ($\bar{X} = 8.64$, $n = 11$) compared to low years ($\bar{X} = 1.68$, $n = 19$). An increase in cow-calf pairs at FB was generally observed when HOB had 55 or more cow-calf pairs (Figure 7). Similarly, unaccompanied adult counts at FB were significantly higher in years of high relative abundance of cow-calf pairs at HOB ($U = 187$, $z = 3.86$, $p = 0.001$, $r = 0.7$), with higher mean ranks yielded in high years ($\bar{X} = 7.09$, $n = 11$) compared to low years ($\bar{X} = 0.63$, $n = 19$). A slight increase in unaccompanied adults at FB was observed when the number of cow-calf pairs sighted at HOB was 55 and above (Figure 7).

We found no significant variation in the relative abundance trends at EB compared with HOB. Cow-calf pair counts at EB appear not to differ between high ($\bar{X} = 3.17$, $n = 6$) and low ($\bar{X} = 2.5$, $n = 4$) relative abundance years at HOB ($t(8) = -0.58$, $p = 0.58$). Unaccompanied adults may be fewer in high abundance years at HOB ($\bar{X} = 3.33$, $n = 6$), but this difference was marginally non-significant compared to low years ($\bar{X} = 5.75$, $n = 4$) ($t(8) = 2.07$, $p = 0.07$).

4 | Discussion

Understanding trends in the abundance of endangered species is crucial to assess whether conservation strategies are supporting recovery and achieving management targets. This study investigated trends in the relative abundance of Australian SRWs at key reproductive aggregation areas in South Australia using count data from 1992 to 2022. As the population has increased, SRWs in the western population have expanded from what was a key reproductive area into nearby historically important habitat. Results suggest that the rate of increase at HOB began to slow around 2009 and has moderated since 2016, potentially due to density pressures, whereas the adjacent FB site has shown continued increase in relative abundance since the mid-2000s. Years of high relative abundance at HOB correspond with increased use at FB, suggesting a possible redistribution of whales driven by crowding or saturation in the larger site. Continued growth in small and emerging reproductive areas is expected, and management and legislation must support the reestablishment of whales across their coastal range in Australia. While this study focuses on local-scale relative abundance, these patterns are likely linked to broader, population-level processes—including reproductive output and environmental drivers—which

