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Estimation of population abundance and mixing of southern right whales in Australian and New Zealand regions

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Project A13 – Estimation of population abundance and mixing of southern right whales in the Australian and New Zealand Regions

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Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Background

Southern right whale (*Eubalaena australis*) populations were significantly depleted as a result of commercial whaling operations throughout the Southern Ocean. Southern right whales utilise areas close to the southern coast of Australia during the austral winter to breed, predominantly between the months of May to November. With the occurrence of slowly increasing numbers of sightings along the south coast of Australia, dedicated efforts to monitor the population were initiated in the late 1970s; efforts that continue today. Significant structuring of maternal genetic lineages has been observed between whales occurring in the south-west and those in the south-east, with differences in recovery rates also observed between what are regarded as two sub-populations of the species nominally demarcated by the Victorian-South Australian border.

Within Australian waters, southern right whales are listed as *Endangered* under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). In association with this listing, a recovery plan for the species was first released in 2005. The most recent Conservation Management Plan (Recovery Plan) for the southern right whale, sets out five interim recovery objectives for the period 2011-2021. These are focused on identifying the population abundance of southern right whales in Australian waters, understanding the nature and degree of difference between the two sub-populations of the species in the south-east and south-west of Australia and ensuring ongoing recovery of the species.

To date, monitoring of southern right whales across the whole of their range in Australian waters has consisted of aerial surveys, land-based surveys and opportunistic sightings. Much of the information on the biology of southern right whales gathered by such efforts has relied on the identification of individuals via unique callosity patterns (patches of thickened, keratinised tissue) that allow for the photo-identification of individuals and subsequent resighting of individuals through time. While much has been learned from this research, a comprehensive understanding of the population parameters, recovery rates, movements and degree of spatial connectivity of southern right whales across the whole range of the species in Australian waters is lacking. There is therefore a need to bring together available datasets to further investigate both the population dynamics and connectivity/structuring of the two southern right whale sub-populations.

The Australian Right Whale Photo-Identification Catalogue (ARWPIC), holds photographs contributed by the research community and the general public of southern right whales for photo-identification purposes from south-western Australia (1978-2010), Tasmania (1993-2018) and southeast Australia (1985-2018). While the catalogue could be considered as extensive in nature, a number of additional datasets of photographs collected from the Australian region and used to estimate individual sightings histories have not yet been included in the ARWPIC. The inclusion of these datasets into ARWPIC has been identified as important for progressing research into the population dynamics and connectivity/structuring of populations of southern right whale utilising Australian waters.

Aims/objectives

1. Conduct a workshop engaging key stakeholders to assess (i) the data currently held in the ARWPIC, (ii) the capacity of those data in supporting a population assessment of southern right whales, (iii) what additional datasets might be available and required for supporting a population assessment of southern right whales and (iv) key biological and demographic parameters and aspects of the distribution and movement of southern right whales for incorporation into a population assessment.

2. Facilitate the migration of key datasets not currently housed in the ARWPIC into the ARWPIC.

3. Explore the spatial distribution and connectivity of southern right whales in Australian waters.

4. Develop multi-stage mark-recapture (MSMR) methods to estimate the abundance and annual population growth rate of southern right whales.

5. Undertake an assessment of future data collection needs to ensure robust population abundance and trend estimates can be made for ongoing monitoring of the recovery of southern right whales in Australian waters.

6. Provide a series of logical next steps in progressing the ARWPIC to provide a comprehensive photo catalogue for the Australian region.

Methodology

Datasets

The workshop (held in Hobart in September 2018) identified four primary photo-identification datasets available for migration into the ARWPIC following completion of curation and validation of the existing data in ARWPIC. These included datasets collected by:

- the Western Australian Museum (WAM) long-term aerial survey program (2010-2018);
- the Head of Bight (HoB) long term monitoring program. This included two datasets, one from Head of Bight (1991-2018) and one from Encounter Bay (2006-2019);
- the South East Australia Southern Right Whale Photo Identification Catalogue (SEA SRW PIC; 2015-2018), including those from Tasmania (2016-2018).

The additional datasets from the following programs migrated into ARWPIC by this project includes:

- the WAM long-term aerial survey program: 1029 events, 1511 sightings from 2011-2018 with data processing still underway to cross-match individuals, identify new whales and curate the data. This comprises all individuals in the WAM program dataset across this period of time;
- the HoB long term monitoring program:

  - o Head of Bight: 478 events, 2043 sightings of 903 individuals from 1991-2018 fully curated. This comprises all reproductive females (n=495, 1991-2018) and 53 percent of unaccompanied adults (n=408, 1991-2009) in the HoB program dataset. The remaining unaccompanied adults have been migrated into ARWPIC with data processing pending further funding;
  - o Encounter Bay: 81 events, 99 sightings of 103 individuals (2006-2019), fully curated.
- the SEA SRW PIC: 157 events, 161 sightings of 31 individuals fully curated (including individuals sighted in Tasmania). This constitutes all individuals in the SEA SRW PIC program dataset 2015-2018.

At the time of writing of this report and after migration of the above program datasets, the ARWPIC now holds 3,279 events containing 6,840 sightings of 2,586 individuals represented by 15,625 photographs collected over the period 1978-2019.

Information on effort, identified during the workshop as being important for any estimation of population abundance and trends, was only available in association with the WAM aerial survey and HoB datasets for the period 1992-2018 in association with the systematic nature of data collection. The opportunistic nature of the SEA SRW PIC dataset meant that effort was not able to be calculated.

Spatial analyses

The ARWPIC dataset was filtered to produce a dataset that included only those animals for which there was at least a three star photo (highest quality) available and for which gender class (female, male, unknown) was confirmed. The spatial distribution of sightings through time and exchange of individuals between the two sub-population areas, demarcated by the South Australian border with Victoria following current understanding of sub-population distributions, were then qualitatively investigated.

Population parameters and trends

Following methodology established for southern right whales elsewhere, the ARWPIC dataset was further filtered to produce a dataset that included only those females with calves. The interval between sightings (number of years), and interval (number of years) between sightings of calves and adults was calculated from datasets representing both regions. Sightings from the south-west (1992-2018) were standardised for effort (to sightings per day of effort) – the lack of information on effort associated with data from the south-east meant that only the data from the south-west could be included in analyses focused on population trends. Regressions were calculated on time series to determine trends in sightings (per unit effort) following a previously established approach utilised for the WAM aerial survey dataset.

Delays to the project limited the amount of time the project had in exploring potential population models identified during the planning workshop. After considerable consultation with statisticians familiar with modelling southern right whale mark recapture data, it was agreed that the lack of effort data in association with the dataset from the south-east comprised a significant hurdle to overall population modelling. Further expertise would need to be engaged to determine appropriate models for an investigation into estimation of population abundance at a national scale. As a result of the limited time available, a simple model (previously utilised on the WAM aerial survey dataset) that uses the cow/calf count over three years (to allow for the 3-year periodicity in calving), and multiplies it by a factor of 3.94 was utilised to provide an estimate of the number of females with calves in each year of the time series.

Key findings

Sighting rates

Over the period 1980-2018, individuals (all three star photo and sex category confirmed) were recorded (sighted) 2.43±2.02 (mean±SD) times, with those in the south-east sighted on average a lower number of times that those in the south-west. Individuals in the south-east were predominantly only recorded once in the dataset. Females with calves (1992-2018) were also sighted in the south-east on average a lower number of times that those in the south-west (south-east: 1.91±1.28; south-west: 2.54±1.85).

Spatial connectivity

The spatial distribution of sightings largely reflects the distribution of effort in the south-west and the dispersed, opportunistic nature of sightings in the south-east. The distribution of sightings in the south-west not only highlights predictable aggregation sites well-known along the south-western coastline of Australia including Albany east to Doubtful Island Bay, Israelite Bay to Point Culver, Twilight Cove and HoB in South Australia, but also emerging aggregation areas in eastern South Australia such as Encounter Bay. It is less clear whether expanding distributions of southern right whales in the south-east represent expanding utilisation of habitat or are reflective of increasing effort through the region, although they do reflect the emergence of habitats identified in the Conservation Management Plan as potentially of importance. These include south-east Tasmania and south-west Victoria.

Few individuals in the dataset (2.5 per cent) were recorded in both the south-west and south-east areas. Given the opportunistic nature of data collection in the south-east, the low number of documented aggregation sites in the south-east and the regions contribution to a migratory corridor, however, it is extremely difficult to determine whether sightings of individuals in the two areas represents exchange of individuals between the two sub-populations or simply reflects the transit of individuals through south-east to aggregation sites in the south-west. Collection and analyses of genetic material from individuals, given knowledge of population structuring, would lend some insights into whether sightings represent transitory individuals or true exchange (i.e. shifts – either temporary or permanent – in the utilisation of aggregation habitats) between the two areas.

The sightings of males in the south-east and HoB in the west lends some support to previous suggestions that males are more transient than female and visiting multiple aggregation sites.

Population parameters and trends

The mean number of years until a calf was seen as female with a calf was 9.3±2.5 years (n=12, range 6-14) and the mean number of years until a male was resighted for the first time was 5.1±3.3 years (n=12, range 2-15). While these figures do not necessarily reflect true age at first calving or true return of males to aggregation sites, they do correspond very well with estimates of age at first calving reported elsewhere.

The mean interval between sightings of females with calves (i.e. resight interval) was 4.6±2.6 years (n=427) with the interval between sightings in the south-west slightly less (4.6±2.6, range: 1-18 years) than in the south-east (5.1±2.3 years; range: 2-9 years). These figures are similar to that reported elsewhere and identified as indicative of calving intervals.

Sightings per day of effort (1992-2018) in the south-west demonstrated an increase between 1992 – 2010, after which the number of sightings per unit of effort becomes visually more variable. Exploration of the dataset with regressions suggests that up until 2010, the rate of increase in females with calves could be regarded as exponential, but beyond 2010, no clear pattern in sightings per unit effort is discernible. When a linear annual rate of increase was calculated across the whole dataset, females with calves have been increasing at 4.91 percent per annum. When calculated across 1992-2010, the rate of increase was 6.69 percent per annum, suggesting an overall slowing down in the annual rate of sightings per unit effort. Of note are three distinct anomalous years of low sightings per unit effort in 2007, 2011/2012 and 2014/2015. These were also low years of sightings in the eastern region, although without being able to standardise these sighting in regard to effort, it is unclear if these are actually reflective of the population in the region or an artifact of varying effort. These anomalous years have also been reported from separate analyses of the WAM aerial survey dataset.

It is important to note that this analysis is biased by the underlying datasets included, with only those data from the WAM aerial surveys to 2011 contributing to the dataset (the remaining photo-identification data are yet to be fully curated), so the data contributing to the overall dataset more recently comprises only that derived from the HoB. Whilst there are limitations with this analysis and more complex population modelling is needed to assess trends in population abundance for the Australian population, recent concerningly low count numbers in 2019 and 2020 and an increase in mean apparent calving intervals also suggest that the rate of recovery may have slowed in recent years.

It is difficult to hypothesise as to whether the anomalous years represent some form of a cycle that is perhaps becoming evident as the population recovers to levels at which any cyclicity might become evident, particularly given the low frequency of occurrence and the non-annual breeding cycle of southern right whales. Correlations between food availability and changing foraging strategies and calving rates and intervals have been observed in populations of southern right whales elsewhere. Understanding any potential environmental drivers that might be associated with both the potential shift in population growth rate and cyclical anomalous years will be important for understanding the overall recovery of southern right whales in Australian waters and should therefore be an important next step in research focused on southern right whales.

Using a simplified modelling approach, the number of females with calves in each year across 1980-2018 in the south-west has ranged 4-465. Across the same period, the number of females with calves in each year in the south-east has ranged 4-28. These figures are similar to those reported previously from the south-western and south-eastern areas of Australia.

Implications for relevant stakeholders

The outputs from this project, building on progress against target 1.1 (measuring and monitoring of the population) of the Conservation Management Plan for southern right whales in Australian waters, suggests positive progress against target 1.2 (continued recovery of the population), but that post-2010 a shift may be occurring in recovery rates. They also highlight that being able to tease apart changes in effort with changes in the south-east population are impossible without having some measure of effort. This is particularly important given the small size of the dataset currently available and the apparent lack of an increase in females with calves across the area. These issues make it difficult to be able to determine if progress against target 2.2 (an apparent increase in the population) is being achieved and they identify that while some effort is being undertaken to progress target 2.1 (measuring and monitoring of the population), dedicated efforts are needed to progress this target to a point that it is providing data that can allow an assessment of whether progress against target 2.2 is being achieved across both populations.

Recommendations

Given the key findings of this project and the associated limitations identified in current datasets available for assessing progress against the objectives of the current Conservation Management Plan for southern right whales, five key recommendations for future work can be identified:

1. Continuing the south- west sub-population annual time series is fundamentally important in understanding recovery rates and changes in populations through time and will ensure that important indicators such as the anomalous years identified in this report (and elsewhere) and captured and their impact on recovery rates considered.

2. There is a real need for a dedicated focus on the south-east population and establishing a time series that meets the assumptions of most approaches to population modelling and provides for robust population parameter estimation.

3. Given what appears to be a slowing in recovery rates and the emergence of anomalous years in sightings per unit effort of females with calves in the south-west, there is a need to investigate the potential drivers that might be causing these patterns.

4. Exploration and development of population modelling approaches that are broadly accessible and can be routinely run to provide regular population estimates for the Australian region is needed.

5. To prioritise efforts and tasks and identify pathways to achieve the above, a research prioritisation workshop involving conservation managers, data holders, population modellers and funding agencies should be held.

Keywords: southern right whale, Australian Right Whale Photo Identification Catalogue, spatial connectivity, population parameters, population trends

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1. INTRODUCTION

Southern right whale (*Eubalaena australis*) populations were significantly depleted as a result of commercial whaling operations throughout the Southern Ocean. Within Australian waters, they were the focus of shore-based whaling throughout the early 1800s, particularly along the south-east coast of Tasmania (Nash 2003) and western Victoria, South Australia and southern Western Australia (Bannister 2001). Estimates of the species prior to whaling are unknown, although catch records suggest that at least 26,000 whales were harvested from the Australian/New Zealand region (Dawbin 1986).

Up until the recording of sightings during the 1950s and 1960s southern right whales were considered exceedingly rare within Australian waters. With the occurrence of slowly increasing numbers of sightings along the south coast of Western Australia, an aerial survey was initiated in 1976. Initially this survey was conducted from Cape Leeuwin to Israelite Bay in Western Australia, with the survey extended in 1983 further east to Twilight Cove in Western Australia and then further east again to Ceduna, South Australia in 1993 (Bannister 2001). This survey constitutes the longest continuous record of southern right whales in Australia and the relative abundance of animals collected by the survey is central to understanding of the recovery of the species post-exploitation in the Australian region. Other dedicated efforts in documenting numbers of whales have occurred since across South Australia, notably the land-based survey at the Head of Bight, conducted since 1991 (Burnell 2001, Charlton et al. 2019a) and across Victoria, Tasmania and New South Wales over varying time periods (Watson et al. 2015, Stamation et al. 2020, Watson et al. 2021). Efforts in the south-eastern parts of Australia have not all been continuous and have been largely opportunistic in nature, with the exception of an aerial survey conducted twice between Ceduna and Sydney (including Tasmania) in 2013 and 2014 (Watson et al. 2015).

Southern right whales utilise areas close to the southern coast of Australia during the austral winter to calve and mate, predominantly between the months of May to November. Their distribution and migratory pathways once they leave Australian waters are largely unknown, although a counter-clockwise migratory pattern in the waters south of Australia as far as the ice edge off Antarctica has been postulated (Bannister et al. 1999, Burnell 2001). More recently, electronic tagging of individuals suggests extensive utilisation of Southern Ocean waters south of Australia and the potential for individuals to associate with spatially defined foraging regions (MacKay et al. 2020).

Catch records suggest no discontinuity in the distribution of the population reflective of structuring, however there is clear difference in the rates of recovery post whaling between southern right whales in the western parts of the southern Australian coastline and those in the east. The population west of the South Australian border with Victoria has been estimated to be growing at 6-7 percent per annum (Bannister 2011, Charlton et al. 2019a), although more recently this has been estimated at just below 6 percent (Smith et al. 2020). That part of the population to the east of the South Australian border with Victoria is estimated to be growing at just under 5 percent per annum (Stamation et al. 2020). Significant structuring of maternal genetic lineages has been observed between whales occurring in the south-west and those in the south-east (Carroll et al. 2011a), and there have been low numbers of recorded movements between the south-east and south-west of

Australia (Carroll et al. 2011a, Stamation et al. 2020, Watson et al. 2021), or between Australian breeding areas and those in New Zealand (Pirzl et al. 2009).

Long-term monitoring of southern right whales at several sites across their distribution have recorded female reproductive intervals of 2 – 5 years, with the majority of females estimated to calve every three years (Best et al. 2001, Burnell 2001, Cooke et al. 2001, Davidson et al. 2017, Watson et al. 2021). It should be noted that these do not necessarily reflect true calving intervals because effort has varied across sites and so not all mothers with calves or calvings are observed (e.g. mothers might be seen prior to calving or seen some distance from their calf, or may be in a group where an association between a mother and calf is difficult to discern) (Cooke et al. 2001).

