FINAL REPORT

Project 3.15

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Subcomponent 1:
Aerial survey of the Australian southern right whale (*Eubalaena australis*) 'western' population and development of AI for photo-identification

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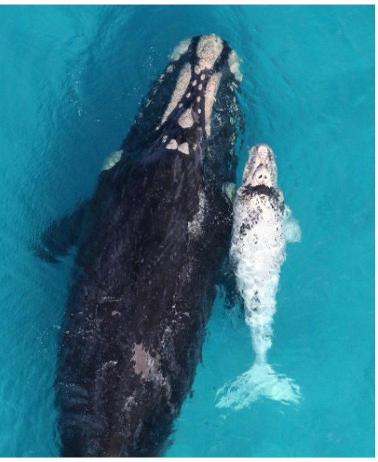

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We greatly acknowledge the late John Bannister and his initiation, leadership and long-term dedication to the aerial surveys of southern right whales in Australia. John established the aerial survey program in 1976 to which this project contributes to and maintains this long-term dataset. We greatly acknowledge Jenny Schmidt (Royal Aero Club of WA) as pilot and Andrew Halsall as photographer for their skills and their many years of dedication to this project. We also greatly acknowledge the collaboration and contributions by Claire Charlton/Steve Burnell of the Head of Bight photo-identification catalogue to help train the AI photo-id models. The aerial survey 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 U26871-6 Scientific Research) and ethical approval from Murdoch University (permit no. O3542/24).

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Figure 1. Clifftop boardwalk on the limestone Bunda Cliffs at Head of Bight, South Australia

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Executive summary

Southern right whales (*Eubalaena australis*) were a target of intense commercial whaling during the 19th and 20th century, resulting in overexploitation and near extirpation of the species throughout much of its range. In Australia, they were considered rare to virtually extinct between 1870 to 1960, with initial signs of recovery from the mid 1970's in south-west Australia. Aerial surveys of southern right whales have been undertaken annually off the south-west Australian coast since 1976 to monitor recovery, resulting in a long-term dataset spanning 49 years. The aerial surveys involve undertaking population counts and collection of photo-identification (photo-id) data to provide relative abundance estimates and inform population demographic trends and reproductive parameters for the 'western' population. While the western population has demonstrated exponential growth rate following early recovery since the 1970s, the overall rate of population increase has declined since 2011, and population abundance has stalled on the southern Australian coast.

To continue to monitor the recovery of this endangered species and inform the long-term population trend (over 49 years), an aerial survey was undertaken between 21-28 August 2024 in coastal waters from Perth (Western Australia) to Ceduna (South Australia). The survey reported a total 576 whales sighted, consisting of 229 cow-calf pairs and 108 unaccompanied adults. The 'western' population of southern right whales in Australian waters shows a slowing in the rate of increase in population size (N = 2,242 whales) across the entire time-series (1993-2024), and since 2011 a non-significant trend in abundance for both unaccompanied animals ($p = 0.18$) and female/calf pairs ($p = 0.60$) and a decline in female-calf abundance (-1.31%) indicating a decline in female-calf abundance. There continues to be highly fluctuating annual variation in abundance for both unaccompanied animals and female-calf pairs over the past decade, with persistent low numbers of unaccompanied animals.

The photo-id data continues to inform demographic parameters for the western population, although manually processing photo-id images is a major impediment to providing up to date population demographic data. Artificial intelligence (AI) tools have successfully been developed in 2023/24 in this project to automate image workflows to process the photo-identification data and improve image processing/matching capabilities. Further development of the AI in 2025 will build on the success of the tools developed, through a more comprehensive training dataset and new AI matching interface to enable visualisation of potential matches.

The results from this survey suggest the western population of southern right whales is no longer recovering at previous growth rates (since 1976), with current abundance well below (~20%) pre-whaling abundance. 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 in southern right whales in this population and other populations across the Southern Hemisphere. It is critical the southern right whale is afforded high levels of protection in biologically important areas (e.g. reproduction BIA) and annual surveys are continued to assess the status of the species through long-term population trend data to inform federal and state conservation management actions and regulatory assessments of marine-based activities (e.g. offshore wind, seismic surveys).

1. Introduction

Southern right whales (*Eubalaena australis*) were hunted almost to extinction during the 19th and 20th centuries from commercial whaling throughout the Southern Hemisphere, resulting in an estimated 300-400 whales remaining by 1920 (IWC, 2001; Jackson et al., 2008). In Australia, southern right whales were considered rare to virtually extinct between 1870 to 1960, with few reported sightings for almost 100 years until 1955 (Chittleborough, 1956; Smith et al., 2025). Since the mid-1970s, there have been signs of recovery for part of the population that migrates to the Australian coast each year, particularly for waters off Western Australia (WA) and western South Australia (SA) known as the ‘western population’. Since 1976, aerial surveys have been undertaken annually along the south-west coast of Australia to determine trends in population abundance, life history information, and obtain individual identification photographs of whales aggregating close inshore in calving areas.

Aerial surveys were initially (from 1976) undertaken along the WA south-west coast from Cape Leeuwin east to Twilight Cove and then extended from 1993 into SA waters to Ceduna, given evidence of intra- and inter-season coastal movement and whale presence in key aggregation areas in SA. 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 (Carroll et al., 2015). Given the slow recovery of the ‘eastern’ population and relative paucity of animals that visit the south-eastern Australian coast, 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. In addition to the long-term aerial survey dataset, annual cliff-based surveys have been conducted since 1991 at a key aggregation site at Head of Bight (SA) to monitor the species abundance and demographics (Figure 1; Charlton et al., 2022).

The annual aerial surveys involve population counts and photo-identification (photo-id) data (Figure 2) to provide relative abundance estimates, population demographic trends, and reproductive parameters of SRWs from the ‘western’ population. The series of surveys from 1993 were designed to provide statistically robust 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. While early stages of the species recovery exhibited exponential growth rates (e.g. 1976-2014; Bannister et al., 2016), recent trends since 2016 have indicated a slowing in population growth rates and even a decline in annual birth rates (Bannister et al., 2016; Grundlehner et al., 2025; Smith et al., 2024).

The annual aerial surveys represent a long-term monitoring strategy to enable efficient monitoring of population trend and abundance and address studies of linkages between population dynamics and environmental changes in the whales’ feeding grounds (Bannister et al., 2011) to directly inform federal and state government conservation planning and decision making and the species national Recovery Plan. Southern right whales are currently listed as ‘Endangered’ and ‘Migratory’ under the Australian *Environmental Protection and*

Biodiversity and Conservation Act 1999 (EPBC Act), both Matters of National Environmental Significance. This critical long-term monitoring aerial survey program addresses a *Very High* priority action (B1.2) in the National Recovery Plan for the Southern Right Whale (*Eubalaena australis*) (DCCEEW, 2024) to '*maintain long-term annual monitoring programs of the western population across its range that are capable of measuring and evaluating population recovery, including continuance of aerial surveys and photo-identification*'.

The associated photo-id data is an important tool for monitoring population trends over time and provides population demographic data (e.g. calving intervals) and connectivity between the 'western' and 'eastern' populations. The annual aerial surveys contribute photo-id to the national southern right whale photo-id database; the Australasian Right Whale Photo-Identification Catalogue (ARWPIC). However, processing photo-id data currently requires manual review and matching of individuals which requires significant investments of time to compare with the large and increasing national catalogue of photo-id images. This ultimately creates inefficiencies to providing timely information to inform conservation management of the species. Recent advances in the application of deep learning algorithms and fully automated image workflows to North Atlantic right whales (Bogucki et al., 2019) demonstrate the feasibility of using AI for processing southern right whale photo-id data. This project will apply, and further refine, an open-source AI algorithm for automating photo-identification data to the national catalogue, including tools that can interface with ARWPIC to integrate images and automatically extracted image metadata into the ARWPIC database. This will increase efficiency in processing southern right whale photo-identification images, improve accessibility to population parameter data (e.g. calving rates) in a timely manner and be accessible to the range of data contributors including citizen scientists.

Figure 2. Group of unaccompanied southern right whales off the southern coast of Australia during 2024 aerial survey.

2. Methods

2.1 Aerial survey count and whale photo-identification

Aerial surveys of southern right whales were undertaken following established survey protocols from previous aerial surveys since 1993 (Bannister, 2001; Smith et al., 2024), using a high wing, single engine aircraft (Cessna 172RG). The survey team comprises 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 (WA) and Ceduna (SA) (Figure 3) in August at the expected period of peak whale abundance, and particularly for cow/calf pairs. Flights are conducted on days when average 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; photo-id) of the whales at 500 feet.