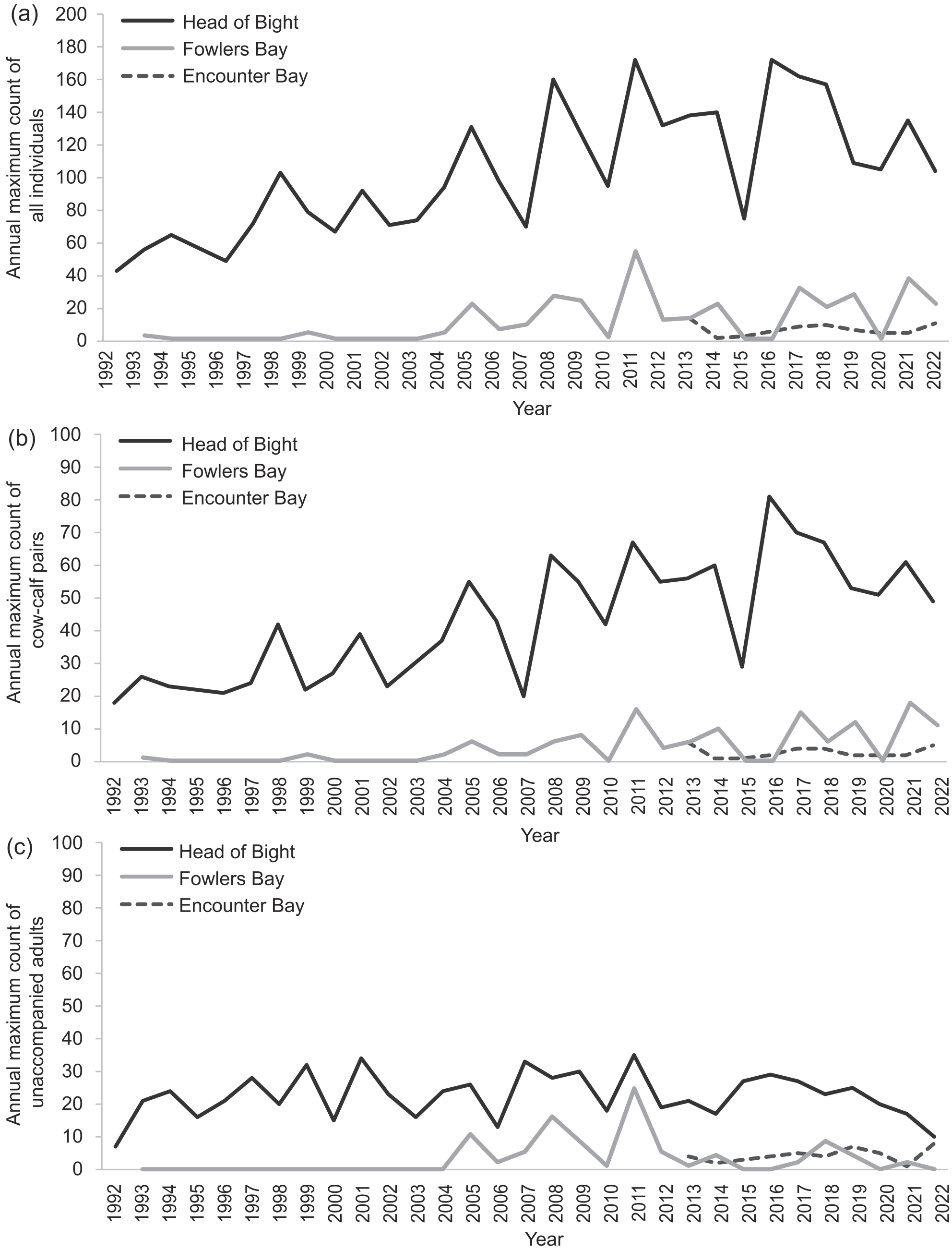

FIGURE 4 | Annual maximum number of southern right whales (*Eubalaena australis*) for (a) all individuals, (b) cow-calf pairs, and (c) unaccompanied adults counted during annual surveys (land and aerial) in South Australian reproductive areas at Head of Bight (1992–2022), Fowlers Bay (1993–2022), and Encounter Bay (2013–2022).

TABLE 2 | Summary of annual mean rate of increase (with 95% CI and *p*-value) for southern right whales (*Eubalaena australis*) using the model of best fit for all individuals (all) and cow-calf pairs (CC) at Head of Bight, Fowlers Bay, and Encounter Bay, South Australia.

Location	Years	Class	Model	Rate of increase %	95% CI	*p*
Head of Bight	1992–2022	All	Linear regression	3.34% p.a.	2.24%–4.44%	< 0.001
Head of Bight	1992–2022	CC	Linear regression	3.93% p.a.	2.69%–5.18%	< 0.001
Fowlers Bay	1993–2022	All	Negative Binomial	15.29% p.a.	7.54%–24.33%	< 0.001
Fowlers Bay	1993–2022	CC	Negative Binomial	14.4% p.a.	8.47%–21.33%	< 0.001
Encounter Bay	2013–2022	All	Poisson	0.68% p.a.	−11.31%–14.22%	0.87
Encounter Bay	2013–2022	CC	Poisson	0.6% p.a.	−7.13%–9.09%	0.92