Population modelling of species such as southern right whales is highly complex largely due to this non-annual breeding cycle. Application of mark-recapture statistics to a catalogue of photographically identified individuals therefore requires some understanding of the population dynamics of the species, how these dynamics might influence survival and sightings probabilities (see Caswell et al 1999; Fujiwara and Caswell 2001). It also requires an understanding of whether or not the population dynamics, and in particular breeding intervals, are changing as a response to environmental conditions or population recovery. Finally, any modelling approach needs to account for variability in sightings and resightings associated with variation in effort, as numbers of individuals identified do not necessarily reflect the numbers of individuals present in a region (Cooke et al. 2001).

Within Australian waters, southern right whales are listed as *Endangered* under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). A recovery plan for the species was first released in 2005 (DEH 2005). Recognising that the objectives of the plan were unlikely to be achieved within the lifetime of the plan (2005-2010), if the plan was to be successful, continued recovery close to or at the optimum biological rate, continued expansion of the population into suitable habitat and maintenance or improvement of domestic and international protection schemes should occur. An assessment of the recovery plan conducted at the end of the plan lifetime, identified that with abundance of the species well below historical estimates and occupancy also below historical utilisation of habitats, a recovery plan was still required (GHD 2010).

The most recent Conservation Management Plan (Recovery Plan) for the southern right whale, sets out five interim recovery objectives for the period 2011-2021. These are focused on identifying the population abundance of southern right whales in Australian waters, understanding the nature and degree of difference between the two sub-populations of the species in the south-east and south-west of Australia and ensuring ongoing recovery of the species.

To date, monitoring of southern right whales across the whole of their range in Australian waters has not been consistent, with monitoring taking multiple forms at a number of locations including aerial surveys, land-based surveys and opportunistic sightings. Much of the information on the biology of southern right whales gathered by such efforts has relied on the identification of individuals via unique callosity patterns (patches of thickened, keratinised tissue on the heads of individuals) that allow for the photo-identification of individuals (Payne 1983, Best 1990).

While much has been learned from this research, a comprehensive understanding of the population parameters, recovery rates, movements and degree of spatial connectivity of southern right whales across the whole range of the species in Australian waters and their Southern Ocean foraging grounds is lacking. There is therefore a need to bring together available datasets to resolve both the population abundance and population structure of southern right whales.

Key to being able to resolve the population abundance and the degree of movements and therefore spatial mixing of southern right whales between south-east and south-west Australia, is the substantial collection of unique photographs of individual southern right whales collected by a number of agencies, institutions, organisations and individuals from various locations around southern Australia. Using unique callosity patterns, individual whales can be identified from a sighting event (the ‘mark’) and then re-identified temporally and spatially at additional sighting events (the ‘recapture’). Analyses of temporal and spatial matches of these photographs using mark-recapture methodology provides insights into the movements and spatial mixing of individuals and through the building of specific population models allows for the estimation of absolute population abundance.

The Australian Right Whale Photo-Identification Catalogue (ARWPIC), housed at and managed by the Australian Antarctic Division, holds photographs contributed by the research community of southern right whales for photo-identification purposes from south-western Australia (1978-2010), Tasmania (1993-2018) and southeast Australia (1985-2018). It also contains a number of photographs submitted by the general public. While the catalogue could be considered as extensive in nature, a number of additional datasets of photographs collected from the Australian region and used to estimate individual sightings histories had not yet been included in the ARWPIC. The inclusion of these datasets into ARWPIC has been identified as important for progressing research into the population dynamics and connectivity/structuring of populations of southern right whales utilising Australian waters.

2. PROJECT OBJECTIVES

1. Conduct a workshop engaging key stakeholders to assess (i) the data currently held in the ARWPIC, (ii) the capacity of those data in supporting a population assessment of southern right whales, (iii) what additional datasets might be available and required for supporting a population assessment of southern right whales and (iv) key biological and demographic parameters and aspects of the distribution and movement of southern right whales for incorporation into a population assessment.

2. Facilitate the migration of key datasets not currently housed in the ARWPIC into the ARWPIC.

3. Explore the spatial distribution and connectivity of southern right whales in Australian waters.

4. Develop multi-stage mark-recapture (MSMR) methods to estimate the abundance and annual population growth rate of southern right whales.

5. Undertake an assessment of future data collection needs to ensure robust population abundance and trend estimates can be made for ongoing monitoring of the recovery of southern right whales in Australian waters.

6. Provide a series of logical next steps in progressing the ARWPIC to provide a comprehensive photo catalogue for the Australian region.

3. PROJECT PLANNING

In addressing the first objective of the project, a workshop involving researchers, state and Commonwealth conservation managers and ARWPIC design expertise was held in Hobart 24-26 September 2018. The workshop aimed to specifically:

- identify the datasets currently held by project partners in Australia and their readiness for use;
- identify the current state of the national database for southern right whale sightings (Australian Right Whale Photo-Id Catalogue; ARWPIC) and its current utility for facilitating the generation of data required for population models;
- identify potential population modelling frameworks that might be suitable for use by the project and their data requirements;
- develop a workplan and timeline for the project to be carried out by the project team.

The workshop identified four main datasets as containing the vast majority of southern right whale photo identification sightings data in Australia: (i) the West Australian Museum (WAM) long term aerial survey program; (ii) the Head of Bight (HoB) long term monitoring program (facilitated through a number of agencies and universities, currently managed by Curtin University and Eubalaena Pty Ltd); (iii) the South-East Australia Southern Right Whale Photo-Identification Catalogue (SEA SRW PIC, managed by the Victorian Department of Environment, Water, Land and Parks (DEWLP); (iv) the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) southern right whale sightings.

In assessing the work-flows associated with ARWPIC, the workshop identified that there was further work needing to be done in developing, refining and clarifying the protocols associated with matching and data entry processes to ensure consistency in data quality. Additional work on database functionality was also required to streamline workflows and alerting processes was also identified. An action list for addressing current bugs and functionality issues was compiled for inclusion in the work plan for the project. It was also identified that in light of a number of errors within the data already contained within ARWPIC that had already been detected, it would be necessary to validate the entire dataset before proceeding with migration of outstanding data held in regional catalogues and data analyses.

This process provided a better understanding of the work needing to be completed on ARWPIC prior to the migration of any datasets and the size of the datasets needing to be migrated into ARWPIC before any analyses could be undertaken. Based on this improved understanding it was recognised that it was unlikely that the project would have either the time or the funding to complete migration of all datasets originally considered in the project proposal. It was agreed that the data migration, coding and matching component of the project would prioritise the Australian datasets in the first instance and within those datasets, focus on females with calves. If time and funds permitted, prioritisation should then be given to other categories of whales (e.g. males, unaccompanied adults) within the Australian datasets. Discussions would continue with New Zealand researchers to identify potential mechanisms for including available datasets at a future time.

In considering population modelling frame works that might be considered by the project, it was identified that off the shelf modelling options may not be sufficient and there is probably a need to consider developing a bespoke model. Key considerations included:

- the time period to include in the model and in association, how habitat might have changed through time and how best to account for these changes;
- the core dataset (e.g. all whales, cows with calves), their categorisation (calving, migratory/transient) and the effort associated with the dataset and how best to account for and standardise differing datasets with different levels of effort;
- the number of matches (resights) in the dataset as this defines the level of effort you put into developing modelling frameworks;
- what spatial factors might be important from a population modelling perspective (e.g. what is the relationship between south-east Australia and south-west Australia);
- the appropriate scale for investigating mixing and defining habitats.

A workplan was then developed setting out tasks and timelines to validate the datasets already in ARWPIC, undertake a revision of the protocols, fix process related bugs in the work-flows of ARWPIC and prepare and complete the migration of datasets into ARWPIC. As part of this workplan, a training workshop was held to bring those members of the project team (and others from current data holder agencies) not currently experienced with using the ARWPIC up to a minimum training standard to assist with processing of sightings data in the migration of additional datasets into ARWPIC.

A full copy of the workshop report is provided in Appendix A.

4. IMPROVING THE FUNCTIONALITY AND DATA ACCURACY OF ARWPIC

4.1 Improving user guidance and agreement templates

All ARWPIC user guidance, data processing protocols and data sharing agreements were updated and reviewed by the ARWPIC Steering Committee for improved usability and consistency. Documentation was uploaded to the ARWPIC website online under the help: documentation tab. The update of data processing protocols included updates to

- identification coding instructions;
- quality control standards and
- image grading protocol.

This resulted in improved and standardised approaches for data processing. The updated data sharing agreements included improved clarity and additional requirement for communication, processing and tracking of data sharing requests, with the aim of promoting collaboration and efficiencies in data sharing.

4.2 Validation of existing data in ARWPIC

Substantial work was undertaken to validate the existing data in ARWPIC prior to importing any new data. All sightings data and individual coding of sightings (that allows for the identification of an individual and any subsequent matching of sightings through time) was checked and curated (validated) by at least one photo-identification cataloguing expert on the project team. Where corrections to sightings data (i.e. incomplete or inconsistent status, sex, image grading) and coding of photo identified individuals were identified, the erroneous data was then corrected with the agreement of curators for the various state data sources. Once curation (validation) was complete the ARWPIC dataset included 1,576 whales from the WAM catalogue spanning 1978–2011 and 343 individuals from the SEA SRW PIC spanning 1993-2015 (which included 109 whales from the DPIPWE dataset spanning 2011-2014).

4.3 Implementing corrections to and improving the functionality of ARWPIC

Entry of data into ARWPIC had identified a number of bugs prior to the project and the validation process identified further bugs in work-flows and errors in datasets. As further datasets were migrated into ARWPIC, identification and resolution of bugs became a continuous process. While the vast majority of bugs and errors were able to be resolved, a small number still remain, with the majority associated with a small number of individuals that have two entries in ARWPIC (~30 individuals), and fewer instances where two separate individuals are under the one unique identification number in the catalogue (< 10 instances). Functionality for merging two entries (IDs) associated with the one individual was developed and is in a testing phase. An efficient method for resolving these duplicate records (requires a detailed description of the error), and the much harder case of two separate individuals under the one unique identification number in the catalogue, is yet to be developed as it will require careful consideration of all resights associated with the original sightings and as a result these individuals have been set aside for later resolving.

Migration of the large HoB and WAM datasets provided a unique opportunity to test the functionality of ARWPIC and in particular processes and protocols associated with the bulk migration of datasets, coding and matching and curation (validation). This process identified a number of ways in which the user-functionality of ARWPIC could be improved. This included:

- the development of data integrity reports so that inconsistencies between sightings and the events (e.g. the day) they were grouped under could be easily identified for correction. This included inconsistencies between the sex of individual, sex determination method and associated confidence, and breeding status (cow with calf);
- easy identification of events and associated sightings requiring curation;
- more efficient management of photos associated with individuals;
- development of a mechanism for merging duplicate animals (when they have been determined as being the same animal);
- streamlining matching;
- mechanisms for saving coding and matching processes part the way through to create efficiencies in project team members time;
- increasing server efficiencies to improve catalogue response rates.

A full summary of corrections and functionality improvements to ARWPIC is provided in Appendix B.

A number of issues for future resolution were also identified, as part of continual improvement of the catalogue. These included:

- considering whether images/ sightings that were linked to an event date and without a whale ID in original databases (but are referenced in comments) can be resolved;
- ongoing review of images for consistency in star ratings, particularly for early years;
- considering records with unknown sex and whether the confidence level should be confirmed or probable, then apply a consistent ‘fix’ programmatically (currently these appear to be used interchangeably);
- revising the format for recording errors to include more specification (to level of image), particularly for cases where multiple whales are assigned to one ID (resulting from incorrect matching);
- considering a process for ongoing review of the data integrity reports (developed as part of this project), to resolve errors that accumulate.

5. MIGRATION OF ADDITIONAL DATA INTO ARWPIC

5.1 Data migration process

Three primary datasets were migrated into ARWPIC following completion of curation and validation of the existing data in ARWPIC. These included datasets collected by:

- the Western Australian Museum (WAM) long-term aerial survey program (2010-2018);
- the Head of Bight (HoB) long term monitoring program. This included two datasets, one from Head of Bight (1991-2018) and one from Encounter Bay (2006-2019);
- the South East Australia Southern Right Whale Photo Identification Catalogue (SEA SRW PIC; 2015-2018) including those from Tasmania (2016-2018).

The process for migration of the WAM and HoB datasets involved the following steps:

1. Bulk upload of datasets and associated images;
2. Transformation of datafiles into ARWPIC formats, including splitting events so that each event was associated with a maximum of ten sightings;
3. Cross matching of individuals to existing individuals in ARWPIC;
4. Coding of any new individuals (identification and classification of unique features to be used in the matching process) identified through the cross-matching process;
5. Curation of datasets by a second expert project team member and
6. Resolution of discrepancies or errors identified during the curation process.

Steps 1 and 2 were facilitated by the ARWPIC database developer for the WAM and HoB datasets via specialised scripts. These scripts were developed in collaboration with data holders to ensure that upload processes resulted in correct tabulation of data and connectivity of events, sightings and individuals with photos. The SEA SRWPIC dataset, which was much smaller than the WAM and HoB datasets, was entered manually into ARWPIC and involved creating individual events and sightings associated the event, entering the details of each sighting and uploading photographs associated with each sighting. This process followed protocols developed specifically for ARWPIC and available via the ARWPIC portal once a data provider is registered as a ARWPIC user. These are supplemented with explanatory video tutorials available online.

Coding of individuals in the HoB and SEA SRW PIC datasets was conducted external to ARWPIC, with the coding tables migrated into ARWPIC, whilst coding of the WAM datasets was conducted within ARWPIC. The WAM dataset also had pre-specified matches to individuals existing in ARWPIC, which streamlined the coding and matching process. If the match was accepted only a review of the coding for identifying features was required, to capture the latest snapshot of features. Coding of individual whales followed protocols developed specifically for ARWPIC (see Appendix A for a full list of features included in the coding process). Once individuals were coded, they were cross-checked against the existing catalogue in ARWPIC using a computer-assisted matching system "BigFish Code Compare" (Pirzl et al. 2006) to determine if individuals had been sighted previously. This cross-checking or matching process involves a six-step search process, beginning with a search on the maximum number of features available for an individual and then progressively broadening the search by removing features at each step. This results in either a suggested match being assigned to the individual, or the individual being identified as new to the catalogue. Once cross-checking of individuals is completed, the event and sighting is submitted to the curation queue for validation by an appointed expert curator. The curation process, again followed protocols developed specifically for ARWPIC. To create efficiencies in the curation process a centralised spreadsheet was maintained by the project team so that curators could flag potential discrepancies associated with individual whales and data holders could respond to those queries quickly. This also provided an effective means of flagging errors in entries that ensured efficient correction of those errors. Where changes were suggested by the curator, data holders were consulted and any suggested changes were resolved prior to accepting sightings and finalising the process of migration into ARWPIC. Once the data was accepted in the curation step, the data were formally updated in ARWPIC.

5.2 Summary of datasets

At the time of writing of this report, the ARWPIC now holds 3,279 events containing 6,840 sightings of 2,586 individuals represented by 15,625 photographs collected over the period 1978-2019. The additional datasets from the following programs migrated into ARWPIC by this project includes:

- the WAM long-term aerial survey program: 1029 events, 1511 sightings from 2011-2018 with data processing still underway to cross-match individuals, identify new whales and curate the data. This comprises all individuals in the WAM program dataset across this period of time;
- the HoB long term monitoring program:
    - Head of Bight: 478 events, 2043 sightings of 903 individuals from 1991-2018 fully curated. This comprises all reproductive females (n=495, 1991-2018) and 53 percent of unaccompanied adults (n=408, 1991-2009) in the HoB program dataset. The remaining unaccompanied adults have been migrated into ARWPIC with data processing pending further funding;
    - Encounter Bay: 81 events, 99 sightings of 103 individuals (2006-2019), fully curated.
- the SEA SRW PIC: 157 events, 161 sightings of 31 individuals fully curated (including individuals sighted in Tasmania). This constitutes all individuals in the SEA SRW PIC program dataset 2015-2018.

6. SPATIAL CONNECTIVITY OF SOUTHERN RIGHT WHALES

6.1 Dataset

To investigate the spatial connectivity of southern right whales across the Australian region, the ARWPIC dataset needed to be filtered to reduce biases and uncertainty in potential resights of individuals (e.g. false positives, mismatches or missed matches). The catalogue was filtered to produce a dataset that included only those animals for which there was at least a three star photo (highest quality) available and for which gender class (female, male, unknown) was confirmed. Photographic quality, assessed by scoring by metrics such as lateral angle, sharpness and grain (Calambokidis et al. 2001), is routinely incorporated into studies utilising photo identification techniques (e.g., Carroll et al. 2011a, Constantine et al. 2012). This minimises uncertainty in resightings caused by lack of clarity in features and assists in reducing biases that might be introduced by resightings associated with distinctive features (that might be more obvious in lower quality photographs) thereby introducing capture heterogeneity into the dataset. Furthermore, southern right whale behavioural patterns, and hence recapture rates, vary by sex, reproductive status and age (Carroll et al. 2013, Rowntree et al. 2001), so assuming all demographic classes have the same patterns would be erroneous.