Figure 3. Approximate survey area for southern right whales off the southern coast of Australia (within *ca* one nautical mile) in 2024 between Perth (Western Australia) and Ceduna (South Australia). The dashed line represents the offshore survey area boundary, although is illustrative only and not to scale.

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 (photo-id) 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 photo-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 WA east to Ceduna in SA (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.

2.2 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 was 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 that could result in a possible under-estimation of whales (Bannister 1998, 2002).

2.3 Development of AI tools for processing photo-id data

Matching photo-id images of southern right whales in Australian waters occurs within the online platform of ARWPIC (https://data.marinemammals.gov.au/arwpic), which was developed to facilitate collaboration and the sharing of images and sightings of southern right whales in Australia. It is supported, maintained and hosted by the Whale Research Team and the Australian Antarctic Data Centre of the Australian Antarctic Division, DCCEEW. Currently, matching individual whale photo-ids is undertaken using a code-based categorical matching framework (i.e. BigFish CodeCompare), which requires significant time investment to code, and curate, and compare images with the large, and increasing, national catalogue of photo-id images.

Existing open source Artificial Intelligence image recognition algorithms have been applied to North Atlantic right whales (Bogucki et al., 2019), and integrated into the automatic matching software interface Flukebook (Blount et al., 2022). This approach has had substantial success in quickly and accurately (87% top 1 accuracy) matching North Atlantic right whales using a series of convolutional neural networks (Bogucki et al.,2019). This current project will further refine an existing open-source AI algorithm (e.g. Piev2) for automating the processing of southern right whale photo-id data in Australian waters, including tools that can interface with ARWPIC to integrate images and automatically extract image metadata into the ARWPIC database.

There were two main components to the development of the AI to southern right whale photo-id data, consisting of 1) AI server infrastructure setup and 2) AI model algorithm(s) refinement and deployment, including a bulk image upload function.

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 ten days in total and six flying days, between the 21-30 August 2024 over a combined 35.9 survey hours. During the entire survey there were a total 1,151 southern right whales recorded including 453 calves, although this count inevitably incorporates double counts of individual whales given the survey area is surveyed twice (due to outward and inward flights) (Appendix A). There were an additional twelve groups of humpback whales totalling 21 individuals, including three female-calf pairs between Esperance and Perth (Appendix A).

The maximum whale counts from each leg (either 'outwards' or 'inwards') between Cape Leeuwin and Ceduna were used to determine population size and trend for the 'western' population, which totalled 576 southern right whales comprising 229 female-calf pairs and 108 unaccompanied whales including one yearling (Appendix A).

3.2 Distribution

Sightings of southern right whales during the 2024 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 4):

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

Female-calf pairs showed a more concentrated pattern in distribution compared to unaccompanied animals, with clumped distributions in three main areas; 1) Doubtful Island Bay, 2) Israelite Bay and 3) Head of Bight (Figure 4b). Unaccompanied whales consist of adults (males and females) in which a calf is not present and have a broader distribution, particularly from Albany to Doubtful Island Bay and Esperance to Caiguna (Figure 4a). From 7791 images obtained on the 2024 flight, preliminary analysis is being undertaken to select individual photo-ids to conduct computer-assisted 'matching' with those images already available in the ARWPIC catalogue.

3.3 Trends in population abundance

3.3.1 Population count

Overall, the total number of southern right whales in the western population sighted during the 2024 aerial survey (N = 576) was comparable to recent years (since 2007), with the exception of notable years of substantially lower counts in the time series (Figure 5a, Appendix B). This demonstrates a lack of increase in population counts over that time, although increased inter-annual variation is evident in the numbers of whales sighted over that period (Figure 5a). Furthermore, since 2007 there is evidence of years of pronounced low whale numbers (i.e., 2007, 2015, 2020, 2023) that are not anomalous and becoming more frequent (Figure 5a).

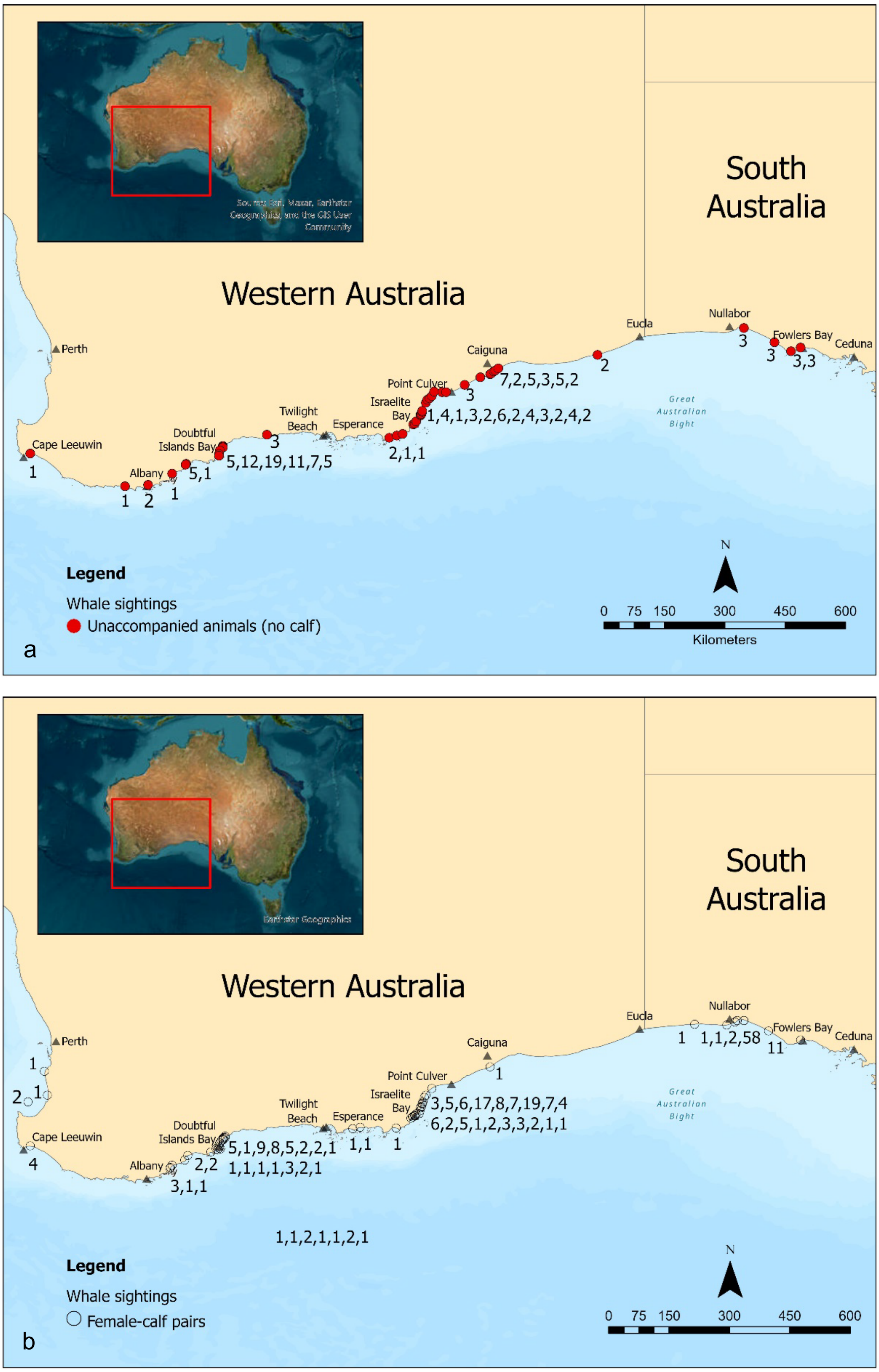
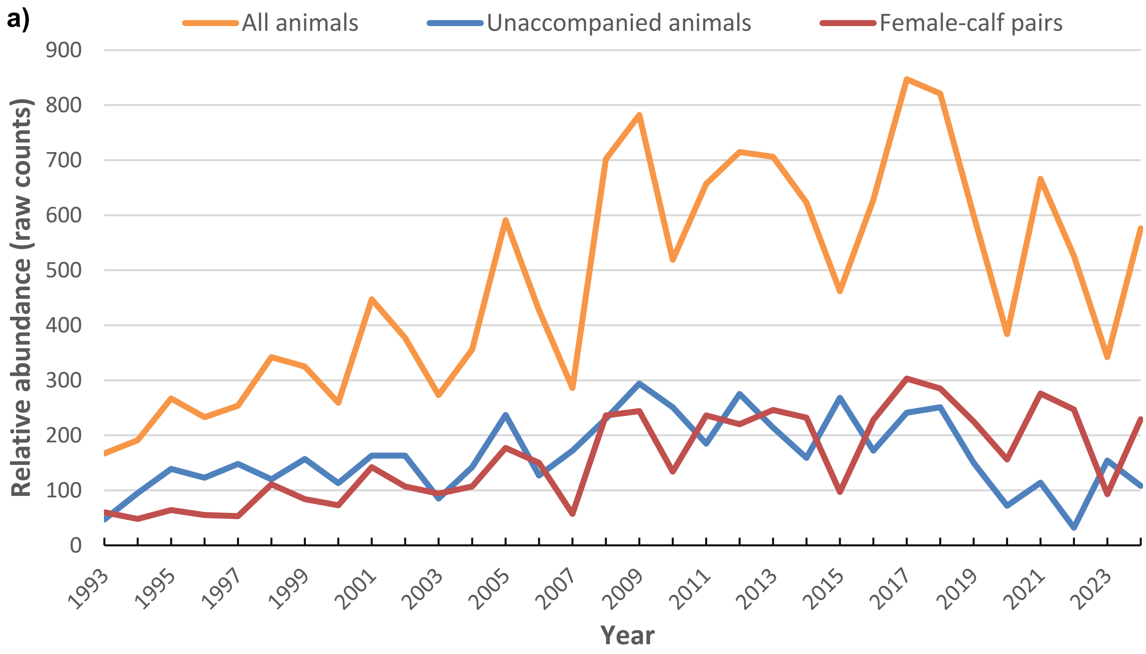