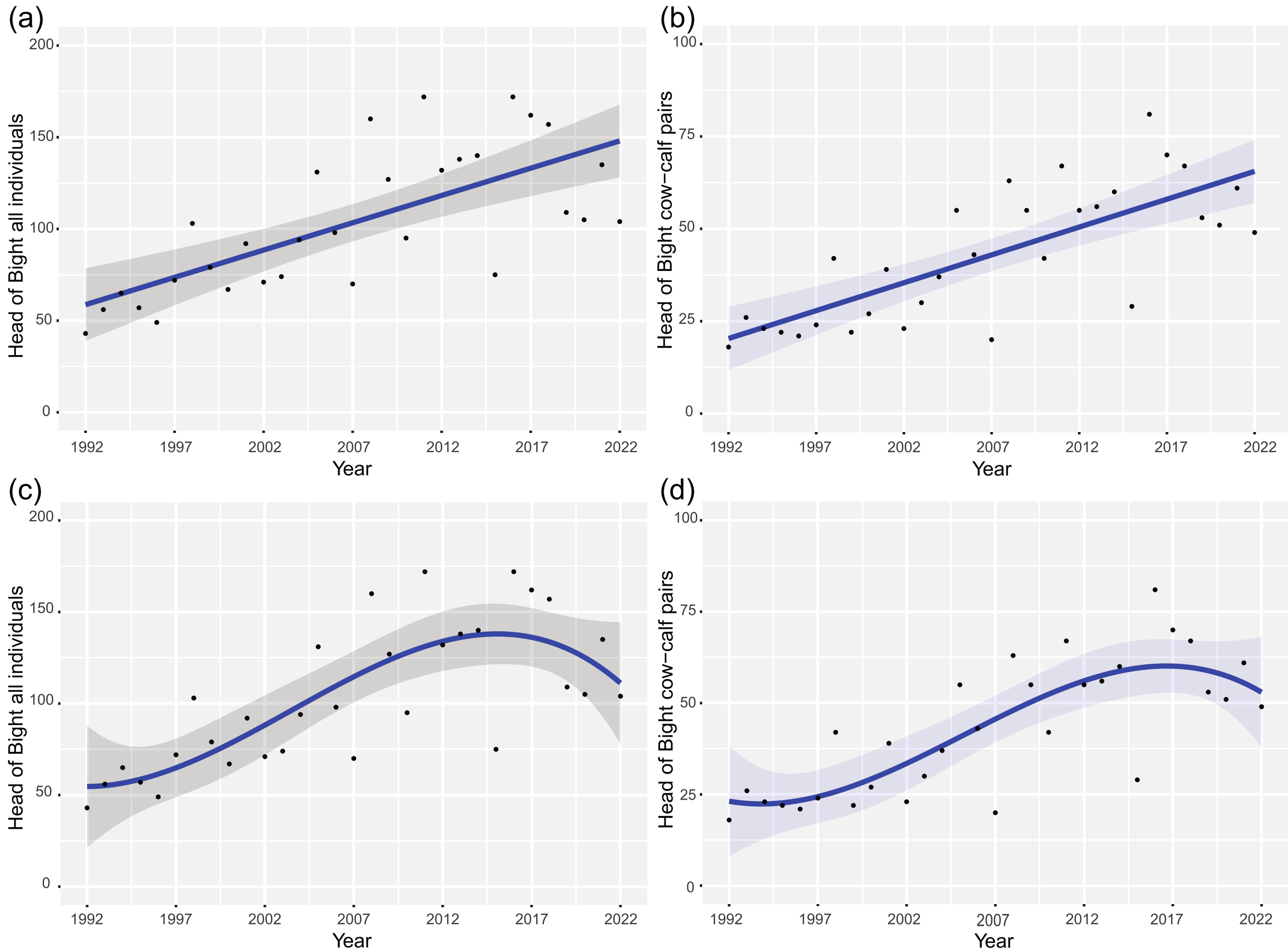

FIGURE 5 | Rate of change in the annual maximum number of southern right whales (*Eubalaena australis*) at Head of Bight, South Australia, from 1992 to 2022 using a linear regression model for (a) all individuals and (b) cow-calf pairs, and a cubic polynomial regression model for (c) all individuals, and (d) cow-calf pairs, fitted curves and 95% confidence intervals represented by the shaded areas.