The dataset was limited to 1980-2018 as there were very few sightings and limited effort prior to 1980 (n=3). Investigation of the dataset identified some discrepancies in the identification of age classes of individuals (calf, sub-adult, adult, cow with calf) with some individuals being classified as younger age classes in years subsequent to them being classified as older age classes (e.g. a sighting being classified as a sub-adult in a subsequent year to the individual being classified as an adult). These individuals were removed from the dataset (n=3).

This resulted in a dataset of 1,057 individuals comprising 756 females, 97 males and 204 individuals of an unknown gender (Table 1). The dataset was categorised into two population areas demarcated by the South Australian border with Victoria following current understanding of sub-population distributions (Carroll et al. 2011a). The western component of the dataset (south-west) was comprised 710 females, 88 males and 100 individuals of unknown gender, while the eastern component of the dataset (south-east)was comprised 46 females, 9 males and 104 individuals of unknown gender.

Table 1. Mean±SD (range) of numbers of sightings of individuals by area and gender, 1980-2018.

	N	All	South-west	South-east
All	1057	2.4±2.0 (1-12)	2.7±2.1 (1-12)	1.1±0.5 (1-5)
Female	756	2.8±2.2 (1-12)	2.9±2.2 (1-12)	1.7±1.4 (1-6)
Male	97	2.2±1.5 (1-8)	2.3±1.6 (1-8)	1.1±0.3 (1-2)
Unknown	204	1.1±0.5 (1-6)	1.2±0.7 (1-6)	1.0±0.1 (1-2)

Information on effort, identified during the workshop as being important for any estimation of population abundance and trends, was only available in association with the WAM aerial survey and the HoB datasets for the period 1992-2018 in association with the systematic nature of data collection (Table 2). It should be noted that although the number of days of effort associated with the WAM aerial survey varied from year to year, the survey design remained the same from 1993 onwards. Most of the variability in days of effort across 1993-2018 was associated with the ability to fly due to suitable weather conditions. Effort associated with the WAM survey and the HoB study coincides with the period of peak abundance of calving female southern right whales during the months of July and August (Bannister 2001, Charlton et al. 2019a). The opportunistic nature of the SEA SRW PIC dataset meant that effort was not able to be calculated.

Table 2. Effort (days) associated with the WAM aerial survey and HoB datasets.

Year	WAM aerial survey	HoB
1992		60
1993	11	112
1994	9	88
1995	12	46
1996	7	40
1997	7	41
1998	10	35
1999	9	30
2000	11	32
2001	9	33
2002	11	32
2003	10	36
2004	11	36
2005	10	33
2006	11	26
2007	11	15
2008	6	15
2009	5	12
2010	5	9
2011	5	13
2012	5	9
2013	5	8
2014	5	41
2015	6	41
2016	6	33
2017	4	20
2018	6	20

6.2 Sightings of individuals and composition

Individuals within the dataset were recorded (sighted) 2.4±2.0 (mean±SD) times with those in the south-east sighted on average a lower number of times that those in the south-west (Table 1). The densities of sightings from the two areas (i.e. the probability density function of sightings) shows that individuals in the eastern area are predominantly only recorded once in the dataset (Figure 1).

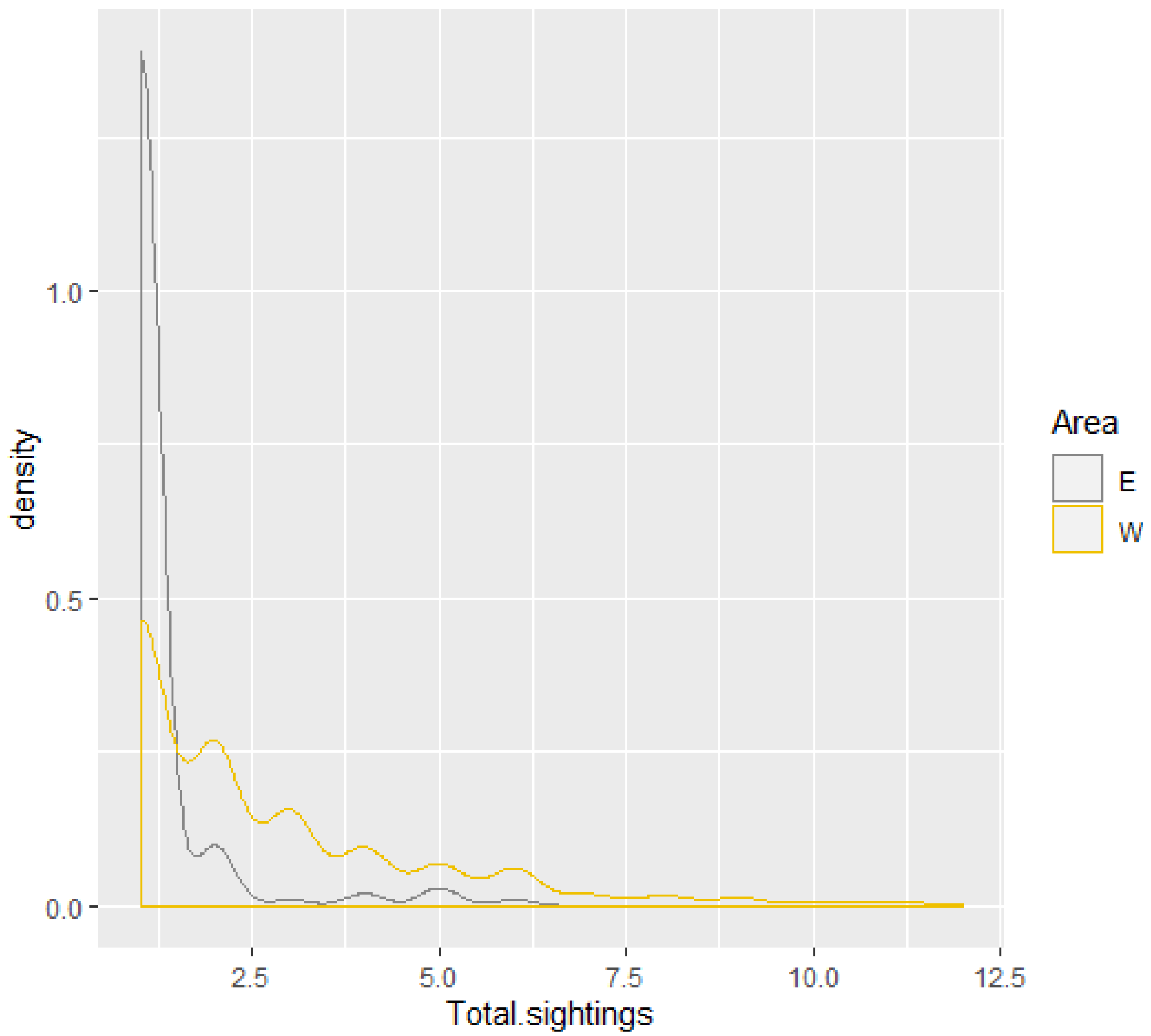

Figure 1. The probability density function of sightings of individuals by area, 1980-2018. E: south-east; W: south-west.

All individuals were predominantly recorded as adults, with females predominantly recorded as females (cows) with calves in both areas (Table 2), reflecting the prioritisation of collecting information on females with calves within most datasets and the prioritisation of the data migration process, particularly in regards to the HoB dataset, to females with calves. Individuals were recorded as calves on 27 occasions (female: 14, male: 12, unknown: 1), with those records restricted to the south-west and specifically the HoB. All but one calf was resighted, with the majority of calves (n=20) later resighted as adults (either female/male adults or females with calves). The remaining calves were resighted either as sub-adults only or as sub-adults and then subsequently as adults.

6.3 Spatial distribution and connectivity

The spatial distribution of sightings largely reflects the distribution of effort associated with the WAM aerial surveys and land-based surveys at the HoB in the south-west and the dispersed opportunistic nature of sightings in the south-east (Figure 2).

The WAM aerial surveys have employed the same survey design and covered the same region from Cape Leeuwin, Western Australia to Ceduna, South Australia since 1993. Prior to 1993 a smaller section was flown from Cape Leeuwin to Israelite Bay and occasionally to Twilight Cove, Western Australia. Given the wide spatial area covered by the WAM aerial survey and the consistency of effort through time (the same aerial survey design), sightings along the survey area prior to 1993 likely reflect expanding habitat use by southern right whales. Any apparent expansion of the spatial area utilised by southern right whales during at least the first few years after 1994 is somewhat confounded by the extension of the aerial survey area, however the distribution of sightings from the late 1990s to 2010, given the consistency of surveys conducted, is likely to reflect expanding habitat utilisation (Figure 2).

The distribution of sightings not only highlights predictable aggregation sites well-known along the south-western coastline of Australia including Albany east to Doubtful Island Bay, Israelite Bay to Point Culver, Twilight Cove and HoB in South Australia, but also emerging aggregation areas in eastern South Australia such as Encounter Bay and those in neighbouring areas to the HoB.

Table 3. Mean±SD percent of annual sightings of individuals in each age class, 1980-2018.

	Calf	Sub-adult	Adult	Cow with calf
Female				
All	0.4±3.6	1.3±9.4	12.6±25.8	85.5±28.5
South-west	0.5±3.7	1.4±9.7	23.4±11.4	86.7±26.6
East	–	–	31.2±45.6	86.7±26.6
Male				
All	4.7±13.3	13.1±30.1	82.3±31.2	–
West	5.1±13.9	13.3±30.0	81.6±31.1	–
East	–	11.1±31.4	88.9±31.4	–
Unknown				
All	0.5±7.0	7.3±25.5	92.2±26.3	–
West	1.0±9.9	11.9±31.5	87.1±32.7	–
East	–	2.9±16.7	97.1±16.7	–

Without some clear mechanism for accounting for the extent and distribution of effort in the eastern area, it is difficult to discern if changes in the spatial distribution of sightings through time are associated with expanding utilisation of habitats across the region, or increasing overall opportunistic effort. The small number of sightings from this region further compounds any interpretation of any changes in the spatial distribution of sightings with time. However the distribution of sightings does reflect the emergence of habitats identified in the Conservation Management Plan as potentially of importance. These include south-east Tasmania and south-west Victoria.

Few individuals in the dataset were recorded in both sub-population areas. Of the 1057 individuals in the dataset, 26 (2.46 per cent) were observed in both areas (16 females, 5 males, 5 unknown). Nine individuals were first seen in the south-west and then seen in the south-east in subsequent years, while seven individuals were first seen in the south-east and then seen in the south-west in subsequent years (Table 4). Three individuals were observed intermittently between the two areas across years. Seven individuals were observed in both areas in the same year, with one individual (male) seen in both areas in the one year on two occasions. On all but two occasions, individuals were observed in the south-east earlier in the season and then subsequently seen in the south-west. One of these was seen as an adult in the south-east and then subsequently as a cow and calf in the south-west, suggesting this was an animal transiting through the south-east to utilise nursery/breeding habitat in the south-west. On the two occasions individuals were observed in the south-west first and then subsequently seen in the south-east, one involved a male and one involved a sub-adult. Individual spatial plots of sightings of individuals utilising both areas are provided in Appendix C.

Table 4. Number of individuals first seen in the south-east and then seen in the south-west (east-west), first seen in the south-west and then seen in the south-east (west-east) and seen intermittently between the two areas (interchange).

	N (total	West-East	East-West	Interchange
All	26	9	7	10
Female	16	5	6	6
Male	5	3	–	2
Unknown	5	1	1	2

The observations of individuals moving between the two sub-population areas is somewhat lower than that reported in Watson et al. (2021) who estimated that 7 percent of all individuals included in their analyses moved between the two areas. The discrepancies between the two studies is most likely influenced by quite different approaches to investigating connectivity. Watson et al. (2021) based their estimates on matching between the SEA SRWPIC and the broader ARWPIC, where individuals in SEA SRWPIC are assumed to have originated from the south-east, whereas here sightings and resightings across both areas and in either direction are included. Further, the percentage calculated here is based the whole dataset (both the data from the south-west and the south-east), whereas the percentage calculated by Watson et al. (2021) is based only on the smaller south-east dataset (22 individuals in a dataset of 299) included in their analyses. Watson et al. (2021) identified nine females from the south-east as matched to individuals in the south-west, a figure only slightly higher than that observed here (n=6). The lower numbers of individuals observed here are also likely to be influenced by the filtering of the dataset conducted as part of this study with all sightings of all quality and confidence classes included in Watson et al. (2021).

The historical habitats of southern right whales are not well known due to their early extirpation from a number of regions and slow recovery, with individuals still rarely documented at a number of regions historically utilised including the Peru/Chile region (Galletti Vernazzani et al. 2014) and mainland New Zealand (Carroll et al. 2014). In a number of regions, however, as recovering southern right whale populations have been monitored, expansion of habitats has been documented including Argentina (Rowntree et al. 2001, Sueyro et al. 2018) and South Africa (Best 1990).

Within Australian waters, the historical habitat of southern right whales is similarly unclear, although early whaling records suggest that particular areas in the south-east such as the lower reaches of the Derwent River in Tasmania were important (Nash 2003). The WAM aerial surveys have progressively identified a number of aggregation sites along the south-western coastline of Australia including, Albany east to Doubtful Island Bay, Israelite Bay to Point Culver, Twilight Cove and HoB in South Australia (Smith et al. 2020). The aggregation of southern right whales at the HoB has been the focus of biological studies since the early 1990s (Burnell and Bryden 1997, Burnell 2001) and small numbers of cows with calves have regularly utilised inshore areas around Logans Beach in western Victoria. As the Australian southern right population recovers, aggregation areas such as the HoB have already been observed to reach saturation capacity during years of high abundance (Charlton et al 2019a) and there are already signs of expansion into neighbouring areas such as Fowlers Bay (Charlton et al. 2019b).

Observations of individuals at multiple sites across both the eastern and western areas have been recorded previously (Burnell 2001) and the south-east of Australia is thought to comprise part of the migratory corridor for individuals utilising breeding/nursery areas in the south-west of Australia (Burnell 2001, Stamation et al. 2020). Given the opportunistic nature of data collection in the eastern area, the low number of documented breeding/nursery areas in the eastern area and the regions contribution to a migratory corridor, it is extremely difficult to determine whether sightings of individuals in the two areas represents exchange of individuals between the two sub-populations or simply reflects the transit of individuals through the eastern area to breeding/nursery areas in the south-west of Australia. Genetic investigation of samples collected from females at aggregation areas in the east and west have reported strong maternal philopatry, supporting previous observations of high female fidelity to breeding/nursery areas (Carroll et al. 2011a). Collection and analyses of genetic material from individuals in the eastern area would lend some insights into whether sightings represent transitory individuals or true exchange between the two areas exchange (i.e. shifts – either temporary or permanent – in the utilisation of aggregation habitats), with previous genetic analyses supporting the hypotheses that migratory corridors contain individuals from multiple nursery grounds (Carroll et al 2015).

The sightings of males in western Victoria and the HoB lends some support to previous suggestions that males are more transient than female and visiting multiple aggregation sites (Burnell 2001). Dispersal of males and high site fidelity demonstrated in females (Burnell 2001) is supported by genetic investigations into southern right whales in the Australian and New Zealand region, with population structure observed in maternal lineages, but little structuring evident in paternal lineages (Carroll et al. 2011a).