Figure 4. Survey area covered during the aerial survey undertaken in August 2024 for southern right whales. Map shows locations of southern right whale sightings for **a)** unaccompanied animals and **b)** cow / calf pairs.



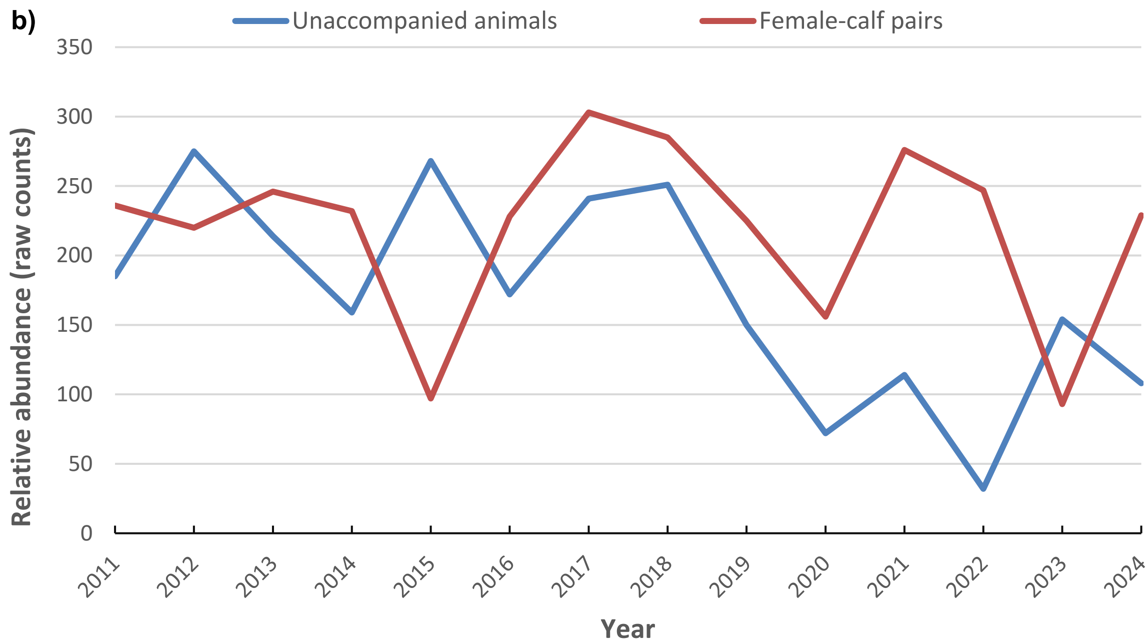


Figure 5. Graph of the relative abundance of the 'western' population of southern right whales for **a)** all animals, unaccompanied animals and female/calf pairs between 1993 and 2024 and **b)** unaccompanied animals and female/calf pairs between 2011 and 2024.

3.3.2 Population trend analysis

The exponential regression analysis of the whale count data for 'all animals' over the entire time series between 1993 and 2024 (excluding 1996/97) suggests a weak exponential rate of increase of 0.03 (95% CI 0.020 - 0.049), which is equivalent to an annual percentage increase of 3.31% (95% CI 1.91 - 4.73) (Table 1, Appendix C1). The estimated exponential rate of increase based on counts of cow/calf pairs was 0.04 (95% CI 0.026 - 0.059) and an annual percentage increase of 4.39% (95% CI 2.68 - 6.12) (Table 1, Appendix C).

Given the weak rate of increase over the entire time series (1993-2024), an exponential regression analysis of a subset of the count data between 2000 and 2024 (i.e., ~ seven breeding cycles) demonstrates a weak trend count data over time for all animals and non-significant trend for cow-calf pairs (Table 2). In the more recent count data between 2011 and 2024, there is a poor model fit and non-significant trend in count data over time, indicating population counts do not change consistently over this period (Table 2, Figure 5b). The rate of increase of both 'all animals' and 'cow/calf pairs' has been declining over the past 25 years, from 9.5% in 2001 compared to 4.39% in 2024 for cow-calf pairs (Figure 6).

Table 1. Best fit regressions for maximum counts of whales in each leg of the southern right whale aerial survey for years between 1993 - 2024 (excl. 1996 & 97) and a comparison with 1993 – 2023.

Period	**1993 - 2024**		**1993 - 2023**	
Class	All animals	Cow/calf pairs	All animals	Cow/calf pairs
Exponential increase	0.0326	0.0429	0.0323	0.0441
SE	0.006	0.008	0.007	0.009
95% CI (Lower – Upper)	0.019 – 0.046	0.026 – 0.059	0.020 – 0.049	0.027 – 0.062
p-value	< 0.001	< 0.001	< 0.001	< 0.001
R^2	0.47	0.50	0.47	0.49
Percentage annual increase	**3.31**	**4.39**	**3.49**	**4.51**
SE	0.67	0.81	0.71	0.86
95% CI (Lower – Upper)	1.91 – 4.73	2.68 – 6.12	2.00 – 4.99	2.69 – 6.37

Table 2. Best fit regressions for maximum counts of whales in each leg of the southern right whale aerial survey for years between 2000 - 2024 and 2011 - 2024 (excl. 1996 & 97)

Period	**2000 - 2024**		**2011 - 2024**	
Class	All animals	Cow/calf pairs	All animals	Cow/calf pairs
Exponential increase	0.0205	0.0328	-0.0315	-0.0132
SE	0.009	0.011	0.018	0.025
95% CI (Lower – Upper)	0.002 – 0.039	0.009 – 0.056	-0.072 – 0.009	-0.067 – 0.041
p-value	0.032	0.011	0.117	0.603
R^2	0.02	0.03	-0.03	-0.01
Percentage annual increase	**2.07**	**3.33**	**-3.10**	**-1.31**
SE	0.90	1.15	1.87	2.49
95% CI (Lower – Upper)	0.20 – 3.99	0.91 – 5.81	-6.96 – 0.93	-6.46 – 4.13