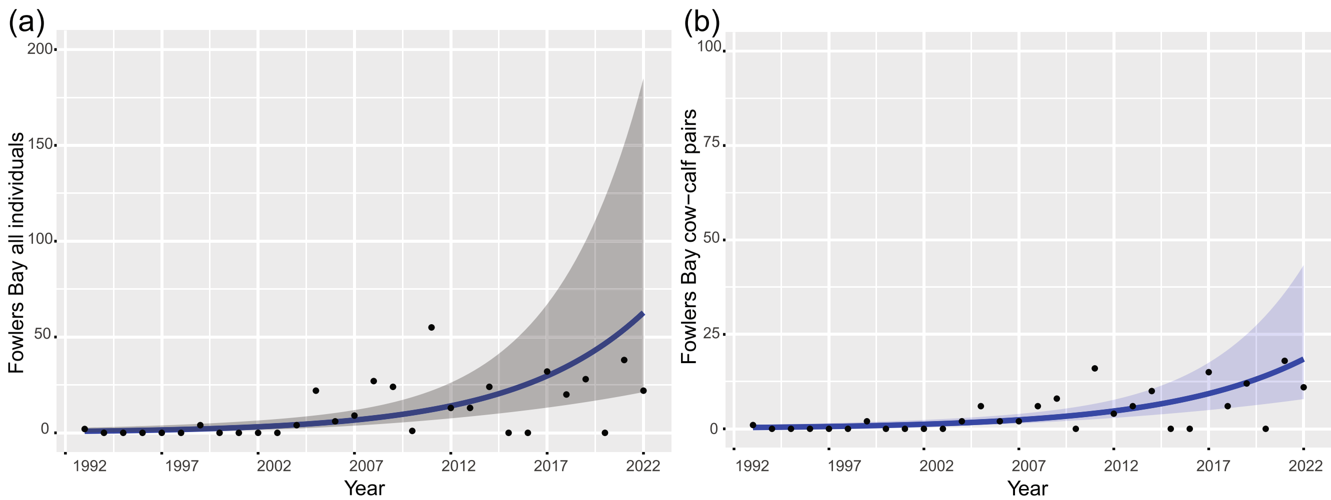

FIGURE 6 | Rate of change in the annual maximum number of southern right whales (*Eubalaena australis*) at Fowlers Bay, South Australia, from 1993 to 2022 for (a) all individuals and (b) cow-calf pairs fitted with negative binomial regression and 95% confidence intervals represented by the shaded areas.

have been highlighted in recent studies (e.g., Grundlehner et al. 2025; Germishuizen et al. 2024). These findings also align with the emerging view that variability in local site use and relative abundance may be early indicators of population-wide demographic changes, such as reduced calf production and increasing calving intervals.

Increased whale numbers have led to a plateau in relative abundance at HOB and a recolonization of other suitable habitats (Charlton et al. 2019, 2019; Table 2; Figures 5 and 6). A non-linear trend observed at HOB after 2016 suggests a moderating rate of increase when considering all population classes (Figure 5). The moderating rate of increase at HOB and subsequent increase at the adjacent FB site suggest density dependence may limit growth, supporting the hypothesis that HOB has reached saturation capacity. At FB, the rate of increase exceeded the population growth rate of 6% (IWC 2013), suggesting high immigration into the area. The 15.29% p.a. rate of increase from 1993 to 2022 is lower than the 29.0% p.a. estimated by Charlton et al. (2019) for 1993–2016. However, the previous model was not statistically significant, with a very wide 95% confidence interval (0–54.2) that included zero.

TABLE 3 | Correlation matric showing the relationship between trends in annual maximum counts of southern right whale (*Eubalaena australis*) cow-calf pairs (CC) and unaccompanied adults (UA) at Head of Bight, Fowlers Bay and Encounter Bay, South Australia.

Correlation	Head of Bight CC	Head of Bight UA	Fowlers Bay CC	Fowlers Bay UA
Fowlers Bay CC	0.63*	0.1		
Fowlers Bay UA	0.6*	0.24		
Encounter Bay CC	0.17	−0.27	0.19	−0.19
Encounter Bay UA	−0.11	−0.13	−0.02	0.01

Note: Darker green represents a stronger positive correlation, lighter green represents a weaker positive correlation, while dark red represents a stronger negative correlation, and light red represents a weaker negative correlation.
*Significant *p*-values.

In contrast, the updated model provides a more reliable estimate, with a better fit and narrower confidence interval.