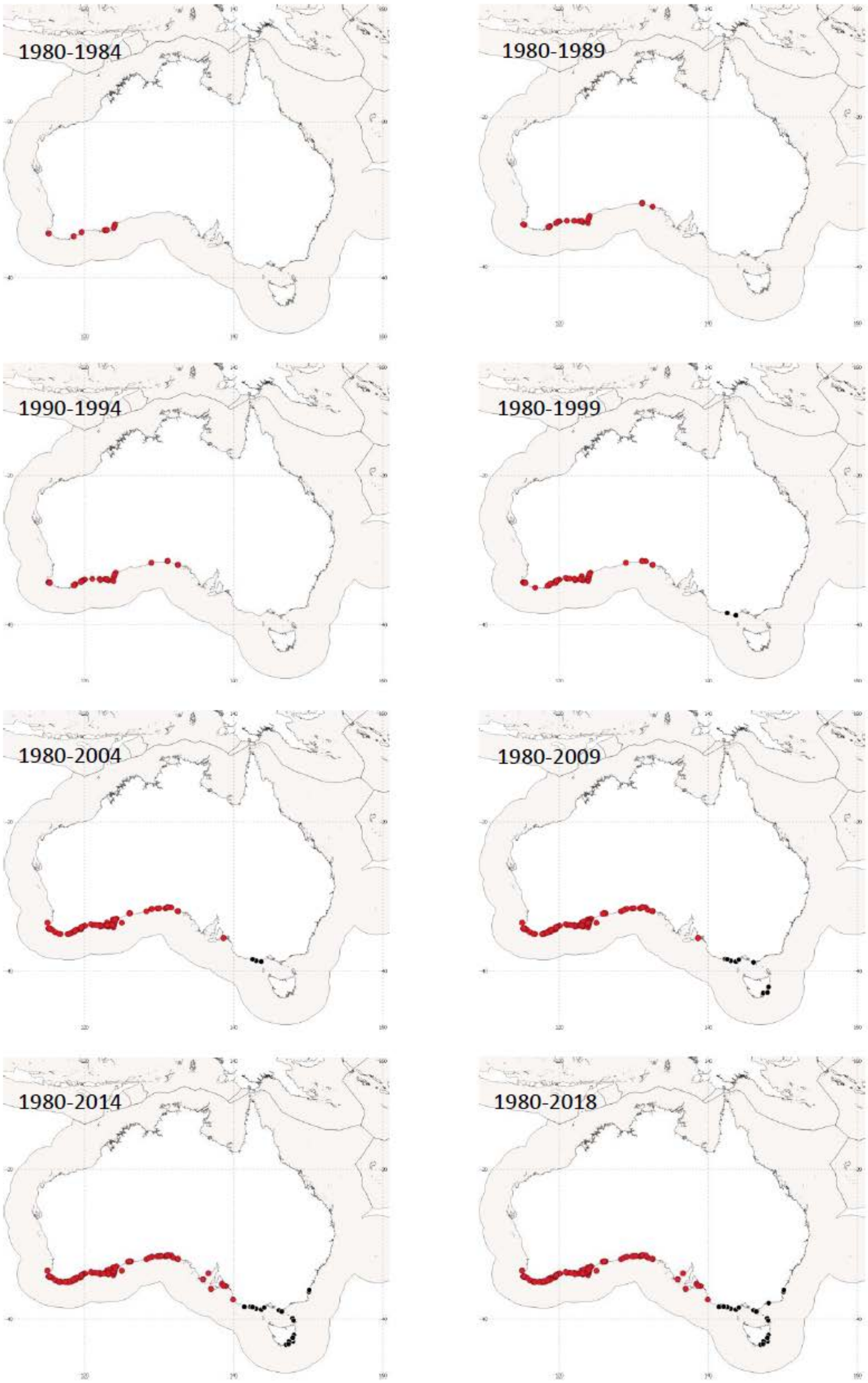

Figure 2. Spatial distribution of sightings across Australia 1980-2018. Sightings from the south-west are in red, those from the south-east are in black.

An interesting additional insight that this dataset provided was observation of calves both in terms of when they were first observed as females with calves and when males were first sighted as adults. Of the 24 calves that were sighted more than once in the dataset, the mean number of years until a calf was seen as female with a calf was 9.3±2.5 years (n=12, range 6-14) and the mean number of years until a male was resighted for the first time was 5.1±3.3 years (n=12, range 2-15). While these figures do not necessarily reflect true age at first calving or true return of males to aggregation sites, as not all individuals are resighted in any year and not all calvings and calves are seen (see section 7.1), they do correspond very well with estimates of age at first calving reported elsewhere (Best et al. 2001, Cooke et al. 2001). Not surprisingly, given the contribution to the dataset utilised here, the mean number of years until a calf was seen as female with a calf corresponds with the mean age of first calving reported in Charlton (2017).

7. POPULATION PARAMETERS AND TRENDS

7.1 Dataset

Filtering of the catalogue to provide a dataset for investigating population parameters and trends used the same selection methods as those used previously for the investigation of spatial connectivity. Only sightings associated those animals for which there was at least a three star photo (highest quality) available and for which sex class was confirmed were included, with the dataset limited to 1980-2018 (for the same reasons as outlined in section 6.1). Following Payne et al. (1990) and Cooke et al. (2001) this dataset was further filtered to only include females (cows) with calves. Limiting the dataset to females with calves is considered appropriate because:

i. in the vast majority of cases the sex and age class of a female is confirmed by the presence of a calf. Those individuals not seen with a calf are in most instances recorded as being of an unknown gender and a probable age class (unless obviously a juvenile). The probability of a whale occurring at an aggregation site may well depend on gender and maturity, which therefore influences the probably of being observed.

ii. although some females might return to an aggregation site in years in which they do not calve, a sighting of a female without a calf does not necessarily imply that a calf is not present. Calves may not be distributed sufficiently close to a female to be associated with that female or there may be multiple animals in close proximity limiting clear association of a calf with a mother. Further, females might be observed prior to when a calf is born (for example, see section 6.2). It therefore becomes difficult to divide datasets into reproductive classes and account for potential influences on the probability of being observed.

iii. previous studies have identified that a female is much more likely to be seen in a study area with a calf than when the female does not have a calf. Because most mark recapture models require independence of sightings probabilities between years, inclusion of females without calves in the dataset results in this requirement not be able to be fulfilled.

This resulted in a dataset of 714 females with calves. The dataset was categorised into two population areas demarcated by the South Australian border with Victoria following current understanding of sub-population distributions (Carroll et al. 2011a). The western component of the dataset was comprised 682 females with calves, while the eastern component of the dataset comprised 32 females with calves. The small number of females in the eastern area is similar to that analysed by Stamation et al. (2020), who included 37 females with calves in their analyses, noting that the dataset here is limited to only those individuals for which high quality photographs were available, rather than all sightings so as to reduce uncertainty in matching associated with re-sightings.

7.2 Sightings and effort

Females with calves were recorded (sighted) 2.5±1.8 times with those in the south-east sighted fewer times on average than those in the south-west (east: 1.9±1.3; west: 2.5±1.9). The densities of sightings from the two areas (i.e. the probability density function of sightings) shows that females with calves in the south-east, similarly to the dataset described in section 6.1, are predominantly only recorded once (Figure 3).

Effort associated with sightings is detailed in section 6.1 (Table 2). Given the consistency in survey design, overall effort associated with the WAM aerial survey can be considered as constant across years. To adjust for annual variability in the number of days of the survey (due to shortened or skipped days due to weather), the median number of days over the whole time series (median = 7) was assumed be representative of each year's effort. Effort associated with sightings from the western region was calculated by summing the median effort from the WAM aerial survey with effort (in days) from the HoB study.

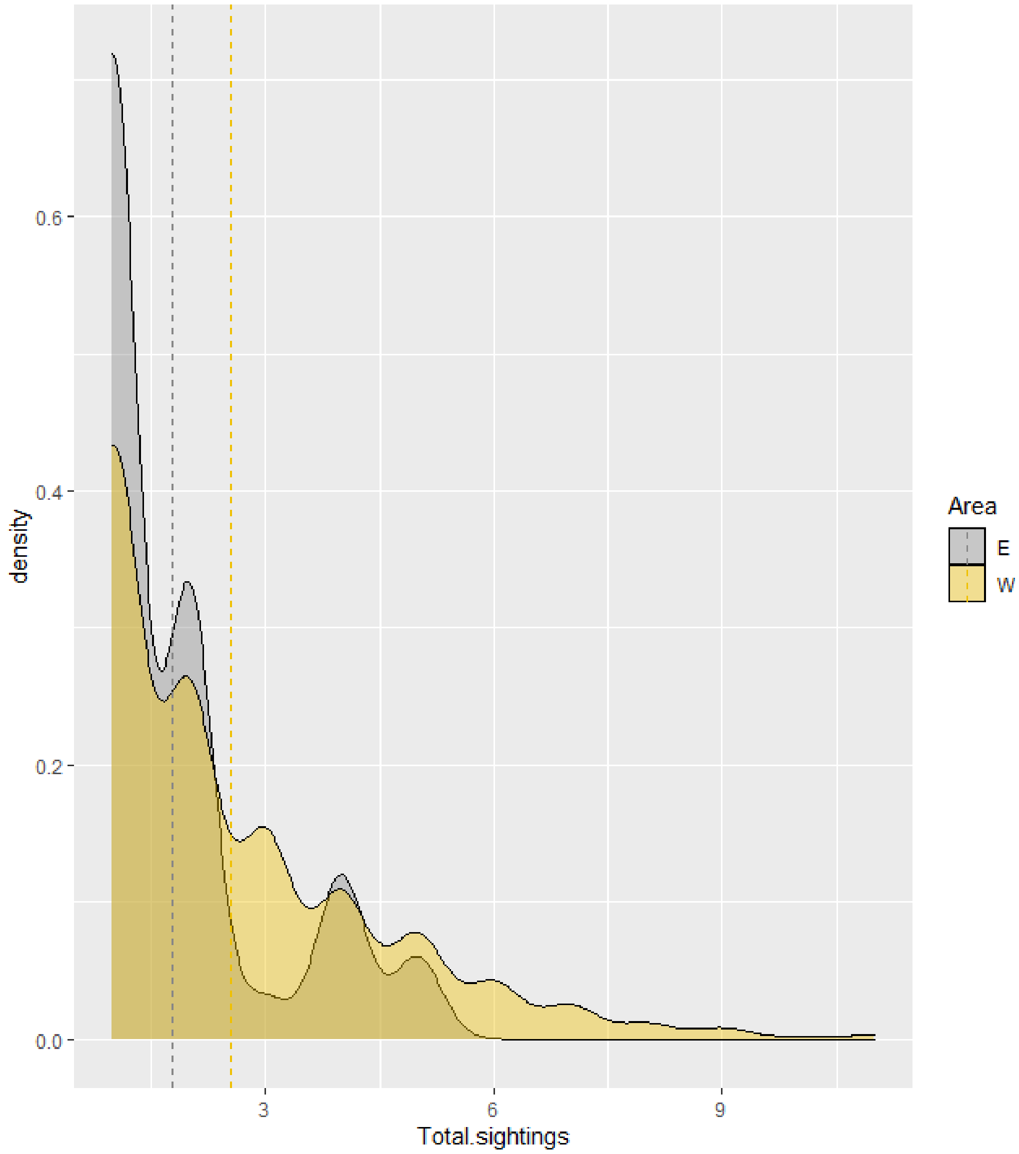

Figure 3. The probability density function of sightings of females (cows)with calves by area, 1980-2018. Vertical dotted lines represent the mean for each area.

The total number of sightings in each year in the south-west did not necessarily demonstrate an obvious relationship with effort through time (Figure 4), noting that data on effort was limited to 1992-2018, suggesting some independence of underlying population dynamics. This is not surprising, given that the population is undergoing recovery and the non-annual periodicity in the breeding cycle of female southern right whales.

7.3 Population trends and parameters

When the number of sightings (1992-2018) are standardised for effort (to sightings per day of effort), sightings per day of effort (1992-2018) in the south-west demonstrated an increase between 1992 – 2010, after which the number of sightings per unit of effort becomes visually more variable. (Figure 5). Whether this represents some form of a shift in sightings of females and calves per unit effort in the south-west is unknown given the relatively short time series of data since 2010 and the non-annual breeding cycle of southern right whales (see also section 7.2).

Of note are three visually distinct anomalous years of low sightings per unit effort in 2007, 2011/2012 and 2014/2015. These were also low years of sightings in the south-east, although without being able to standardise these sighting in regard to effort, it is unclear if these are actually reflective of the population in the region or an artifact of varying effort. These anomalous years have also been reported from analyses of data collected by the WAM aerial survey (Smith et al. 2019), noting that data from the WAM aerial survey program 2011/2012 and 2014/2015 are not included in this analysis; the appearance of similar patterns between the two analyses suggests that patterns observed are consistent across the south-west area.

It is difficult to hypothesise as to whether the anomalous years represent some form of a cycle that is perhaps becoming evident as the population recovers to levels at which any cyclicity might become obvious, particularly given the low frequency of occurrence (n=3) and the non-annual breeding cycle of southern right whales. However, these anomalous years have occurred at 3-4 year intervals, which is somewhat similar to the calving interval estimated from populations of southern right whales in South Africa, Australia and New Zealand (Best et al. 2001, Burnell 2001, Davidson et al. 2017), although slightly shorter than the 5 year interval estimated in populations from Argentina (Cooke et al. 2001); see also section 7.3.

The overall time series of sightings per unit of effort was slightly better described by an exponential regression ($R^2 = 0.48$, $p<0.001$), than a linear regression ($R^2 = 0.34$, $p=0.001$). When the time series was split into two components 1992-2010 and 2011-2018, based on the visually distinct shift in sightings per unit effort, the fit of the exponential regression to the 1992-2010 improved substantially ($R^2 = 0.94$, $p<0.001$). Both a linear regression and an exponential regression explained the time series 2011-2018 poorly (linear: $R^2 = 0.20$, $p=0.27$; exponential: $R^2 = 0.09$, $p=0.47$). This suggests that up until 2010, the rate of increase in females with calves could be regarded as exponential, but beyond 2010 no clear pattern in numbers is discernible. When a linear annual rate of increase was calculated across the whole dataset, females with calves have been increasing at 4.91% per annum. When calculated across 1992-2010, the rate of increase was 6.69% per annum, again suggesting a change resulting in a slowing down in the annual rate of sightings per unit effort for the period after 2010.

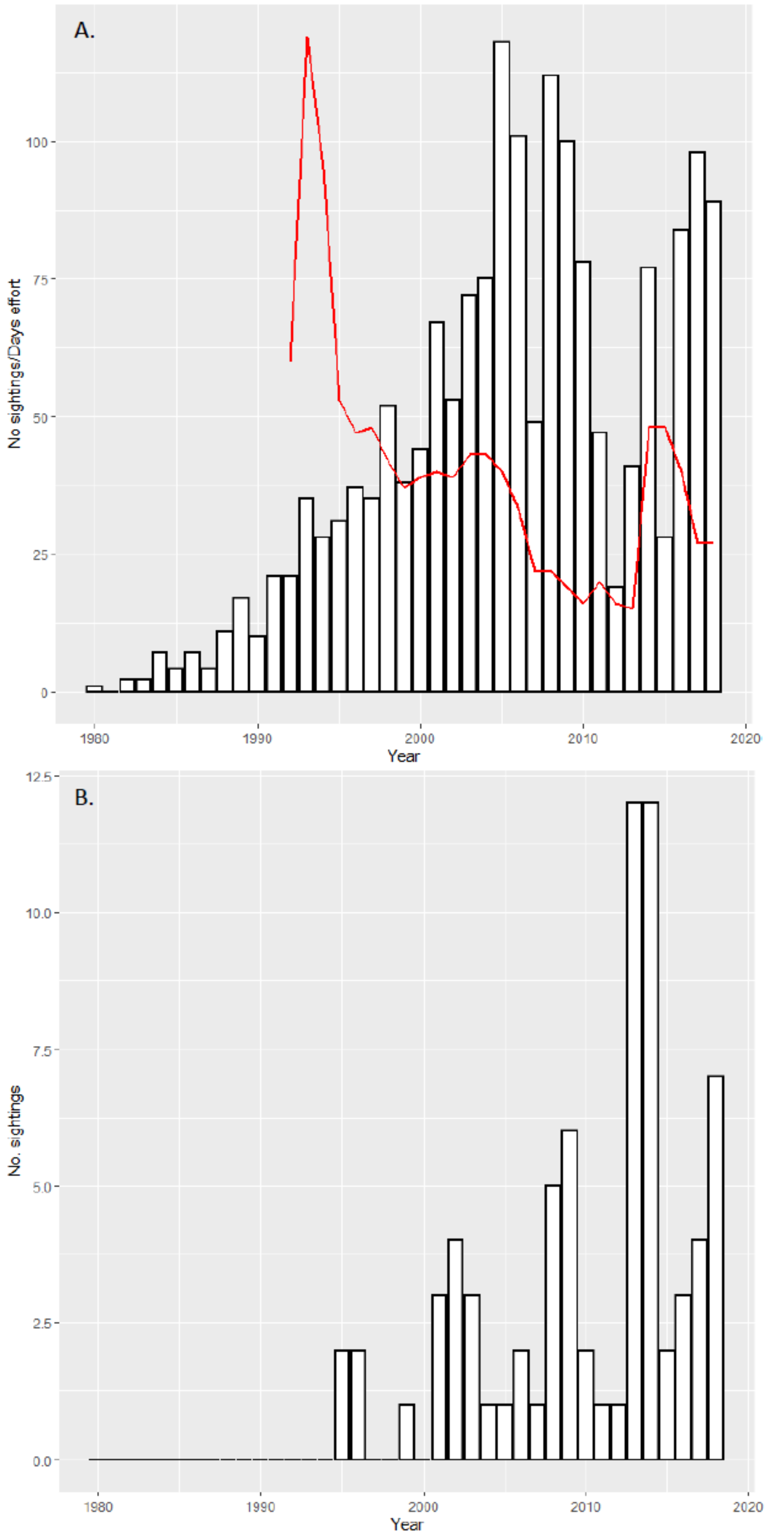

Figure 4. (a) The number of sightings of females with calves with the number of days of effort per year (red line) in the south-west; (b) the number of sightings of females with calves per year in the south-east.