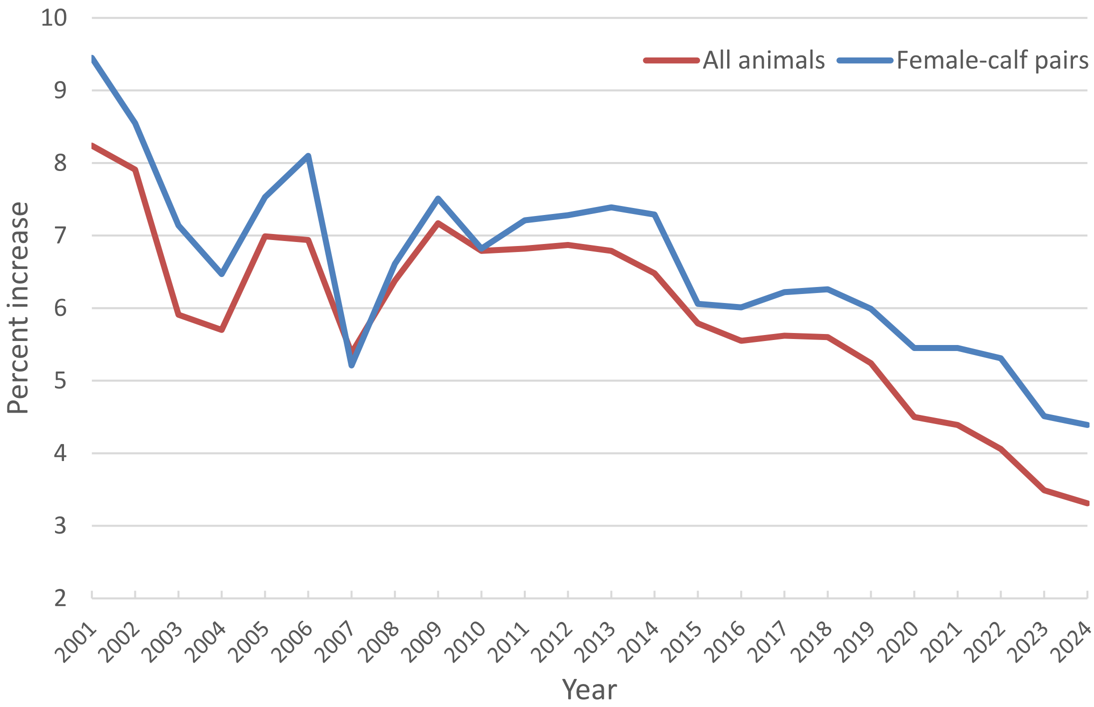


Figure 6. Rate of percent annual increase in abundance of the western population of southern right whales based on regression analyses of annual count data since 1993 (i.e., Table 1; 2023). Note, counts early in the program (1993-2000) are not included due to either low sample size and/or lack of data to cover a minimum 3 years breeding cycle, resulting in a trend analysis being either not possible or unreliable.

3.3.3 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, 2022 to 2024) of 2,242 whales. This is a similar estimate, although slightly lower, to the estimated population size over the previous five years (2019-2024) with no apparent increase in change over this period (Appendix B). Figure 7 demonstrates a shift from an exponential rate of population increase from 1993, to a plateau and stalling of the population size from 2011, and a recent decline since 2017.

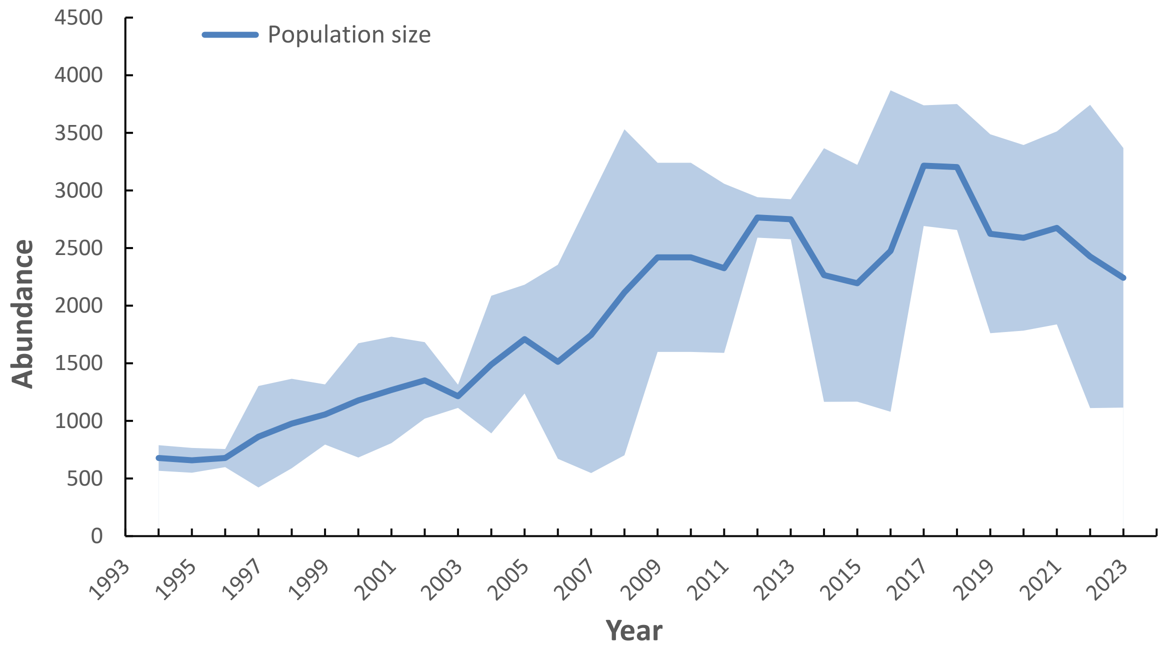


Figure 7. Population size (95% CI) and trend for the 'western' population of southern right whales.

3.4 Development of AI tools for photo-id data

The development and application of AI to SRWs involved refinement of an existing open source AI algorithm (Piev2) for automating the processing of southern right whale photo-id data in Australian waters. This included the development of an automated workflow and tools to interface with ARWPIC to integrate images and automatically extract image metadata into the ARWPIC database. There were two main components to the development of the AI to southern right whale photo-id data, consisting 1) establishment of the AI server infrastructure and 2) AI model algorithms refinement and automated workflow development.

3.4.1 AI server infrastructure

ARWPIC is now composed of 3 components hosted on Amazons AWS infrastructure:

1. ARWPIC server that runs the ARWPIC code and houses the database,
2. AI GPU server that runs the code and houses the algorithms and models used to train and predict, and
3. Image server which stores all the images and serves images to both the ARWPIC and AI servers as required.

The ARWPIC application can now provision an AI GPU server on demand on the Amazon AWS infrastructure using Terraform. This can be accessed and will run on demand, given the prohibitive high costs of running it continuously. The script installs an operating system, connects to storage, and builds separate machine learning environments to enable the three parts of the image processing pipeline to occur - detection, orientation and identification.

Prediction requests occur as browser requests, for example detecting southern right whale heads in a batch of images and returning the bounding boxes and confidence scores. The AI server then sends the results of each prediction request to ARWPIC to store in the database.

3.4.2 AI model refinement and deployment

There are two main phases to the AI algorithm/model refinement and deployment in its application to matching southern right whale photo-ids, consisting of 1) algorithm training and 2) predictions. To undertake the first phase of the initial training of the AI algorithm, there are four main steps:

1. Bulk image import
2. Head detection
3. Head orientation
4. Extracting a training set and training the algorithm to produce a model.

Bulk image import

Functionality has been built inside ARWPIC to guide users through a four-step process to connect an external storage provider to ARWPIC, select an image folder, and initiate image processing. The initial process utilises an interface developed to connect and bulk import images from any directory among a range of Cloud storage providers (e.g. Dropbox, G Drive, AWS, Cloud Compute and S3 Compatible).

The bulk upload process transfers all image files from the storage area to ARWPIC, and into the ARWPIC users Image Processing area. The process renames each image by creating a unique name across images (including project and date taken), uploads each image, reads embedded image metadata which is then saved in the database, resizes the image, and saves it to the S3 storage server and the '*import*' folder in the ARWPIC contributors Image Processing area (Figure 8).