Long-term trend data for the western population demonstrates pronounced inter-annual variation, particularly from 2011, and suggests SRWs are no longer recovering at previous historical growth rates (Smith et al. 2024; Grundlehner et al. 2025). Despite earlier periods of exponential growth, annual calf production has decreased since 2016, alongside a 66% reduction in unaccompanied individuals between 2012 and 2024 (Grundlehner et al. 2025). Increasing calving intervals and fluctuating recovery rates have been observed across Southern Hemisphere populations (Brandão et al. 2023; Charlton et al. 2022; Germishuizen et al. 2024; Grundlehner et al. 2025). Decreased prey availability, linked to increased sea surface temperatures in the sub-tropical convergence zone, may increase calving intervals in SRWs (Germishuizen et al. 2024; Leaper et al. 2006; Seyboth et al. 2016; Tulloch et al. 2019; van den Berg et al. 2021). These correlations may explain the pronounced inter-annual variation and slowing population growth. In Australia's western population, the previously consistent triennial calving peaks have weakened since 2011, with only a weak relationship remaining between calf abundance and prior reproductive cohorts (Grundlehner et al. 2025). This decoupling from expected demographic patterns highlights the vulnerability of SRWs to ongoing environmental change, and suggests that reproductive success may be increasingly shaped by broader climatic and ecological changes, in addition to local factors such as density and site availability.

The moderating rate of increase at HOB, combined with continued growth at FB and the correlation between sites, supports the hypothesis that once HOB exceeds a density threshold (approximately 110 individuals), whales may seek adjacent habitat. Density dependence has been shown to influence dispersal in several taxa (e.g., insects, birds) (Matthysen 2005; Rutherford et al. 2022). As SRW populations increase in Australia, shifts from large to smaller and emerging reproductive areas may be expected in high abundance years (Carroll et al. 2014; Charlton et al. 2019; Sueyro et al. 2018). High

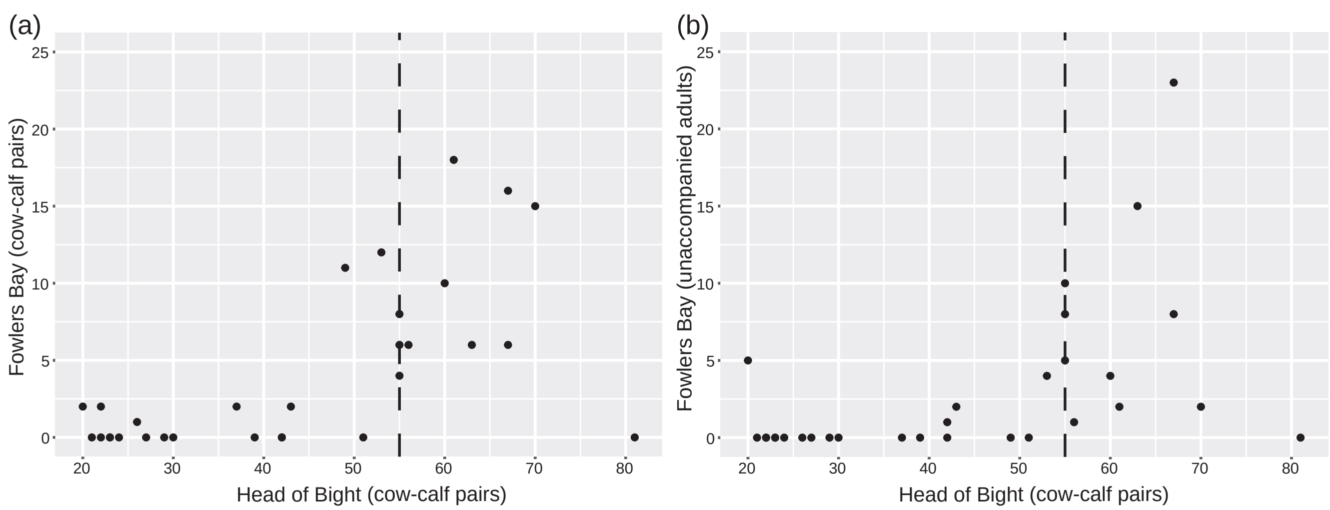

FIGURE 7 | Relationship between trends in annual maximum counts of southern right whales (*Eubalaena australis*) in South Australia, with cow-calf pairs at Head of Bight plotted against corresponding counts at Fowlers Bay for (a) cow-calf pairs and (b) unaccompanied adults between 1993 and 2022. The dashed line indicates the 55 cow-calf pairs mark at Head of Bight.

growth rates for SRWs have been observed in southern Brazil (Groch et al. 2005) and New Zealand (Carroll et al. 2014). Similar shifts in habitat preference have been observed in Argentina, where high-density nursery areas at Peninsula Valdés experienced a decelerated growth rate and shifts to nearby San Matiás Gulf (Arias et al. 2018; Crespo et al. 2019; Sueyro et al. 2018). The proposed mechanism behind observed shifts for SRWs is density-dependent changes promoting the search for alternative habitats (Sueyro et al. 2018).