It is important to note that this analysis is biased by the underlying datasets included, with only those data from the WAM aerial surveys to 2011 contributing to the dataset (the remaining photo-identification data are yet to be fully curated), so the data contributing to the overall dataset more recently comprises only that derived from the HoB. Whilst there are limitations with this analysis and more complex population modelling is needed to assess trends in population abundance for the Australian population, recent concerningly low count numbers in 2019 and 2020 and an increase in mean apparent calving intervals also suggest that the rate of recovery may have slowed in recent years.

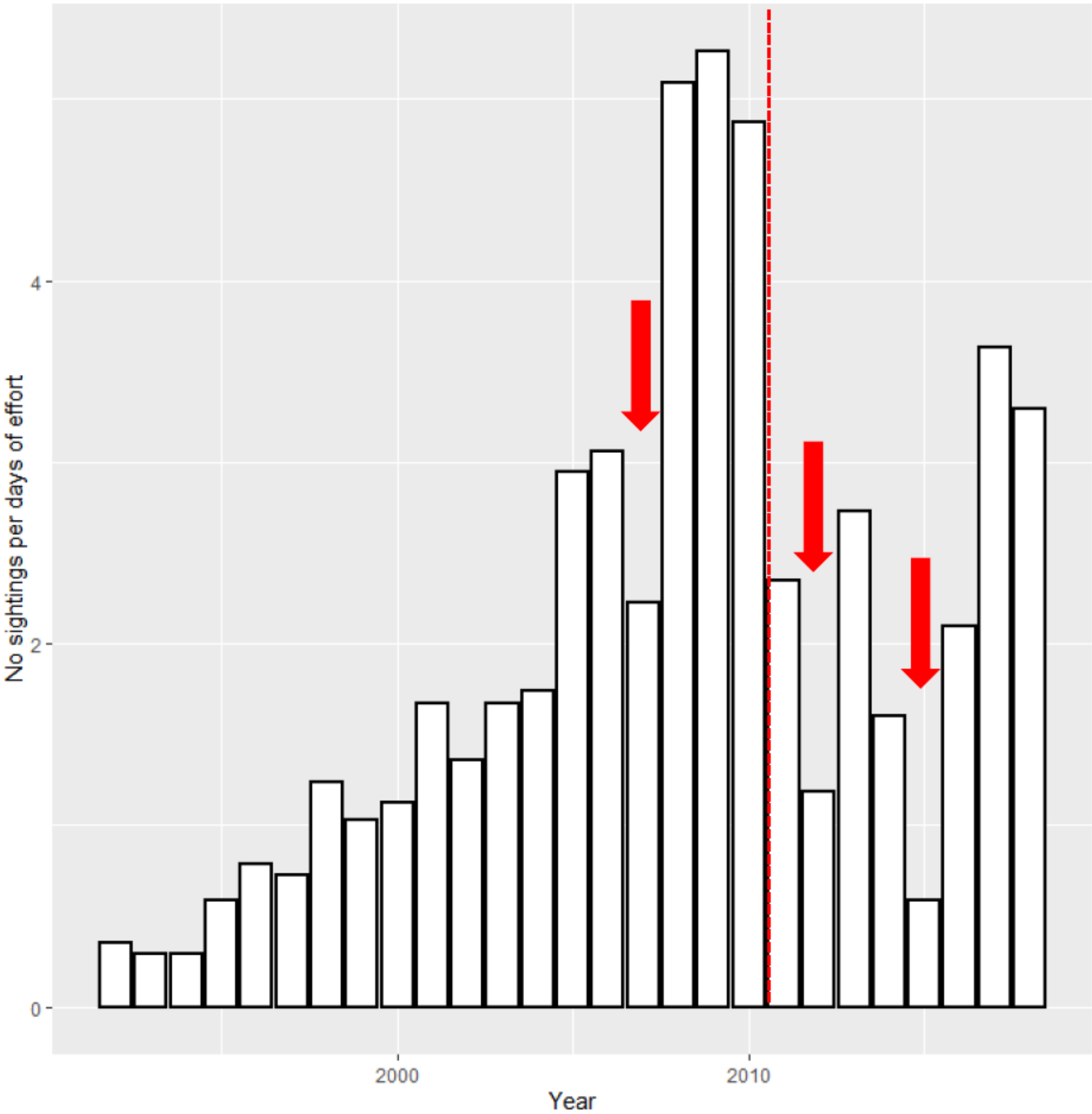

Figure 5. The number of sightings in each year per unit effort (days) in the south-west.

Correlations between krill densities (representing food availability) and calving rates have been observed in populations of southern right whales from Brazil (Seyboth et al. 2016) and the duration of reproductive cycles in populations of southern right whales from Argentina (Leaper et al. 2006) at varying time lags. Maternal condition has been observed to influence calf growth rates (Christiansen et al. 2018) and declines in food abundance prior to calving has been postulated to result in poorer condition in females and higher energetic stress in calves (Valenzuela et al. 2010). A similarly timed shift in calving rates in the South African population of southern right whales has also been observed with high calving rates throughout the 1990s and lowered calving rates throughout the late 2010s (van den Berg 2020). This reproductive decline has, similarly to previous studies, been linked to changing foraging strategies and a decrease in abundance and southward range retraction of Antarctic krill (*Euphausia superba*).

The condition of females during all parts of the breeding cycle is understood to influence the likelihood that females will breed, their success in breeding once pregnant and therefore the recovery of southern right whale populations. Understanding any potential environmental drivers that might be associated with both the apparent shift in the population growth rate of females with calves after 2010, and a potential 3-4 year cycle in sightings per unit effort from the south-west of Australia will be important for understanding the overall recovery of southern right whales in Australian waters and should therefore be an important next step in research focused on southern right whales.

For those females with calves that were observed more than once (west: n=413; east: n=14) the mean interval between sightings (i.e. resight interval) was 4.59±2.55 years with the interval between sightings in the south-west slightly less (4.58±2.55, range: 1-18 years) than in the south-east (5.07±2.32 years; range: 2-9 years). These figures should not be associated with calving intervals, because not all animals that might occur across southern Australia in a year are seen and photographed and not all calves have necessarily been born when a female is seen and therefore recorded (Cooke et al. 2001). However, the distribution of the interval between sightings is similar to that reported elsewhere and identified as indicative of calving intervals (Best et al. 2001, Cooke et al. 2001), where the majority of observations associated with resight intervals are less than 5 years and demonstrate a clear peak at 3-4 years (Figure 6).

7.4 Population modelling and estimation of abundance

Delays to the project caused through the contracting process and subsequent flow-on delays to sub-contracting of project partners, limited the amount of time the project had in exploring potential population models beyond those already developed (and identified during the planning workshop). The opportunistic nature of the eastern component of the dataset poses substantial problems in its utilisation in population modelling approaches, particularly as both effort and survey extent are not well defined in each year and vary across the whole region through time. After considerable consultation with statisticians familiar with modelling southern right whale mark recapture data, it was agreed that the lack of effort data in association with the dataset from the south-east comprised a significant hurdle to overall population modelling. An approach that was capable of addressing these limitations with the dataset and in particular the unordered level of uncertainty introduced by varying (unknown) effort was not obvious. Further expertise would need to be engaged to determine the utility of the dataset and whether a model could be developed to account for unknown effort in order to facilitate an investigation into estimation of population abundance at a national scale. Recently, approaches based on a Markov-modulated Poisson process have been developed that show some promise for opportunistic datasets (Choquet 2018). However, development of these approaches to date has been limited to populations where the whole population is available to be sampled at any one time and so their extension to populations with non-annual breeding cycles has not been tested as yet.

As a result of the limited time available, a simple model that uses the cow/calf count over three years (to allow for the 3-year periodicity in calving), and multiplies it by a factor of 3.94 was utilised to provide an estimate of the number of females with calves in each year of the time series. This followed methods utilised previously on the southern right whale population in the south-west, allowing for direct comparison across the datasets. Using this approach, the number of females with calves in each year in the western area has ranged 4-465 across 1980-2018. Across the same period, the number of females with calves in each year in the eastern area has ranged 4-28. These figures are similar to those reported previously from the western and eastern areas of Australia (Smith et al. 2020, Stamation et al. 2020).

Most population modelling efforts conducted on southern right whales to date have taken the approach of relatively complex multi-state mark-recapture models that require complex sampling models in order to relate observations (that often only sample part of the population at any one time) to the actual population (see also Appendix A). These have included bespoke modelling approaches based on estimation of population parameters driving recruitment into the population (e.g. calving interval, age at first calving, survival rates; Payne et al. 1990, Best et al. 2001, Cooke et al. 2001) that then provide estimates of the reproductive female component of the population.

A number of models provide abundance as a super-population estimate that provides for the inclusion of whales resident at aggregation sites (this can include either breeding or foraging aggregations sites, but when applied to southern right whales includes breeding sites only) in addition to those transiting through survey regions (e.g. Carroll et al. 2011b, 2013; Stamation et al. 2020). These models assume that each individual has an equal capture probability, all individuals have the same survival probability and that the area of capture and recapture is constant (Pollock et al. 1990). Although survivorship in southern right whales, and particularly in adults is likely to be high (see Cooke et al. 2001), it is unlikely that individuals have equal capture probabilities and in the case of the Australian dataset, and in particular the south-east component of the dataset, the area of capture and recapture is not constant between years. While some of these assumptions can be somewhat addressed by limiting datasets to components of the population (e.g. adult females with calves) or utilising alternative mark -recapture datasets (e.g. genetic approaches that allow males and females to be modelled separately; Carroll et al. 2013) to reduce uncertainty in recapture probabilities and capture with confidence other components of the populations (e.g. males), universal approaches to estimating abundance remain unavailable.

The complexity of these models and the likelihood that in most cases of application, assumptions are not upheld have been recognised as issues that are currently limiting understanding of populations of southern right whales across their range and in particular, comparisons of population abundances (Carroll et al. 2020). Some progress has been made in developing simpler approaches that could be applied across populations (see Butterworth and Ross Gillespie in Carroll et al. 2020) and is an active work area of the International Whaling Commission Scientific Committee Southern Hemisphere sub-committee working group.

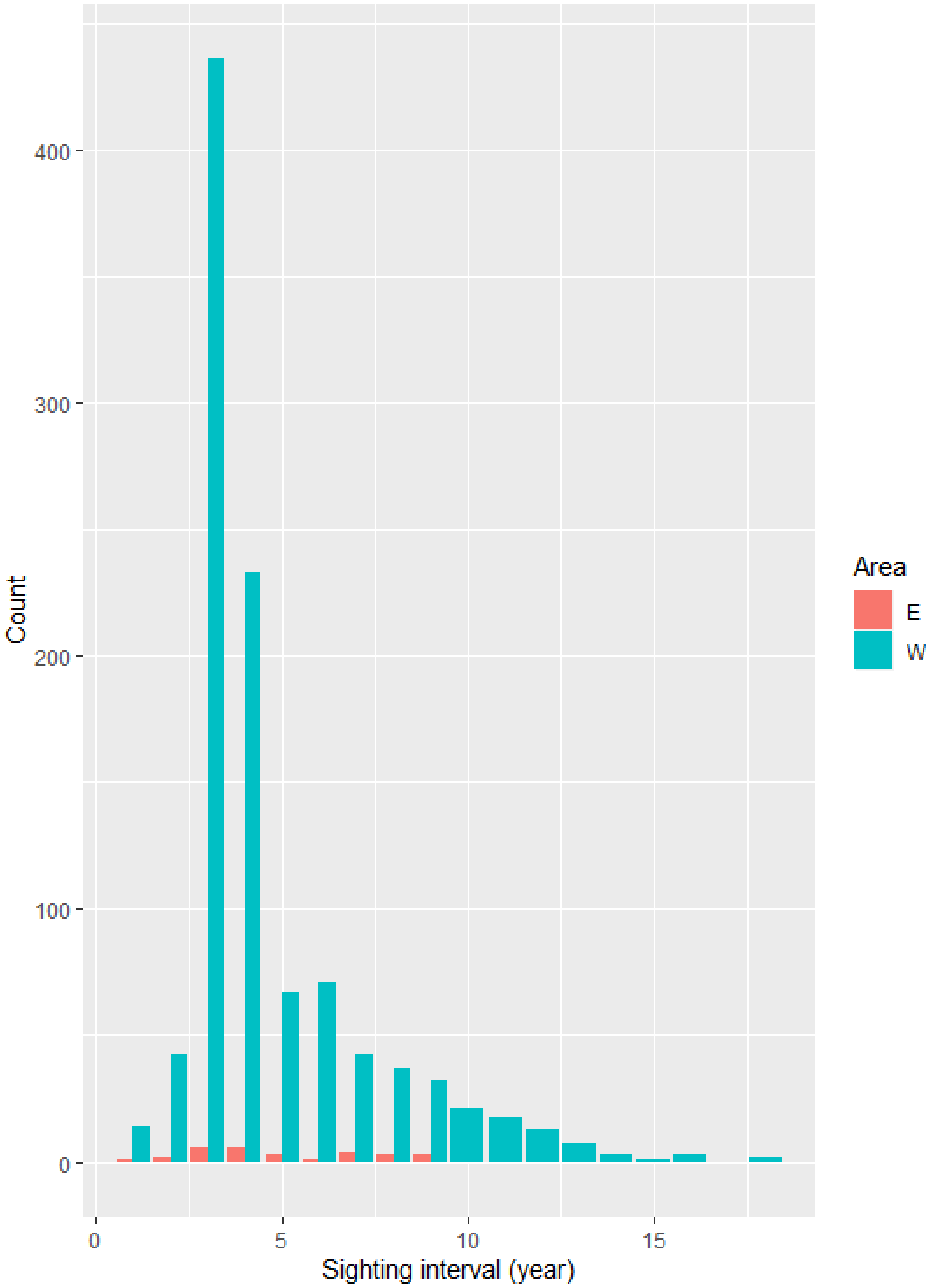

Figure 6. The distribution of the interval between sightings of females with calves 1980-2018 across Australia. E: south-east area; W: south-west area.

8. IMPLICATIONS FOR DOMESTIC MANAGEMENT AND PRIORITIES FOR SUPPORTING CONSERVATION MANAGEMENT

The Conservation Management Plan for southern right whales identifies targets associated with two interim objectives which are being used to assess the success of the long-term objectives of the plan. These are:

Interim objective 1:

Target 1.1: the south-western population of southern right whales is measured and monitored.

Target 1.2: an annual increase in abundance close to or at maximum biological rate is recorded off south-west Australia.

Interim objective 2:

Target 2.1: the south-eastern population of southern right whales is measured and monitored.

Target 2.2: the number of whales off south-east Australia shows an apparent increase for the period 2011–2021 relative to 2005–2010:

The outputs from this project, building on progress against target 1.1, suggests positive progress against target 1.2 up until 2010, but that post-2010 a shift may be occurring in recovery rates. They further suggest that while there are some indications that overall sightings of southern right whales in the eastern area are increasing, being able to tease apart changes in effort with changes in the population are impossible without having some measure of effort. This is particularly important given the small size of the dataset currently available and the apparent lack of an increase in females with calves across the area (reported in Stamation et al. 2020). These issues make it difficult to be able to determine if progress against target 2.2 is being achieved and they identify that while some effort is being undertaken to progress target 2.1, dedicated efforts are needed to progress this target to a point that it is providing data that can allow an assessment of whether progress against target 2.2 is being achieved.

8.1 Key recommendations

Given the key findings of this project and the associated limitations identified in current datasets available for assessing progress against the objectives of the current Conservation Management Plan for southern right whales, five key recommendations for future work can be identified:

1. Continuing the south- western sub-population time series is fundamentally important in understanding recovery rates and changes in populations through time, particularly given that at the moment, it is the only area in which continuous time series that allow for quantification of effort are available. Having continuous time series is fundamental for understanding the recovery of this species and given the species' non-annual breeding cycle, skipping years can miss important indicators such as the anomalous years identified in this report (and in other Australian analyses), thereby providing misleading information on

recovery rates. The need for conducting continuous annual surveys has been identified previously for these reasons (Bannister et al. 2011) and this need remains .

2. There is a real need for a dedicated focus on the south-east population and establishing a time series that meets the assumptions of most approaches to population modelling. The current opportunistic approach to data collection does not provide datasets suitable for establishing parameters and trends where effort can be accounted for and direct comparisons between the two sub-populations can be made. In addition, the current small size of datasets introduces large uncertainty into parameters calculated. The low number of whales utilising this area at present requires careful consideration of methods that could be deployed across the region that provide useful benefits in building robust datasets. An aerial survey across the region was conducted across two years in 2013 and 2014 and might be an approach that could be explored further. It should be noted that this area likely comprises both an area of habitat utilisation for calving and nursing calves and a migratory corridor for animals travelling to the western area. Any efforts, whether based around photo-identification methods or other methods (e.g. genetic or passive acoustic approaches) would need to consider how best to account for the multiple uses of the area in establishing datasets for population estimation.