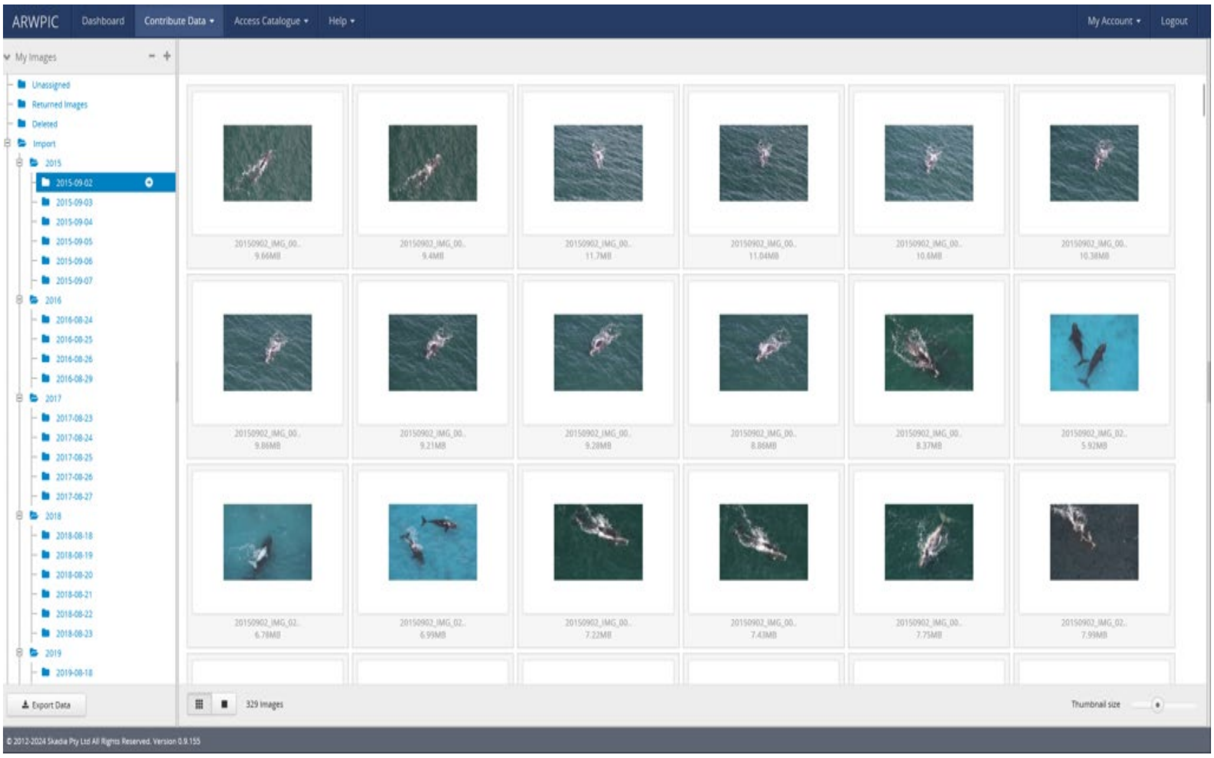


Figure 8. Example of the outcome of the bulk image import function showing images in the ARWPIC contributors Image Processing area.

Head detection

The automated head detection process identifies the head of the southern right whale (adults and calves) within an image from an aerial top-down perspective, given this is the angle that best provides the necessary callosity pattern information required for an accurate identification. Once a head is detected within an image, a bounding box is drawn around the head and tagged with associated coordinates and a confidence probability level (Figure 9). The algorithm has an 85% prediction accuracy using video and still images.

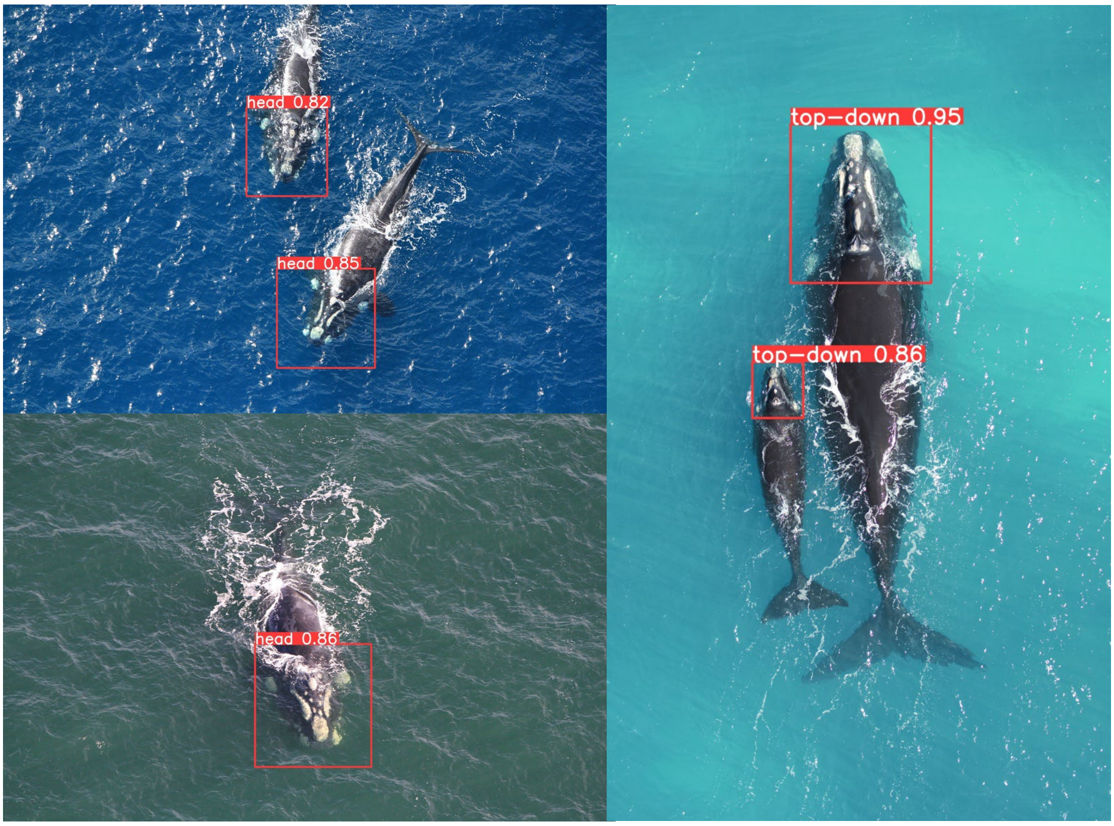


Figure 9. Examples of the automated head detection output resulting in a bounded box and associated confidence probability

Algorithm prediction accuracy is refined and determined over two steps, Firstly, in the algorithm training process, various base models were used to seed the learning and training accuracy against model training time. These foundations, plus hyperparameter tuning and adjusting settings like learning rates and batch sizes, allows training accuracy to be determined. Secondly, with the new detection model from the first step, prediction accuracy is determined using a separate dataset not used in the training. The algorithm's prediction accuracy was determined by comparing the human annotated bounding boxes in the test set against the algorithm's predicted bounding boxes and confidence scores.

Head orientation

When the algorithm has identified a bounding box with high confidence within an image, the coordinates and associated images are transferred to the orientation algorithm which rotates and re-centres the image (Figure 10). The algorithm has an 80% prediction accuracy using video and still images. The bonnet callosity is at the top of the image and the post-blow hole and eye patch callosities are at the bottom of the image to ensure consistency across the training and prediction datasets.

The orientation model's prediction accuracy was determined using a similar method to the detection model described above. Prediction accuracy was determined using the orientation model output (Figure 10) and counting the number of test images where the red and yellow dots are within 90 degrees (+/- 5 deg).

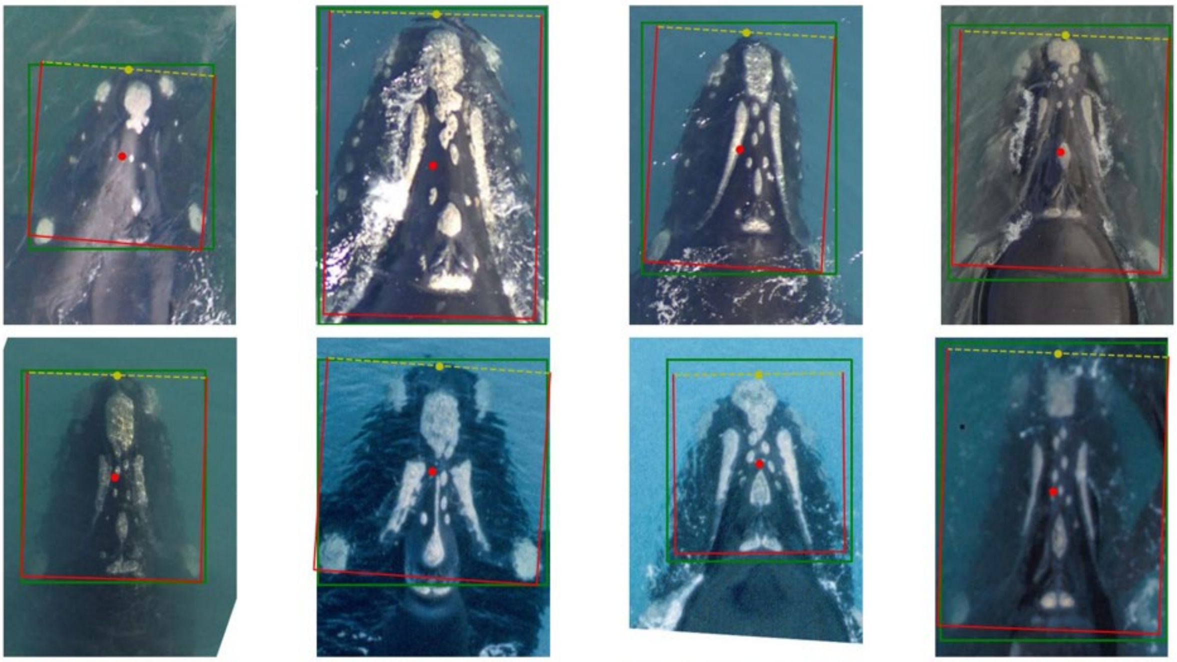


Figure 10. Examples of the automated head orientation output

Algorithm training dataset and model training

The final step is the identification process, which takes an orientated image and provides a series of predictions against a catalogue of trained images of known whales and ranks the predictions in order of confidence that matches the query image. Currently, an interface to display the photo-id matching results is yet to be created and is a critical next step in the application of the AI to the southern right whale datasets.