A limitation of this study was the reliance on count data to assess trends in relative abundance and rate of increase, rather than mark-recapture using photo-ID. The number of individuals using reproductive areas exceeds those counted on a single day, as seen at HOB, where the number of individuals photo-ID'd was double the daily counts in some years (Charlton et al. 2019). This supports increased movement into and out of the study area in recent years, highlighting the importance of marine protected area planning and legislative protection across the coastal range. Future research should focus on reconciling the Australian Right Whale Photo Identification Catalogue (ARWPIC) and investigating mark-recapture models for population estimates, rate of increase, and connectivity patterns.

As the population increased, density dependence may have driven the establishment of new reproductive areas. Recent increases in relative abundance have been observed at other areas, including Geographe Bay, Western Australia (Salgado Kent et al. 2022), and Sleaford Bay, South Australia (Charlton pers. comms. 2023). Sleaford Bay, located ~450 km east of FB, is classified as a migratory BIA but is also consistently used by SRWs for calving, nursing, and resting. While the population remains less than 20% of pre-whaling abundance (IWC 2013), appropriate management could support growth and recolonizations of historically important coastal habitat. Conservation management must recognize the significance of connecting habitats in addition to areas utilized for regular and repeated reproduction.

Over the last four decades, SRWs have shown a slow return to EB (Gilmore 2022; Kemper et al. 2022). No significant trends in relative abundance were observed from 2013 to 2022, likely due to the small sample size (low whale numbers and shorter sampling period) and high interannual variability. Detecting trends in count data requires decades of monitoring due to their long calving interval, unless the effect size is large, such as a sudden influx of many whales in the area. Slow recovery may also be explained by local extirpation leading to loss of cultural migratory memory, delaying recolonization (Carroll et al. 2015). The high ratio of unaccompanied adults at EB compared with HOB (Table 1; Figure 4) suggests that smaller reproductive areas may serve as migratory pathways or exploratory sites for immature whales engaging in mating and social behaviors. Whilst it is a known historically important area, EB was considered a migratory corridor for SRWs between summer feeding grounds and winter calving grounds (Carroll et al. 2015). It has only recently been recognized as a significant reproductive area for calving females with the seasonal presence of neonates (DCCEEW 2024; Kemper et al. 2022).

A strong positive correlation was found between the relative abundance at HOB and FB, while no correlation was detected for EB, likely due to the smaller dataset and greater geographic distance. EB may mirror trends observed in the eastern population. Logans Beach, Victoria, is approximately 500 km east of EB and is the primary reproductive area in the eastern population, yet has shown no significant increase in cow-calf pairs over three decades (Stamation et al. 2020). There is uncertainty regarding the delineation between the eastern and western populations. Previously, the boundary of the two populations was set at the South Australian and Victorian border, with EB included in the western population (DSEWPaC 2012). The new SRW Recovery Plan shifted the management unit boundary to Ceduna, South Australia, aligning with the eastern survey boundary of the WAM aerial survey (DCCEEW 2024). This change highlights the need to clarify the boundary between these two populations and further research into connectivity through mDNA and photo-ID studies. Preliminary ARWPIC photo-ID cross matching suggests greater connectivity displayed by whales in EB with the western (78%) than eastern population (22%) (Gilmore 2022), but further comprehensive analysis is needed. Given the ecological significance and ongoing recolonization at EB, systematic land-based surveys are needed for effective long-term monitoring. Mark-recapture population modeling could provide a more robust assessment of relative abundance and enable comparisons with other reproductive areas in the eastern population.