3. Given what appears to be a slowing in the recovery of females with calves in the western sub-population of southern right whales and potentially an emerging cyclical periodicity of anomalous years, there is a need to not only maintain time series to better understand whether these patterns are robust and/or ongoing, but also a need to investigate the potential drivers that might be causing these patterns. Investigation into environmental drivers that might be influencing southern right whale populations and in particular linkages with the foraging ecology of the species has been identified as an area of work that should be initiated broadly (Harcourt et al. 2019, Carroll et al. 2020) and is further supported here as a priority.

4. Exploration and development of population modelling approaches that can be routinely run to provide regular population estimates for the Australian region is needed. The current range of approaches and varying assumptions of approaches results in an inability to directly compare population parameters between populations. Further, the required specialisation of modelling approaches, to account for the unique biology of southern right whales, places routine estimation of population abundance out of reach of researchers and managers requiring this information. Any exploration of approaches should consider more recently developed genetic approaches to population estimation that are capable of estimating cryptic components of populations (e.g. in the case of southern right whales, this would include males) and reducing uncertainty in recaptures, such as close-kin mark recapture (Bravington et al. 2016, Conn et al. 2020).

6. To prioritise efforts and tasks and identify pathways to achieve the above, a research prioritisation workshop should be held that brings together conservation managers, data holders, population modellers and funding agencies. This would allow the identification of tasks of the highest priority and for supporting the Conservation Management Plan, identify

the capability needed in carrying out the work and funding pathways for facilitating the work.

9. COMMUNICATION AND ENGAGEMENT

This project would not have been possible without the open collaborative intent of all of the project partners and the willingness of external experts to provide advice to the project as it progressed.

Throughout the lifetime of this project, project staff have regularly engaged with members of the migratory and protected species sections of the Department of Agriculture, Water and the Environment and provided regular verbal updates on activities to the International Whaling Commission Scientific Committee Southern Hemisphere sub-committee working group, particularly as the working group have been establishing a work program for reviewing southern right whale population parameters and historical exploitation levels. The project has provided regular updates on the project at NESP Marine Biodiversity Hub workshops and a paper for publication in a peer review journal is being drafted from this report.

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APPENDIX A – WORKSHOP REPORT

OCEANS AND ATMOSPHERE
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Southern right whale workshop: report

NESP project A13

24 – 26 September 2018, CSIRO Marine Laboratories, Hobart, Tasmania.

1 Introduction

A comprehensive understanding of the population abundance of southern right whales (SRWs) and degree of spatial connectivity between their wintering grounds in Australian waters is currently lacking. This limits assessments of the species recovery and understanding of the nature and degree of difference between the south-eastern and south-western Australian populations.

In July 2018 a project was initiated under the National Environment Science Program's Marine Biodiversity Hub with the aim of providing, for the first time, an abundance estimate of the total Australian population of SRWs. In doing so the project also aims to investigate the connectedness of whales that utilise breeding areas and migratory corridors on the eastern, southern and western coasts of Australia. Once delivered, the Information provided by this project will allow the Australian government to better evaluate progress made against the Conservation Management Plan for SRWs and ensure conservation efforts for the species are effectively coordinated at the regional level.

As a first step in undertaking the work required for mobilising photographic identification sightings data currently held across a range of project partners and developing the specialised population models required for achieving the projects aims, a workshop was held at the CSIRO Marine Laboratories. This workshop brought together most of the project team and aimed to:

(i) identify the datasets currently held by project partners in Australia and their readiness for use

(ii) identify the current state of the national database for SRW sightings (Australian Right Whale Photo-Id Catalogue; ARWPIC) and its current utility for facilitating the generation of data required for population models

(iii) identify potential population modelling frameworks that might be suitable for use by the project and their data requirements

(iv) develop a workplan and timeline for the project to be carried out by the project team

The agenda for the workshop is provided in Appendix 1.

The workshop was attended by Rachael Alderman (Tasmanian DPIPWE), Emma Carroll (Auckland University), Claire Charlton (Curtin University), Mike Double (AAD), Karen Evans (CSIRO), Natalie Kelly (AAD), Sylvana Maas (Australian DoEE), Andy Townsend (ATDesign), Judy Upston (CSIRO), Mandy Watson (Victorian DEWLP).

2 Data

Four main datasets currently managed by the NESP project partners were identified as containing the vast majority of SRWs photo identification sightings data: (i) West Australian Museum (WAM) long term aerial survey program; (ii) Head of the Bight long term monitoring program (facilitated through a number of agencies and universities, currently managed by Curtin University); (iii) the South-East Australia Southern Right Whale Photo-Id Catalogue (SEA SRW PIC, managed by Victorian DEWLP); (iv) the Tasmanian DPIPWE SRW sightings. There are a number of smaller datasets held by a number of other agencies, however in considering what might be achievable in the timeframe of this project they were not considered further by the workshop.

2.1 West Australian Museum long term aerial survey program

These surveys were started in 1978 and from 1993 were conducted across the area from C. Leeuwin and Ceduna.

The survey is not complex and assumes that all animals are close to shore (within 1nm). The survey counts individuals on the way out, counts again on the way back and whichever is the higher count is then used. The survey has used the same plane, pilot and photographer since the 1990s.

Population estimates generated by the surveys are based on the average number of cows observed with calves over a three year period that is then subject to a multiplication factor that extrapolates the number of reproductive females to total population size. As female SRW typically show a three year calving cycle, this is thought to capture the majority of breeding females in the population. However, given that the average number of cows with calves is a three year average, and can be influenced by consecutive low/high counts, the total population size estimate can be thereby biased by consecutive low/high counts.

The photographic matching method historically used by the program was developed by Lex Hiby – this is complex and involves a number of individual executables, so there are some questions about whether this method should be continued to be used.

The dataset is not fully reconciled; some QC of photos by those involved in the initial migration into ARWPIC means that only those photos of sufficient quality were migrated across. However, the majority of photos through to 2012 are in ARWPIC.

The 2018 survey and associated data collection (under NESP MBH project A7) has recently been completed, however it not clear what state the data is in. Most likely the data are still in paper form/yet to be digitally transferred.

There is still a process in getting on top of data by the new team on project A7.

2.2 Head of the Bight long term monitoring program

This program has been operating for 28 years, but with varying effort (minimum 2 weeks maximum 4 months) focused around a peak abundance that occurs from mid-July to the end of August.

The aims of the program are to assess trends in distribution and abundance, as well as a range of life history parameters through cliff-based population counts and photo ID. Life history parameters include: rate of increase, calving intervals, age of sexual maturity, residency, site fidelity, survival, longevity and mortality.

The program traditionally has focused on the Head of the Bight (HoB) only, however, was recently expanded to include some of the merging or smaller sites (e.g. Fowlers Bay South Australia). Most recently it has been the focus of a PhD (finalised in 2017) that included analyses of population abundance and distribution (HoB), population demographics (Sthn Australia), residency and site fidelity (HoB), population dynamics (Fowlers Bay) and connectivity (Fowlers Bay and other areas in Australia and New Zealand).

The program uses quite strict photo QC and processing procedures for their catalogue and matching is done with Bigfish.

The HoB has been found to have consistently lower rates of increase than those calculated for the western population overall. It has been proposed that this is likely because it is an open population and consists not only of resident animals, but also migratory animals that are moving through.

The mean calving interval calculated from the HoB is 3.3 years, although there may be signs that the calving interval has increased in recent years.

The saturation capacity of HoB is estimated at 55-68 individuals (depending on a 150/200m nearest neighbour distance). The population is not static and immigration and emigration to and from other wintering ground areas has increased with increased abundance.

Other projects being conducted in association with the program include:

- SRW population demographics (Curtin Uni, University of Cape Town, IWC)
- Great whale acoustics (Curtin University)
- SRW Encounter Bay citizen science (emerging calving ground – BigFish catalogue development, Flinders Uni)
- SRW body condition (Murdoch Uni)
- SRW health assessment (Curtin Uni)
- SRW calf development (Curtin Uni, DEWLP, WAM)
- Artificial Intelligence based right whale photo id matching (NOAA, Curtin Uni, Wildme)
- Global comparison of SRW population demographics (IWC)

None of the program's photo catalogue is currently in ARWPIC.

2.3 SEA SRW PIC

The catalogue is based largely on incidental data collected from eastern South Australia, Victoria, NSW and Tasmania between 1993-2017 (including two population assessment aerial surveys from Ceduna to Sydney and around Tasmania in 2013 and 2014).

All of the data to 2016 has been migrated to ARWPIC with three years outstanding (2016-2018).

In migrating data into ARWPIC in the past it was estimated that this process took 3 hours per sighting (including photo formatting, metadata, coding and matching tasks), with the time required for validation of matches additional to this.

Much of the data held in SEA SRW PIC has been contributed by citizen scientists.

2.4 Tasmanian DPIPWE SRW sightings

Most of the sightings are already in ARWPIC with ~30 sightings from recent years still needing to be entered.

Many of the recent photographs in the Tasmanian collection are from the public, which raises questions about incorporating them into ARWPIC – specifically around whether seeking individual permission to use the photos is required. In addition, the collection increasingly relies on drone footage. There is currently no legislation in Tasmania restricting this, but some sensitivities associated with the use of drones to collect photographs need to be acknowledged.

3 ARWPIC

The ARWPIC, the development of which was facilitated through the Australian Antarctic Division's Australian Marine Mammal Centre, was first initiated in 2010 the first phase of which was focused on design development. The infrastructure build occurred in 2012, with the first data migrated in the catalogue in 2013 (consisting of Tasmanian and WAM datasets).

Data input into the catalogue consists of a well-defined workflow, although there is some further work required in developing, refining and clarifying the protocols associated with matching and data entry processes to ensure consistency in data quality. This is particularly important when there are a number of people involved in the curation based in varying locations around the country. Additional work on database functionality is also required to streamline workflows and alerting processes.

3.1 Issues

An overview of some of the issues associated with data quality and functionality of ARWPIC identified during the migration of SEA SRW PIC was distributed prior to the workshop. A summary of these issues is provided in Appendix 2. Additional issues identified during the workshop include:

(i) Sightings are not curating properly – accepted sightings not pushing through to then come off the 'pending' list.

(ii) Missing images. A number of images from the SEA SRW PIC haven't loaded

(iii) There is currently no system for logging validation acceptance/rejection

It was agreed, in stepping through these issues that an action list for addressing current bugs and functionality issues be generated for ATDesign to then work on. It was also agreed that in light of a number of errors within the data already contained within ARWPIC incidentally detected during the SEA SRW PIC migration, it would be necessary to validate the entire dataset before proceeding with migration of outstanding data held in regional catalogues and population modelling.

4 Population models

Mark recapture models can provide unbiased estimates of abundance, survival and population growth rate if model assumptions are met. The assumptions can be specific to each model, but generally include (1) marks are permanent and can be correctly identified; (2) there is no behavioural response to capture; (3) the population is definable; (4) there is no heterogeneity in capture probability between individuals. Closed models further assume that there are no additions (births, immigrations) or deletions (deaths, emigration) to the population, whereas open models can account for these factors.

Data used in mark-recapture studies of right whales

Photo-id of right whales has been used since the 1960s in the North Atlantic and has been collected from populations in Sth Africa, Australia and Argentina since the 1970s.

DNA profiling has been used extensively in the North Atlantic, North Pacific and Indo-Pacific. This approach also allows for identification of sex and in future, potentially also age.

Models

Super-population models have been used on North Pacific right whale and New Zealand SRW data (Wade et al 2011, Carroll et al 2011). The advantage of this open model is that in a migratory setting, the super-population estimate can be thought of as the whales that use the region as well as those that could migrate past but are still part of the same 'population'.

Auckland Islands right whale DNA profile catalogue

This catalogue was started because of difficulties in running aerial surveys across the region and as a result a DNA profiling approach was undertaken.

The site can be regarded as an unusual wintering ground because of its subantarctic location and also because all demographic classes occur in Port Ross.

The capture probability of individuals varies with reproductive state. In the years they calve, females have a higher capture probability, because they have a longer residence time and spend more time at the surface on the wintering grounds. In resting or receptive years, they have a lower capture probability, presumably because they have a shorter residence time.

This variability is not straight forward to address because different females will calve in different years, and calve on average once every three years (noting that some will lose a calf and might have a calving interval of 2 years).

The solution was to develop a capture recapture model that incorporates a lower capture probability in non-calving years, using the addition of parameter tau (τ). Individuals are sighted at time t with a capture probability p. If an individual as a cow is sighted at t3, then her capture probability is adjusted in subsequent and previous years by the parameter tau. This is similar to a behavioural response model, but goes forward and backward in time.

This is applied in a superpopulation POPAN model that incorporates a lower capture probability in non-calving years and is extended so that it estimates growth rates (developed by Rachael Fewster, University of Auckland). Males and females are modelled separately.

Estimates of the abundance of males and females, were found to be quite similar. However, because the female model incorporates changes in capture probability, the growth rates estimated between males and females differed substantially in precision (published in Carroll et al. 2013).

When the use of the parameter tau was explored, if the change in capture probability is not included, the abundance is positively biased, but the rate of change not biased. The model was found to be relatively robust to misclassification of reproductive state.

Heterogeneity in capture probability is linked to reproductive state and sex is an important consideration when using mark-recapture models for SRWs. These have been found to influence recapture probability in the Auckland Islands (Carroll et al. 2013) and Argentina (Rowntree et al. 2001). Although males and females have similar resighting rates in the Auckland Islands, males more likely to be seen in consecutive years, while females have been observed to be more likely to be recaptured between 1990s and 2000s (Carroll et al. 2013).

Other models

Multi-state mark-recapture models (MSMRMs) for SRWs were first developed by Payne et al. 1990 and have since been extended by Cooke, Butterworth, Brandao and others (Pace et al. 2017). These have been used particularly on the Argentinean and South African wintering grounds, where aerial surveys that undertake efforts to photo-identify individual whales are undertaken. The modelling efforts are largely focused on females only as these are the only group able to be routinely identified from photo-id.

In general, MSMRMs model the population based on individuals in different states which can be static (e.g. sex) or dynamic (e.g. age).

These models assume:

- The rate parameters for individuals within a state are homogeneous
- The fate of an individual depends on its present state but not on its past
- Fates and captures of individuals are independent

The SRW MSMR model takes the observed calving interval data and uses it to estimate the 'true' calving internal pattern. The 'true' number of calving events can be used to estimate abundance and growth rate.

This particular model is data intensive, difficult to implement and converge, so probably not something to consider for this project. However, it is another example of how to incorporate reproductive state into the mark recapture framework for SRWs.

Things to consider

Australia has a migratory network which is different to the distinct well studied wintering grounds in other areas in the Southern Hemisphere. Further, the southern coast of Australia comprises different habitats and different behavioural states of animals occupying different habitats and these are not constant.

As a result there is a need to think about:

- what time period to include in the model and how habitat might have changed through time – how do we account for that?
- what should be the focus – known females? How do you factor in different calving grounds with different levels of effort?
- what are the data requirements – the number of matches really defines the level of effort you put into the modelling.

Off the shelf modelling options may not be sufficient and there is probably a need to consider developing a bespoke model.

Suggested framework and associated considerations

Start simple.

Data rich regions (as an example dataset) could be used to test some of the assumptions/identify biases and models that could then be applied more broadly e.g., capture probability linked to effort and unusual years.

Simulations could also be used to evaluate extent of biases on capture probabilities.

A good starting point would be to revisit the comparisons made between the two populations by M. Bravington and S. Hedley (contained in Bannister et al. 2011)) and revisit some of the problems encountered in modelling the data.

There is a need to consider:

- the standardisation of effort – both on an individual basis but also on a seasonal basis – and in association identify a time where there is reasonable effort across all datasets.
- the categorisation of individuals (e.g. calving, migratory/transient)
- what is important from a population estimation point of view? What is the relationship between the south-east and west?
- the appropriate scale for identifying mixing/defining habitats. Could use the latitude and longitudes of sightings and look at the post hoc distributions – removes any preconceived ideas on spatial distributions/habitat assignment.

There may be a need to model data quality and a plan for what to include in the metadata and the format will be required.

5 Workplan

The first process for the project is to validate the current dataset that is in ARWPIC before adding in any further datasets (1,800 individuals). In association it was agreed that:

- Given need to validate, accept all of Mandy's pending list (***done***);
- Run a training workshop to bring those members of the project team (and others from current data holder agencies) not currently experienced with using the ARWPIC up to a minimum training standard to assist with processing;

- Correct the current errors in ARWPIC and introduce a facility for error logging;
- Explore metadata to identify any patterns that might assist in identifying discrepancies;
- Identify images that are missing and allow for greater resolution of images being uploaded;
- Fix process related bugs in ARWPIC;
- Introduce a skip function that will allow for the fast-tracking of 'known' matches – this will allow the first matching process to be skipped/streamlined;
- Step through each of the individuals currently in ARWPIC and check the coding (thereby completing validation of all data currently in ARWPIC);
- Introduce a rejection/acceptance log to allow tracking of decision making and enable fast checking with metadata;
- Include effort information

In considering the process moving forward a number of points were raised:

- The project may want to focus on years with good quality photos across all sites;
- It was agreed that while there are individual catalogues that will continue to be maintained, the emphasis is on a central database to maximise utility of individual catalogues;
- There is a need to ensure the project makes clear what the steps are and what is needed post the project;
- The project may want to identify how many whales/sightings you can process in an hour to be able to estimate how quickly can generate a datatset for modelling (HoB example 45 mins to an hour each whale);
- Associated, the feasibility of achieving curation of all datasets given the time frame and funding available. We may need to prioritise years or datasets.
- There is a need to consider how many levels of a search (for matches) to conduct. In association it would be useful to categorise the current codes on their objectivity/subjectivity and then explore what codes capture most matches.
- In exploring biases it would be useful to identify the characteristics in the metadata that allow you to identify if a whale is distinctive or not distinctive (is there a bias for matching distinctive whales?)