Initially, a range of algorithms were reviewed and tested to determine their appropriateness and effectiveness to the Australian southern right whale datasets, which included Flukebook, PIEv1, PIEv2, Detectron and Teachable Machine. A limited training dataset from ARWPIC was used with a 70-20-10% split for training, validation and testing the algorithms.

Following the initial testing of different algorithms, the final algorithm selected to progress was a modified PIEv2 algorithm from WildMe. A total 1363 individuals from the ARWPIC catalogue matched the model training requirement for the PIEv2 algorithm of at least two images head/top-down. The training set equated to 8203 images, which represents approximately 50% of the individuals in the catalogue (N = 2588).

The training dataset enabled the trained algorithm to create a model to detect embeddings (feature/callosity detection) for all the trained images and any new southern right whale head image in the future. Once an image has an embedding, the algorithm can compare it against other images with embeddings using nearest neighbour distance comparison maths, resulting in similar images scoring higher match confidences. Currently, the algorithm has been tested against a small dataset of known whales (N = 1006) from the Head of Bight (SA) that were not used in the training dataset, which produces 97% accuracy of top-1 and 99% top-20 match rates. However, there were minor variations between the test images and images used to train the algorithm regarding quality of images, environmental conditions, obscurity of callosity patterns etc. These results demonstrate the algorithm performs as expected in identifying individual whales based on callosity patterns, although evaluation against a completely independent test dataset of photo-id images from the aerial survey program still needs to be undertaken to evaluate the accuracy of the algorithm.

4. Discussion and conclusions

The overall count from the 2024 aerial survey of 576 whales (based on the maximum count per leg; 229 cow-calf pairs and 108 unaccompanied animals) is comparable to the counts in the recent time series over the past 15 years (i.e. since 2010), with the exception of very low counts in 2020 and 2023 (Appendix B). Based on the simple population estimator, the population size of the 'western' population is an estimated 2,242 whales, which has also remained stable over the same time period. The long-term aerial survey data shows that while the population has experienced exponential growth rates since 1976 when increased sightings of SRWs provided early indications the species was recovering, recent trends since 2011 show population growth has stalled (Figure 5, Table 2; Grundlehner et al., 2025). Furthermore, analysis of the aerial survey data by Grundlehner et al. (2025) reveals population size is approximately 16-26% of pre-whaling abundance, annual births have started declining since 2016, and calving intervals have increased from an average 3 years to 4-5 years, as also demonstrated at the Head of Bight (Charlton et al., 2022).

Highly fluctuating annual variation in abundance is a prominent characteristic of the Australian southern right whale population trend data (Figure 5). Inter-annual variation of female-calf pairs is largely due to the non-annual breeding female cycle, which becomes more pronounced when calving intervals increase to 4 and 5 years. A possible explanation for a stabilising population size and declines in annual calf abundance in the western population could partially be due to an increase in the calving interval from 3 to 4-5 years (Grundlehner et al., 2025), although this also requires high survival rates. In addition to declines in calf abundance, there have also been declines in unaccompanied animals of approximately 40% based on count data (Figure 5b, Appendix B; 2011-2024) and 66% from modelled data (Grundlehner et al., 2025).

Many of the trends evident in the aerial survey data for the western population of southern right whales, such as strong initial population growth rates, recent declines in calf abundances and unaccompanied animals, and increased calving intervals have been shown in key aggregation site (i.e. Head of Bight; Charlton et al., 2022) within the western population, and also demonstrated in other populations such as South America (e.g. Crespo et al., 2019) and South Africa (Vermeulen et al., 2020). 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). A decadal shift in foraging strategy northward in the southern right whales that occur in South African coastal waters is possibly related to a response to changes in preferred foraging habitat or prey (van den Berg et al., 2021), with ocean warming in the Southern Ocean having an effect on southern right whale population recovery (Agrelo et al., 2021), due to potential links between foraging success, maternal body condition and female reproductive success (Vermeulen et al., 2023). Thus, 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 in southern right whales across the Southern Hemisphere.

Population demographic data fundamentally informs positive and negative effects on population parameters, including abundance. However, a major bottleneck in providing up to date population demographic data is the time-consuming process of manually processing photo-id images to an existing catalogue. Recent advances in the application of deep learning algorithms and fully automated image workflows to North Atlantic right whales (Bogucki et al., 2019) demonstrate the feasibility of using AI for processing southern right whale photo-id data. AI tools have successfully been developed in this project during 2023/24 to automate image workflows (e.g. AI server infrastructure, bulk image import, head detection and orientation, preliminary algorithm training) into the national photo-id repository (ARWPIC) and a preliminary photo-id matching algorithm has been trained using an existing open source AI algorithm (i.e. Piev2). The development of the AI tools for improved data processing/matching capabilities of Australian southern right whale photo-id data is a major advancement to current methods and is undertaken in a staged approach. Further development of the AI in 2025 will build on the success of the tools developed in 2023/24 that now provide an automated workflow process and preliminary working algorithm model that will be further refined.

4.1 Implications for species conservation management

Given the eastern population is estimated at only 268 individuals (Stamation et al., 2020) and there is limited evidence of growth, trends in abundance and demographic data from the western population largely reflects the status of southern right whales in Australian waters. Continued annual population aerial surveys to inform long-term population trend data from the western population will be the best approach to identifying changes in the population growth rate and is a *Very High* recovery action (B1.2) identified in the National Recovery Plan for the Southern Right Whale. Annual surveys still represent the best frequency for detecting change over longer time scales given the high inter-annual variability, the limited understanding of the drivers causing the variation, and long calving intervals (i.e. 3-5 years) (Charlton et al., 2022; Grundlehner et al., 2025).

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 for both the eastern and western population. 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 understand cumulative impacts to the population from natural and anthropogenic threats. This includes identifying possible influences from short-term climate dynamics, longer-term climate change, and/or potential impacts from increasing anthropogenic threats. 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). It is critical the southern right whale is afforded high levels of protection in Biologically Important Areas (e.g. reproduction and migration BIAs – see the Australian Marine Spatial Information System) and annual surveys are continued to assess the status of the species through long-term population trend data and inform federal and state conservation management actions and regulatory assessments of marine-based activities (e.g. offshore wind, seismic surveys).

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Appendix A: Southern right whale aerial survey summary data

Flight	Date	Leg	Leg / flights	Whale sightings							Weather[1]	Flying hrs
				Right whales				Other large whales[2]				
				A[3]	C	Y	T	A	CC	T		
Additional leg	21-08-24		1&2 Perth-Augusta-Albany	12	8	0	20	7	2	11	270 / 10	4.3
Outward legs Albany to Ceduna	22-08-24	1	3&4 Albany-Ravensthorpe-Esperance	58	43	0	101	0	0	0	070 / 10	4.7
	24-08-24	2	5&6 Esperance-Israelite Bay-Caiguna *	183	106	0	289	1	0	1	330 / 15	4.8
	26-08-24	3	7&8&9 Caiguna-Nullarbor (excl HoB) *	7	5	0	12	2	0	2	0 / 10	4.3
	26-08-24	4	10 Nullarbor-Ceduna * (incl HoB) *	82	70	0	152	2	0	2	0 / 10	2.8
Total Outward			**1-10 Perth-Albany-Ceduna**	**342**	**232**	**0**	**574**	**12**	**2**	**16**		**20.8**
Inward legs Ceduna to Albany	27-08-24	4	11 Ceduna-Nullarbor (incl HoB)	79	72	0	151	0	1	2	350 / 20	2.9
	27-08-24	3	12&13 Nullarbor-Caiguna (excl HoB)	2	2	0	4	0	0	0	315 / 25	3.7
	28-08-24	2	14&15 Caiguna-Esperance	204	95	0	299	1	0	1	270 / 05	4.9
	28-08-24	1	16 Esperance-Albany *	71	52	0	123	0	0	0	310 / 10	3.6
Total Inward			**11-16 Ceduna-Albany**	**356**	**221**	**0**	**577**	**1**	1	**3**		**15.2**
Total	**6 days**		**16 flights**	**698**	**453**	**0**	**1151**	**13**	**3**	**19**		**35.9**