4.1 | Implications for Management

Increased protection for whales across the Australian Marine Park Network is recommended. Our study suggests density in high-abundance areas (e.g., HOB) may influence dispersal, highlighting the need for additional habitat protection as whales expand into smaller reproductive areas. Reproductive areas are critical to population growth, yet protection levels vary across Commonwealth and State Marine Park Networks. SRWs favor shallow, sheltered bays (Charlton et al. 2019; Elwen and Best 2004; Pirzl 2008), where they spend extended periods at the surface, increasing vulnerability to human activities. These reproductive areas overlap with recreational and commercial water users, exposing SRWs to threats such as entanglement, habitat disruption, vessel strike, noise disturbance, and coastal development (DCCEEW 2024).

Although the threats faced by Australian SRWs differ in scale and frequency from those impacting North Atlantic right whales (NARWs, *Eubalaena glacialis*), the dire situation for NARWs—where human-caused mortality has significantly constrained recovery (Corkeron et al. 2018)—provides a cautionary example of what may occur without effective mitigation. Reported rates of vessel strikes and entanglements are comparatively lower for SRWs in Australian waters than for NARWs (Kemper et al. 2008; Tulloch et al. 2020), although hidden mortality from ship strike is a possibility (Harcourt et al. 2024–2025). Nevertheless, it is inevitable that Australian SRWs will increasingly encounter interactions with various human activities in the future. Increasing protection through marine park sanctuary zones, vessel speed restrictions, exclusion zones, and spatio-temporal closures for fishery and human activities is recommended, particularly in FB and EB, where our study suggests increasing importance for recovery.

EB Marine Park lacks adequate protection. EB is a small but important reproductive area, consistently used by calving females and serving as an important migratory corridor, as indicated by the higher proportion of unaccompanied adults (Figure 4). Although a Sanctuary Zone exists within the Encounter Marine Park, activities such as boating, jet skiing, and tourism remain permitted, potentially disturbing whales during critical life stages. Furthermore, the sanctuary zone does not fully encompass the whale nursery area identified in Kemper et al. (2022). To address these gaps and support both protection and population growth, implementing vessel exclusion zones from Port Elliot to Goolwa during calving season (May–September), similar to protections at HOB, is recommended.

Like EB, the newly announced South Coast Marine Park presents similar gaps (DBCA 2024). The whale sanctuaries do not adequately safeguard migrating and calving SRWs in reproductive BIAs between Esperance and Israelite Bay, Western Australia. In contrast, HOB's Marine Mammal Protection Zone (established in 1995) demonstrates the benefits of vessel exclusion zones, with whale numbers increasing to the point where the area may have reached saturation capacity. Key threats identified in the Australian SRW Recovery Plan—such as entanglement, habitat disruption, vessel strikes, noise disturbance, and coastal development—remain unaddressed in some sanctuary zones. In EB, private and commercial vessels, including whale watching, overlap with representative core areas and home ranges of SRWs (Gilmore 2022). As whale numbers and human activity continue to rise, stricter management of marine-based industries—including oil, gas, and renewables—is crucial as title areas overlap with SRW BIAs. A comprehensive strategy is needed to mitigate human impacts while ensuring sustainable development and the recovery of threatened species.

4.2 | Conclusion

This study highlights the increasing utilization of coastal habitat by SRWs in South Australia and the need for an adaptive management approach for enhanced protection of the species in Australia. This study focuses on the trends in relative abundance of SRWs in coastal reproductive areas off South Australia as an example of an expanding component of the western population of Australia. As the population has grown, increased movement and habitat utilization along the southern coastline were observed. This emphasizes the importance of monitoring and managing these areas to minimize human impacts, and to support the re-establishment of whales in coastal areas. The study informs state and national conservation efforts, offering recommendations for increased protection and future national research priorities.

Author Contributions

Bridgette O'Shannessy: data curation, formal analysis, investigation, project administration, visualization, writing – original draft. **Luciana Möller:** conceptualization, supervision, writing – review and editing. **Robert D. McCauley:** conceptualization, data curation, methodology, writing – review and editing. **Guido J. Parra:** conceptualization, supervision, writing – review and editing. **Joshua N. Smith:** data curation, resources, writing – review and editing. **Stephen Burnell:** conceptualization, data curation, methodology, writing – review and editing. **Claire M. Charlton:** conceptualization, data curation, funding acquisition, methodology, resources, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.