5.1 Specific tasks and timelines

Once a month

Karen to:

(i) Organise a virtual meeting to discuss progress

By October 5

Andy to:

(i) Run check against (i) group size and status (ii) status in individual and event (iii) cows are flagged as female (iv) sex, sex confidence and sex determination method to identify discrepancies

(ii) Run a report of all events, sightings and image data for the SEA SRW PIC submissions to assist Mandy to work out which images have not uploaded in the SEA SRW PIC migration

Mandy to:

(i) Provide list of errors already identified to Andy to implement corrections (***done***)

Mandy and Rachael to:

(i) Rank code categories on the basis of objectivity/subjectivity (***done – see Appendix 3***)

Claire to:

(i) Claire to provide Mike with double ups in John's dataset (***done***)

Karen to:

(i) Investigate document sharing facilities hosted by NESP/CSIRO (***underway***)

Mike to:

(i) Create a what's app group for the project to facilitate rapid communication (***done***)

By October 12

Mike to:

(i) Cross check JBs data in ARWPIC against data in the access database (depending on number may need a bulk correction from Andy) - include the double-ups identified by Claire
(ii) Produce a 2 page summary of the state of the WA dataset
(iii) Identify if there are additional photos of individuals to those currently in ARWPIC

Claire to:

(i) Provide a metadata summary of WA photos from HoB and matching done to date

By end of October

Rachael, Mandy, Claire to:

(i) Agree on coding principles and refine coding and work flow protocols as preparation for a training workshop(s) to reduce subjectivity in curation by a range of individuals and agree on a set of "training" whale images as preparation as preparation for the workshop (s).

Karen, Rachael, Mandy, Judy, Mike, Claire to:

(i) Run a training workshop to bring Karen, Judy, Mike and others (AAD, DPIPWE, DoEE) up to a minimum training standard to help with processing (note identified that this might need to be two workshops to coordinate across availabilities). In association:
   a. Run through check of codes and then divide up and assign validation tasks
   b. Have a draft update to protocols ready for workshop and include further updates to the protocols as we work through the examples

Claire to:

(i) Finalise HoB database curation 1991-2018 (inclusive) and provide Andy with data to explore efficient ways of importing large dataset. Including: image upload, sightings data, ID Coding, description of image descriptions.

By early December

Karen, Rachael, Mandy, Judy, Mike, Claire, others (AAD, DPIPWE) to:

(i) Complete validation of the data currently in ARWPIC including:
   a. Step through individuals, check codes and correct
   b. Pick up any errors and correct
   c. Run a report on whales with the same coding to identify double ups/errors

Rachael, Mandy, Claire, Mike to:

(i) Complete effort table metadata sheet

Emma (and Jen) to:

(i) Identify format for export tables for ARWPIC metadata to send to Andy

Andy to:

(i) Export metadata and send to Emma – do that through document sharing facilities

Rachael, Mandy and Claire to:

(i) Identify what are the characteristics in the metadata that allow you to identify if a whale is distinctive or not distinctive in order to guide some exploration of the data for biases

(ii) Check on a subset of the new curators to ensure that all new curators are appropriately conducting the validation process

By mid-December

Mandy, Rachael and Claire to:

(i) Complete all back-end preparation of Tas, Vic, HoB with datasets ready to begin the migration process (note may need to push this back a little depending on availability)

(ii) Completion of all SEA SRW PIC and Tasmanian data curation so that ARWPIC is ready for input of HoB data.

By beginning of April

Karen, Judy, Claire (with others if interested) to:

(i) Complete initial spatial exploration of sightings to identify habitat distributions

Emma and Jen (with others if interested) to:

(i) Complete exploration of resight data to identify biases and identified some options for modelling frameworks

Rachael, Mandy and Claire to:

(i) Migrate Tas (first), Vic (second) and HoB (third) datasets into ARWPIC (Andy to facilitate bulk migration)

Karen, Rachael, Mandy, Judy, Mike, Claire, others (AAD, DPIPWE) to:

(i) Complete validation of migrated datasets from Tas, Vic, HoB

Claire to:

(i) Provide Mike with a list of HoB image names/photo codes and ARWPIC codes to facilitate quick searches/matches of the WAM data from the HoB

Andy to:

(i) Write some code allowing quick matching of above photos

Yet to be determined

Andy to:

(i) Check coding of whales to see if there are consistencies in coding differences that might be causing the doubling up on whale IDs
(ii) Construct process to merge individual animals that are currently identified as two individuals
(iii) Increase limits on image size
(iv) Provide image quality grade with each image listed with each sighting and an ability to change the grade from the individual sightings page
(v) Error log needs to be built into the database so they can be logged as you move through the database and then the curators check to make sure that the error is really an error
(vi) Fix bugs with curation process so pending list is cleared efficiently
(vii) Include an acceptance/rejection log within the database
(viii) Introduce a skip function that will allow for 'known' matches – will still be validated, but allows the first matching process to be skipped/streamlined
(ix) Do a bulk upload of effort information (opportunistic/survey) for images
(x) Develop export capability for export of metadata
(xi) Edit view of CodeCompare so that adjustments are not required when searching through multiple individuals.

Mike, Karen and Judy to:

(i) Complete all back-end preparation of WA dataset
(ii) Migrate WA data into ARWPIC

Karen, Rachael, Mandy, Judy, Mike, Claire, others (AAD, DPIPWE) to:

(i) Validate migrated dataset from WA
(ii) Validate migrated dataset from HoB

Mandy and Rachael to:

(i) Explore avenues for Indigenous engagement

6 Additional considerations

Some consideration was also given to Indigenous engagement by the project. It was agreed that it would be beneficial if the project could assist in identifying potential opportunities for capacity development, particularly in migrating data across to ARWPIC and the associated validation process. It was noted that many traditional owner groups were already overwhelmed by requests to be part of processes, so finding beneficial, useful and appropriate ways of engagement was important. It was identified that Victorian DEWLP was exploring an internship opportunity and there might be the potential as part of the internship to build ARWPIC curation capacity as part of this, particularly if avenues for additional funding for the internship could be identified. Exploration of avenues for engagement with Tasmanian ranger groups was also identified as potentially useful.

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Appendix One: workshop agenda

Monday September 24

Introduction

9:00: Welcome, introductions, housekeeping

9:30: Project and workshop overview – Karen Evans

Data

10:00-11:00: Datasets held – Mike Double, Claire Charlton, Mandy Watson, Rachael Alderman

11:00-11:30: Morning tea

11:30-12:45: Discussion on current state of datasets and 'readiness' for the ARWPIC – all

12:45-13:30: Lunch

ARWPIC

13:30-14:00: Overview of ARWPIC: Mike Double

14:00-15:00: Identified issues with ARWPIC and associated processes for cataloguing photos – Mandy Watson and Rachael Alderman

15:00-15:30: Afternoon tea

15:30-17:00: Discussion on tasks required for addressing current issues with ARWPIC – all

Tuesday September 25

09:00-09:30: Recap of previous day – Karen Evans

Population modelling

09:30-10:00: Population models developed for SRWs – Emma Carroll

10:00-11:00: Discussion on suitability of models for the Australian region – all

11:00-11:30: Morning tea

11:30-13:00: Discussion on minimum requirements for photo id mark recapture for models/QA&QC of data – all

13:00-13:45: Lunch

Current data, ARWPIC and requirements for QA and QC

13:45-15:00: Discussion on QA & QC requirements, current data in ARWPIC and capabilities of ARWPIC – all

15:00-15:30: Afternoon tea

15:30-17:00: Discussion on QA & QC requirements, data to be migrated into ARWPIC– all

18:00: Workshop dinner – Venue TBA

Wednesday September 26

09:00-09:30: recap of previous day – Karen Evans

Next steps

09:30-11:00: development of a workplan for datasets and ARWPIC – all

11:00-11:30: Morning tea

11:30-12:30: remaining business from days 1 and 2 and close of workshop – all

12:30-13:30: Lunch

Appendix Two: summary of issues with ARWPIC

Discussion points around issues with ARWPIC for the workshop

Real time processes

- Need to upload all photos in (and matched) before validation can occur
- Not clear if uploaded photos become immediately available or if there is a lag
- Creates some issues around having multiple users uploading/matching and validating at the same time

Searching, matching and validating processes

- Search algorithms not universal – some issues regarding the use of classification categories (e.g. field left blank/unknown categories don't return the same results)
- Requires several searches to be run in order to match whales – this, with the requirement for visual matching results in individual whales taking 2 or more hours to match
- There is a need for clear guidance around coding of whales to reduce incorrect coding and subjectivity associated with coding. This will reduce the number of incidences where the same whale is identified as multiple whales or multiple whales identified as the same whale and therefore increase certainty in matches
- Ease of use – some functionality in the search functions could be improved. For example being able to skip to certain results and an ability to scroll through more than 5 search results at a time

Data entry and processing

- Most datasets have been ordered into folders by whale under BigFish (with each folder then containing multiple sightings) - because ARWPIC requires breaking down each folder into individual events there is a process in translating individual files for bulk upload to ARWPIC
- Is often a loss of image quality once photos are uploaded, which can impact the ability to match photos and validate matches
- At the moment meeting the requirement for a standardised file name format requires manual modification of file names prior to bulk upload
- There is a lack of a notification process for errors in upload (users therefore are not aware when images don't load) and rejection of matches during validation. Further, a record of rejected matches is not kept.

Appendix Three: Coding Appraisal

CODING FEATURES	OBJECTIVE OR SUBJECTIVE	RELIABILITY/CONFIDENCE (HIGH, MED, LOW)	CAN BE USED FOR LATERAL IMAGES?
GREY - YES	OBJECTIVE	HIGH	YES
GREY - NO	OBJECTIVE	HIGH	YES
DORSAL BLAZE - GREY	OBJECTIVE	HIGH – IF COMPLETE BODY IMAGES ARE AVAILABLE	NO
DORSAL BLAZE – WHITE	OBJECTIVE	HIGH – IF COMPLETE BODY IMAGES ARE AVAILABLE	NO
DORSAL BLAZE – MIXED GREY/WHITE	OBJECTIVE	HIGH – IF COMPLETE BODY IMAGES ARE AVAILABLE	NO
DORSAL BLAZE - ABSENT	OBJECTIVE	HIGH – IF COMPLETE BODY IMAGES ARE AVAILABLE	NO
LIPS (L AND R) PRESENT	OBJECTIVE	HIGH	YES
LIPS (L AND R) ABSENT	OBJECTIVE	HIGH	YES
LIPS (L AND R) SHORT	SUBJECTIVE	AMBIGUITY ABOUT THE INTERPRETATION OF SHORT LIPS, TO BE MORE TIGHTLY DEFINED IN THE PROTOCOLS	YES
SUBS (L AND R) PRESENT	OBJECTIVE	HIGH	YES
SUBS (L AND R) ABSENT	OBJECTIVE	HIGH	YES
N ISLANDS (L AND R) 0 - 9	OBJECTIVE	HIGH	YES – DEPENDING ON ANGLE
POST BLOWHOLE FUSED	OBJECTIVE	HIGH	NO
POST BLOWHOLE SEPARATE	OBJECTIVE	HIGH	NO
CENTRAL FEATURE PRESENT	OBJECTIVE	HIGH	NO
CENTRAL FEATURE ABSENT	OBJECTIVE	HIGH	NO
BARS (L AND R) PRESENT	OBJECTIVE	MEDIUM - DISTINGUISHING BARS FROM CLOSE ISLANDS CAN BE PROBLEMATIC DEPENDING ON IMAGE QUALITY	NO
BARS (L AND R) ABSENT	OBJECTIVE	MEDIUM – AS ABOVE	NO
COAMING – NONE	OBJECTIVE	HIGH	NO
COAMING – CONTINUOUS	OBJECTIVE	HIGH	NO
COAMING – ELONGATED,	SUBJECTIVE		NO
COAMING – NOT DISTINCTIVE	SUBJECTIVE		NO
COAMING – OTHERWISE DISTINCTIVE	SUBJECTIVE		NO
BONNET ERODED – YES	SUBJECTIVE	LOW - AMBIGUITY ABOUT EXTENT AND DEPENDS ON ANGLE OF IMAGE	NO
BONNET ERODED - NO	SUBJECTIVE		NO
COMPLEX - NO	SUBJECTIVE		NO
COMPLEX - YES	SUBJECTIVE		NO

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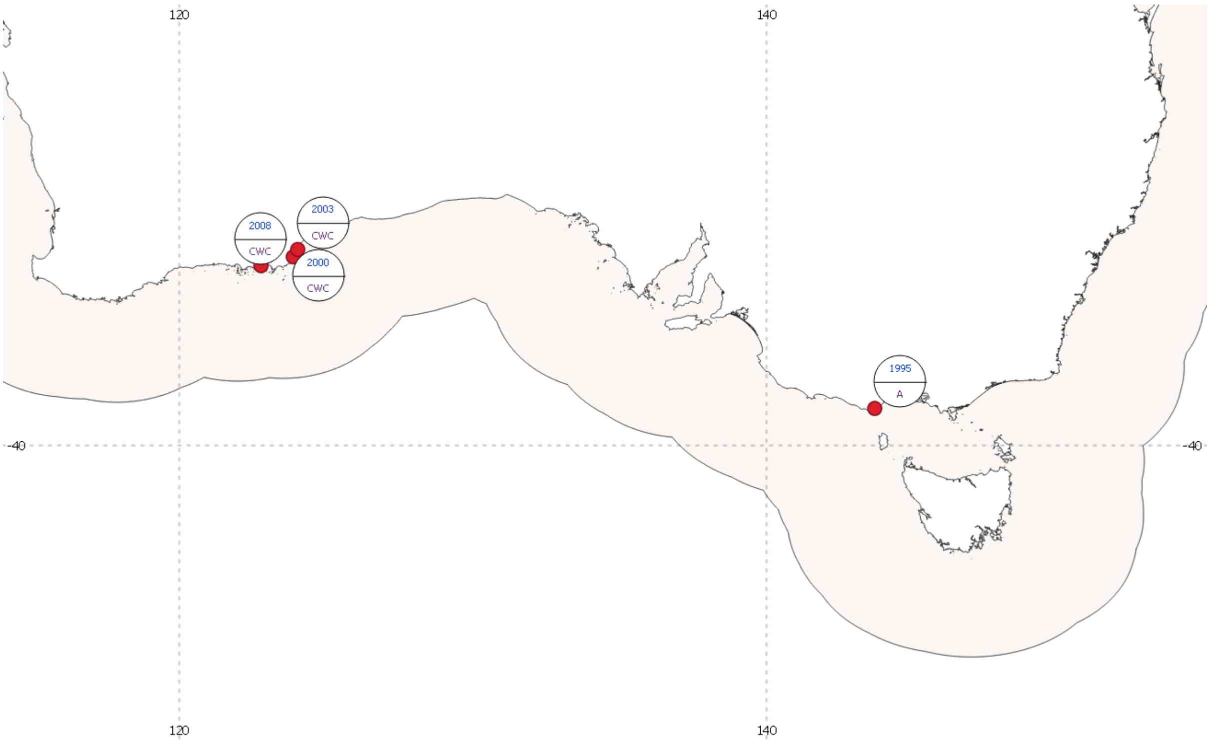
APPENDIX B – ARWPIC ERROR, WORKFLOW AND FUNCTIONALITY CORRECTIONS/DEVELOPMENTS