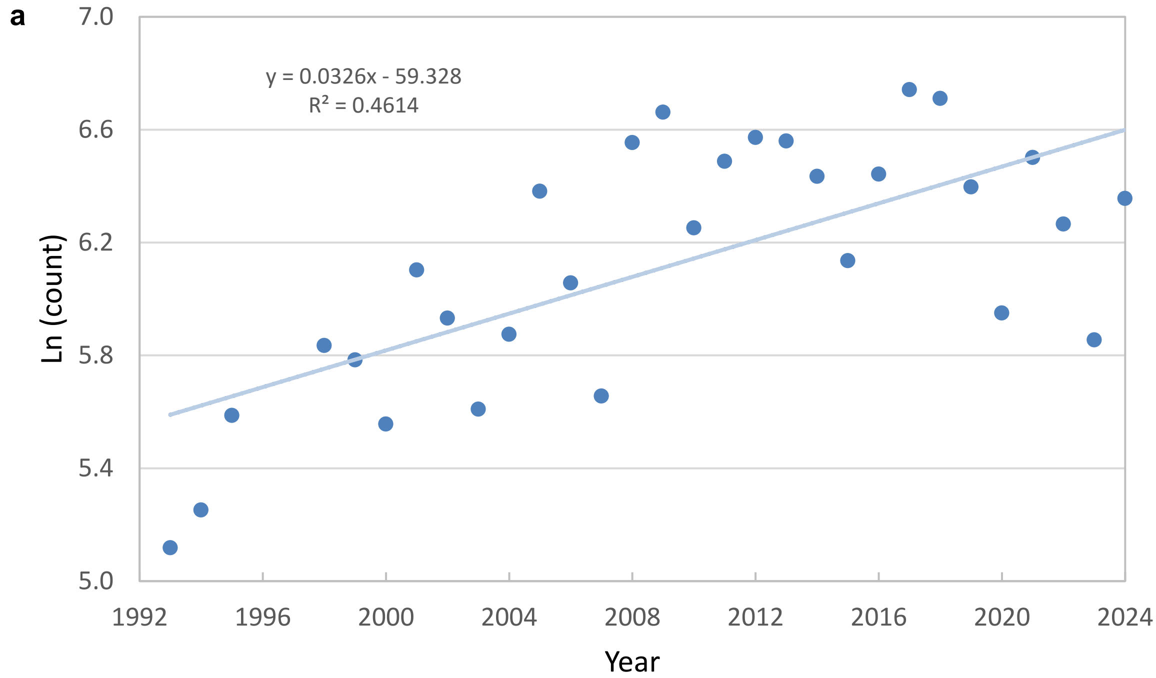
[1] direction of wind/wind speed (knots)
[2] all humpback whales; no other large whales recorded
[3] A = adult, C = calf, Y = 'yearling', T = total, CC = cow/calf pair
* survey legs with maximum numbers of whales used for mapping and calculating trend (i.e. in Table 2)

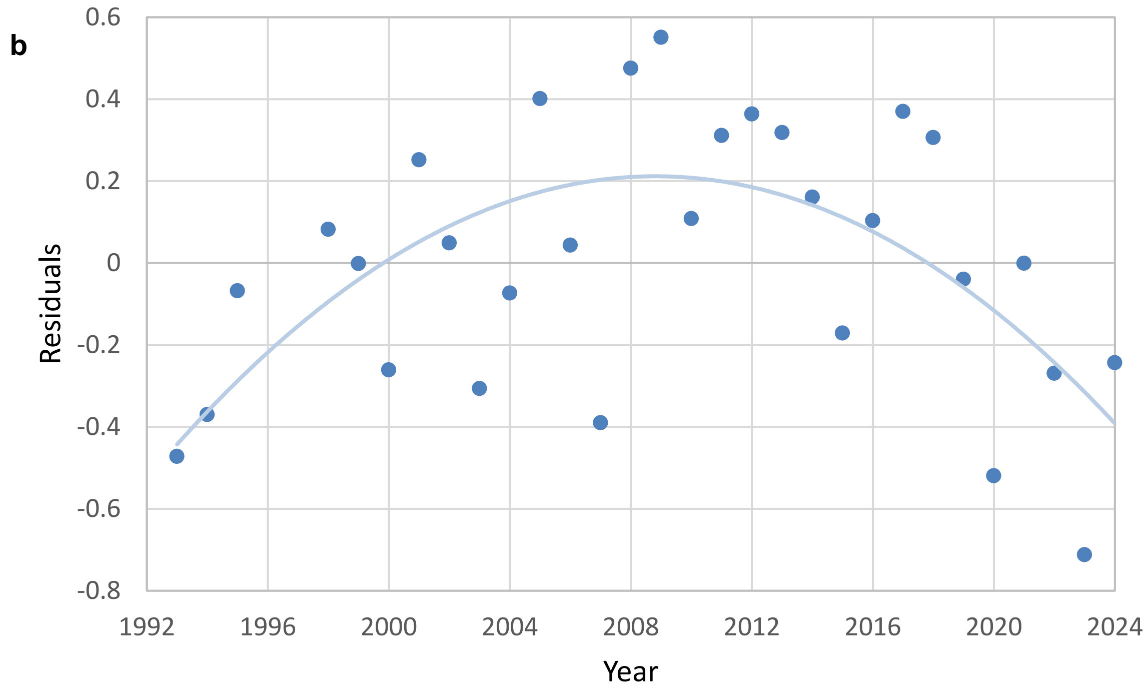
Appendix B: Summary table of aerial survey count data

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	154	93
2024	576	108	229

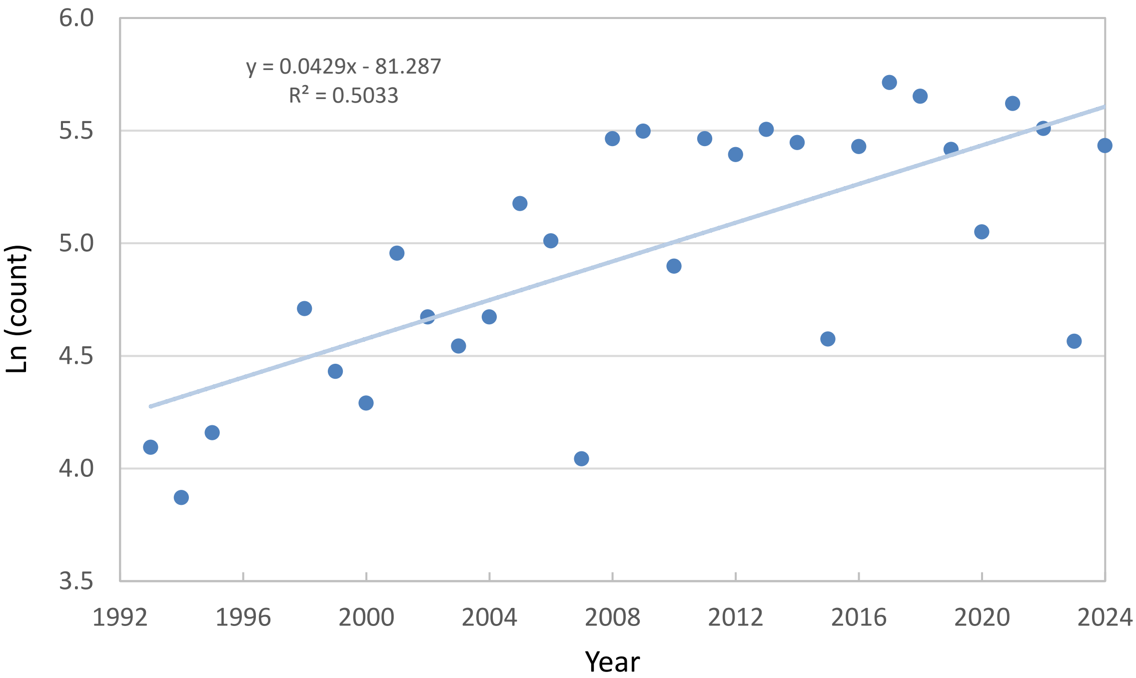
Appendix C: Linear regression analyses of whale trend data



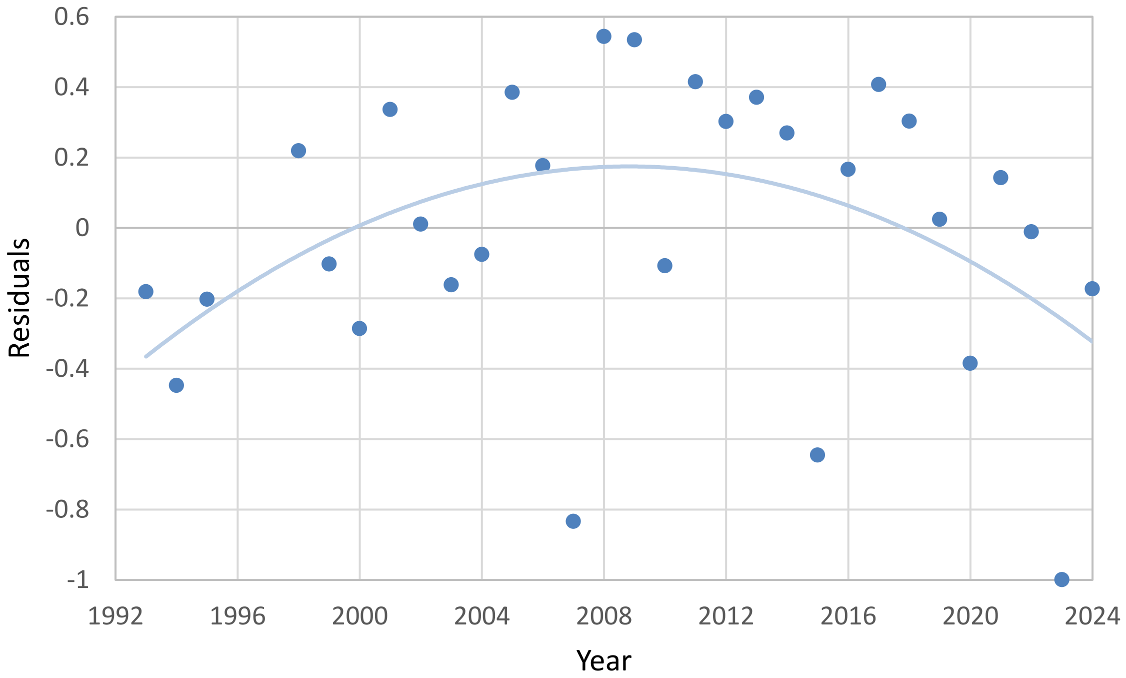


Appendix C1. Plots for *All animals* of the fitted (a) linear regression and (b) residuals for the maximum counts of whales in each leg of aerial surveys undertaken between 1993-2024 (excluding 1996/1997).

a

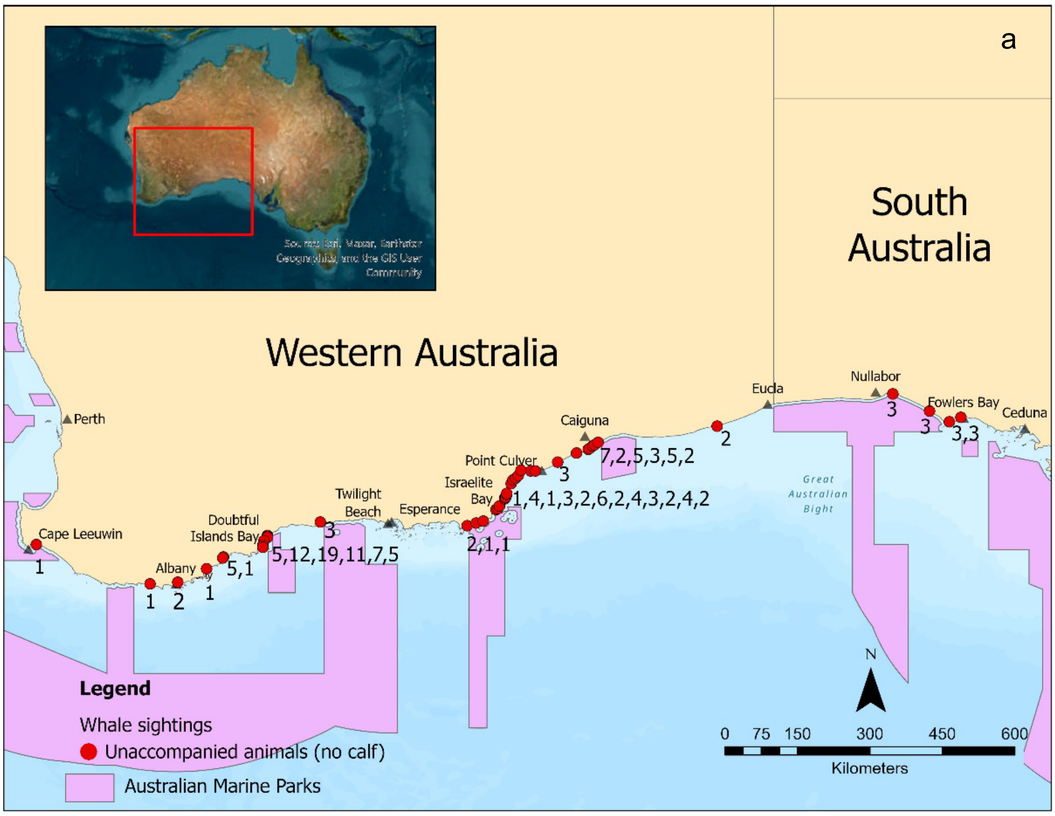


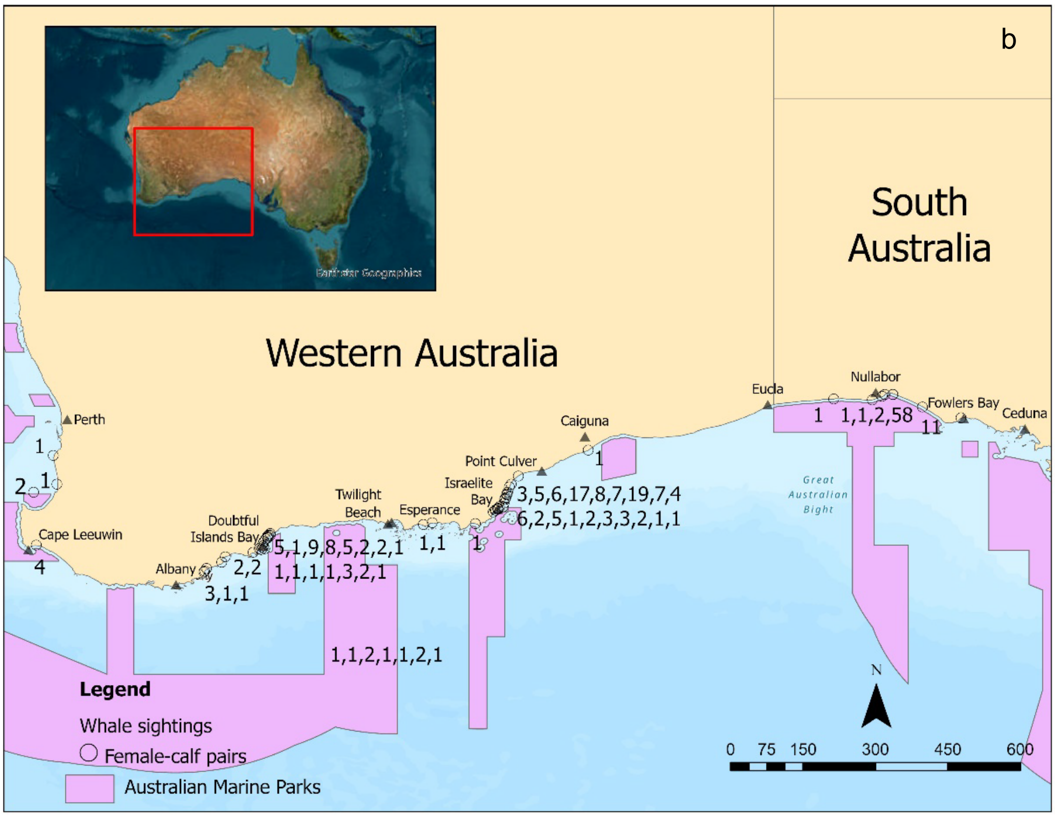
b



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 1993-2024 (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

Marine and Coastal

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