Timeline	Error & Workflow corrections/Functionality maintenance
August 2018	Redesign and rebuild the Photo-Identification Catalogue container on a new AADC server. Created new build scripts, docker containers, databases, web server and database admin.
September 2018	Diagnose and fix bugs with the curation process so the sightings pending list is cleared efficiently. Build data integrity reports for (i) group size and status; (ii) status in individual and event; (iii) cows are flagged as female (iv) sex, sex confidence and sex determination method to identify discrepancies. Build catalogue filters to allow curators to easily find and fix records with issues. Provide access to reports via the catalogue filter from the dashboard with the ability to download raw data to CSV. Change code to allow curators to appear in the filter dialog box (currently only contributors are shown). This will allow curators to filter the catalogue to show only their datasets. Development of instructions for running filters to allow verification of images uploaded to ARWPIC. Add new setting to allow administrators to change the upload limit without the need to change code. Change catalogue image limit to 10MB and increase medium catalogue files to 690 pixels to give users better imagery to match by. Fix bug with editing administrator & curator profiles to ensure profiles are saved as expected. All new code pushed to the shared code repository
October 2018	Fix bug with catalogue filter dialog not working as expected on the first usage. Check all ARWPIC code changes. Conduct individual integrity checks as a number of images of the same name are attached to different whales. Add code so the curator can run a filter on the catalogue and see individuals that have the same image attached. Add facility to delete an image from an individual. Add a facility to drag photos attached to the wrong whale to the correct individual folder as required. Start on data integrity reports to make it easier for curators to find duplicate individuals including (i) individuals with the same coding but different ARWPIC ids and (ii) subjective code matches with possible coding errors. Build a report to show individuals in order of "quality" determined by: i) individuals that have all their codes filled out i.e. no nulls; ii) the number of times the individual has been sighted and iii) the number of images attached that are 3 stars, then 2 stars and then one. Tie these reports to the catalogue filter as done with the other data integrity reports to allow curators to manage this data. Once each pair of matches has been verified (either it's a duplicate and should be joined or not), it will be checked off and not appear in the curator's queue again. Push code to the shared code repository Check all ARWPIC code changes. Finish individual code match reports for allow curators to view animals that are similarly coded. Work on functionality to allow a curator to merge two individuals or mark two individuals as different. Push code to the shared code repository

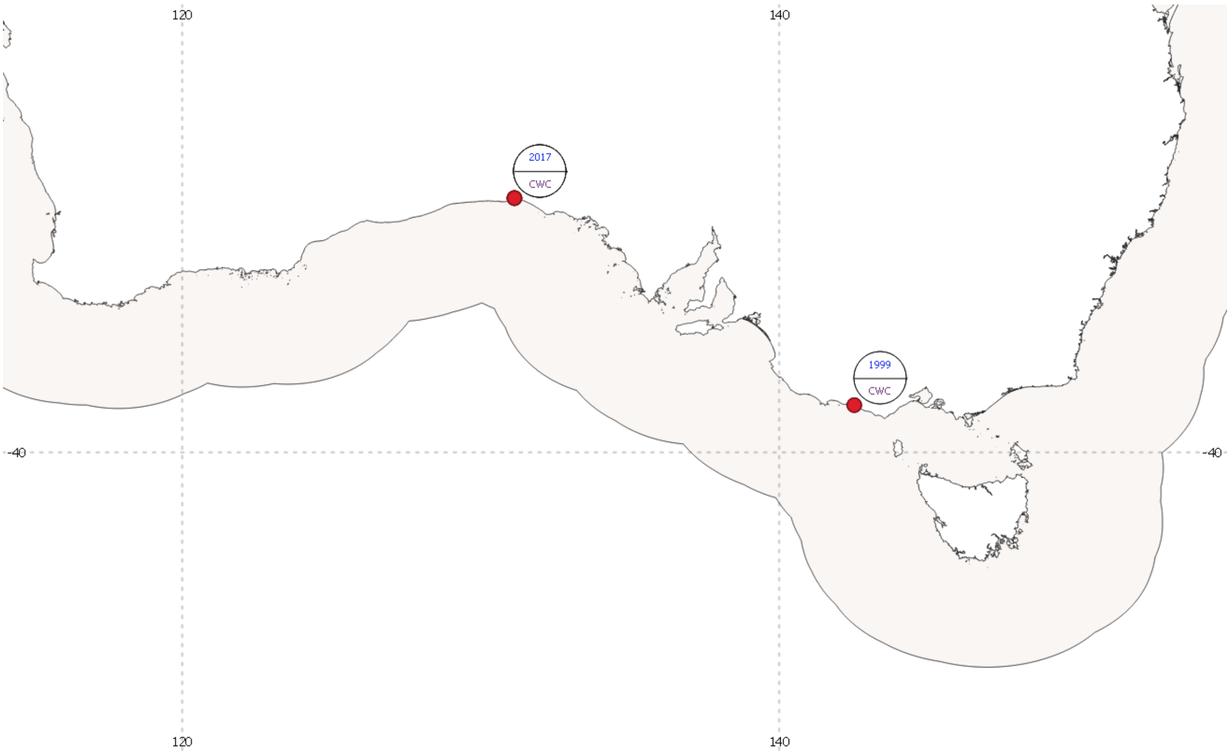
	Check all ARWPIC code changes. Change blaze and coaming codings, adjust data integrity reports, adjust BigFish matching engine. Push code to the shared code repository and copy to live server. Add new BigFish matching protocol to server.
November 2018	Add catalogue message, prevent catalogue submit and use of Code Compare during major curation. Push code to the shared code repository and copy to live server. Create code to bulk upload images. Write data migration scripts to transform from BigFish to ARWPIC formats. Accept and upgrade ARWPIC accounts. Write and test migration scripts for bulk upload of HoB data. Push code to the shared code repository and copy to live server. Check changes copied to live server.
December 2018	Add report links to ARWPIC dashboard.
January 2019	Transform from BigFish to ARWPIC formats and then run checks on the data. Write and run script to move missing images from the image processing area to the correct sightings and individuals. Rewrite code to calculate integrity report numbers in the background as currently causing significant server load and resulting in dashboard loading very slowly. Linked sightings between BigFish and Code Compare causing a server memory issue that creates problems retrieving and updating data - fixed.
October 2019	Diagnose ARWPIC Bug, Develop ARWPIC protocols for split and merge. Download of WAM Access database from Cloudstor, convert tables to .csv, translate to ARWPIC events, sightings and individuals.
November 2019	Migrate WAM data to ARWPIC. Write scripts for the bulk import of images.
December 2019	Upgrade code for new PHP version 7. Fix errors associated with the event form not saving – issue with geometry coding. Run through data checks.
January 2020	Develop documentation describing a new CodeCompare save functionality, write scripts. Bulk process of the curation queue. Accept sightings, events, changes to existing individuals, new individuals and ensure sighting images are brought over to individuals. Prepare ARWPIC upload templates for new datasets. Database backup.
February 2020	Check and fix errors causing ARWPIC to run slow. Fix administrator's submission area, running OK. Fix sandbox issue and ARWPIC errors from Google spreadsheet.
March 2020	Start developing protocol for addressing issues with HoB dataset errors, issues with bulk grouping of events and sightings and adjust so that in line with other user's data entry protocols. Move HoB data automatically accepted into the catalogue back to her contributor work area.
April 2020	Analyse HoB image data, past census data and new sighting data.

	Develop scripts for splitting the data into smaller event packages with less than 10 sightings per event, including (i) run through all the sightings in each year (excluding EB data); (ii) check each of the images inside the sighting; (iii) create a new event and add the sighting(s); (iv) identify associated photos by either camera date/time or a file name that can be interpreted as a date. Provide reports on: 1) Images not attached to sightings. Attach images to sightings as required. 2) image metadata date/time not matching image filename date/time. Time to QA/QC after each stage.
May 2020	Develop protocols for splitting workflow.
June 2020	Fix errors associated with the catalogue changes causing some data to become blank. Rebuild the event latitude and longitude point geometries that had become corrupted in the database. Repair and validate corrupt region and jurisdiction polygons. Rebuild event region and jurisdiction links. Test ARWPIC filtering via regions and jurisdictions. Fix errors with whales that had different suggested ids to final ids. Reattach deleted images and fix duplicate images across sightings. Adjust curator protocols associated with removing duplicate whales .
September 2020	Fix image loading bug to ensure all images load into the centre of the work area.
October 2020	Develop capture/recapture reports, catalogue image breakdown report.
November 2020	Create image gallery report. Save coding and load coding from the CodeCompare screen to allow researchers to code whales in the individual screen and load coding into the CodeCompare screen.
December 2020	Build summary reports and encounter history reports.
January 2021	Build summary reports, encounter history reports and new regional overlap report.

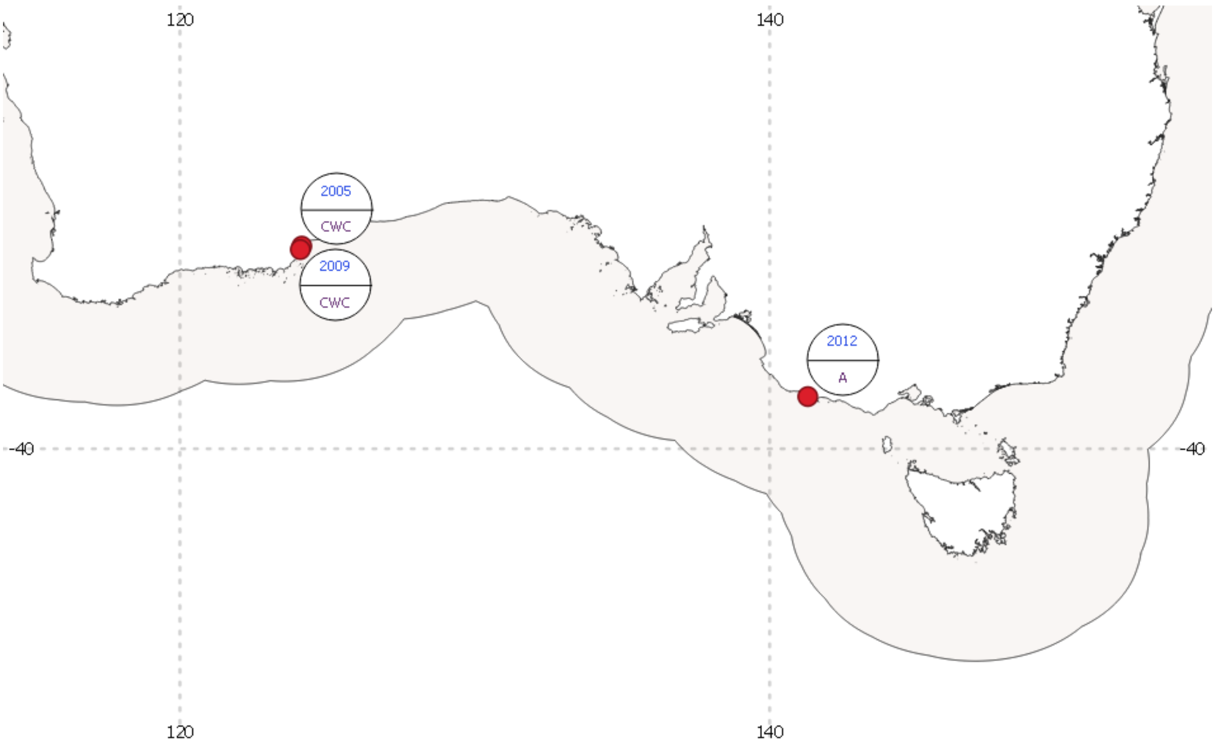
APPENDIX C – SPATIAL DISTRIBUTION OF SIGHTINGS OF INDIVIDUALS OBSERVED IN BOTH THE WESTERN AND EASTERN AREAS OF SOUTHERN AUSTRALIA



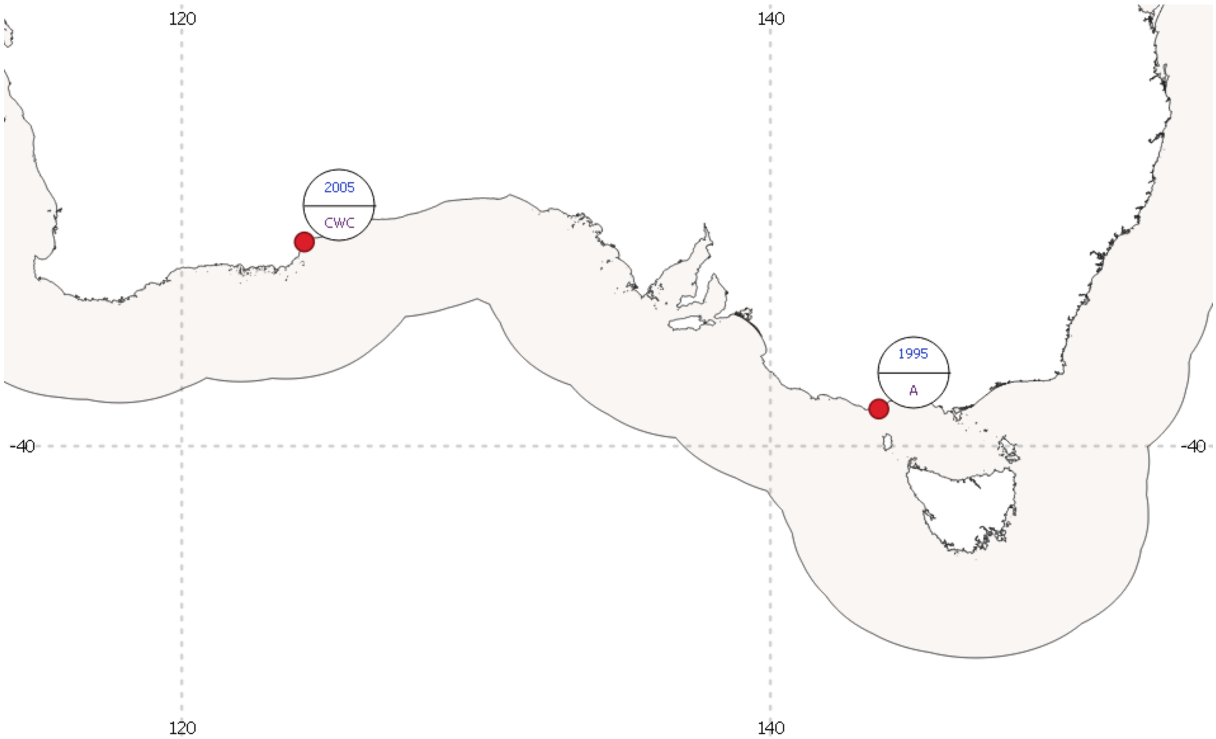
The spatial distribution of sightings (life stage and year) of ARWPIC ID 126 (female). A: adult; CWC: cow with calf.



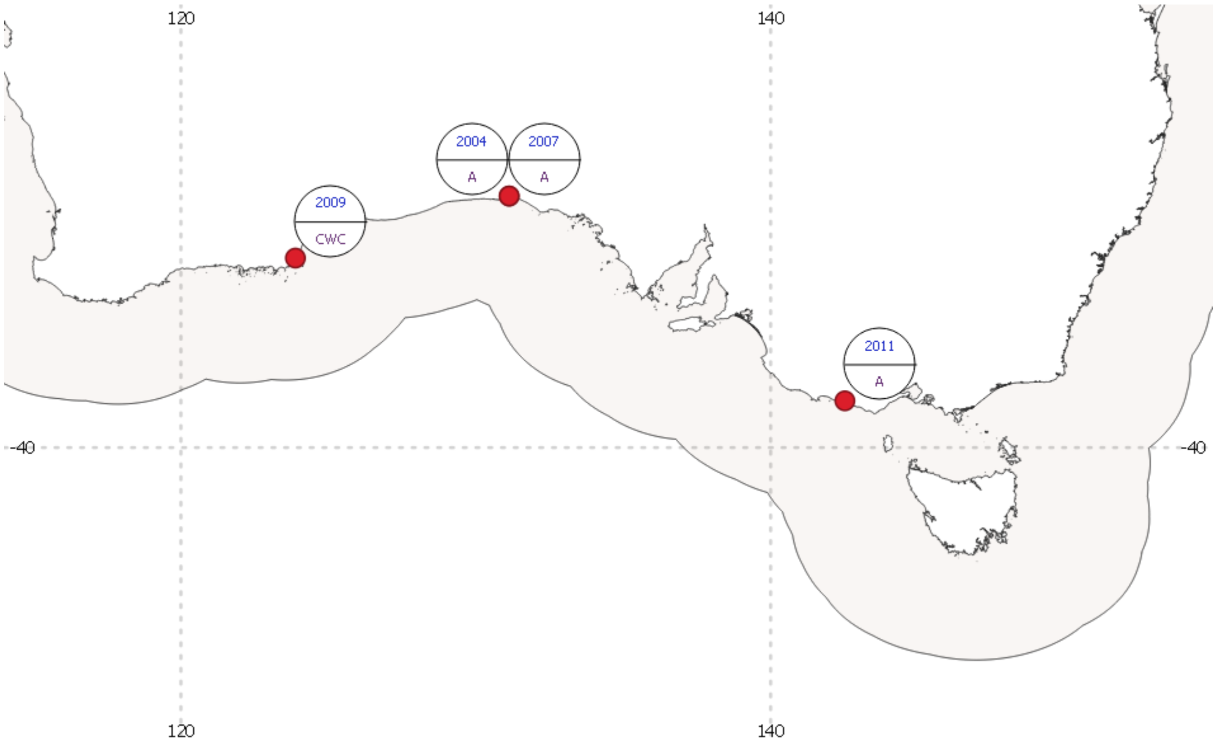
The spatial distribution of sightings (life stage and year) of ARWPIC ID 296 (female) .CWC: cow with calf.



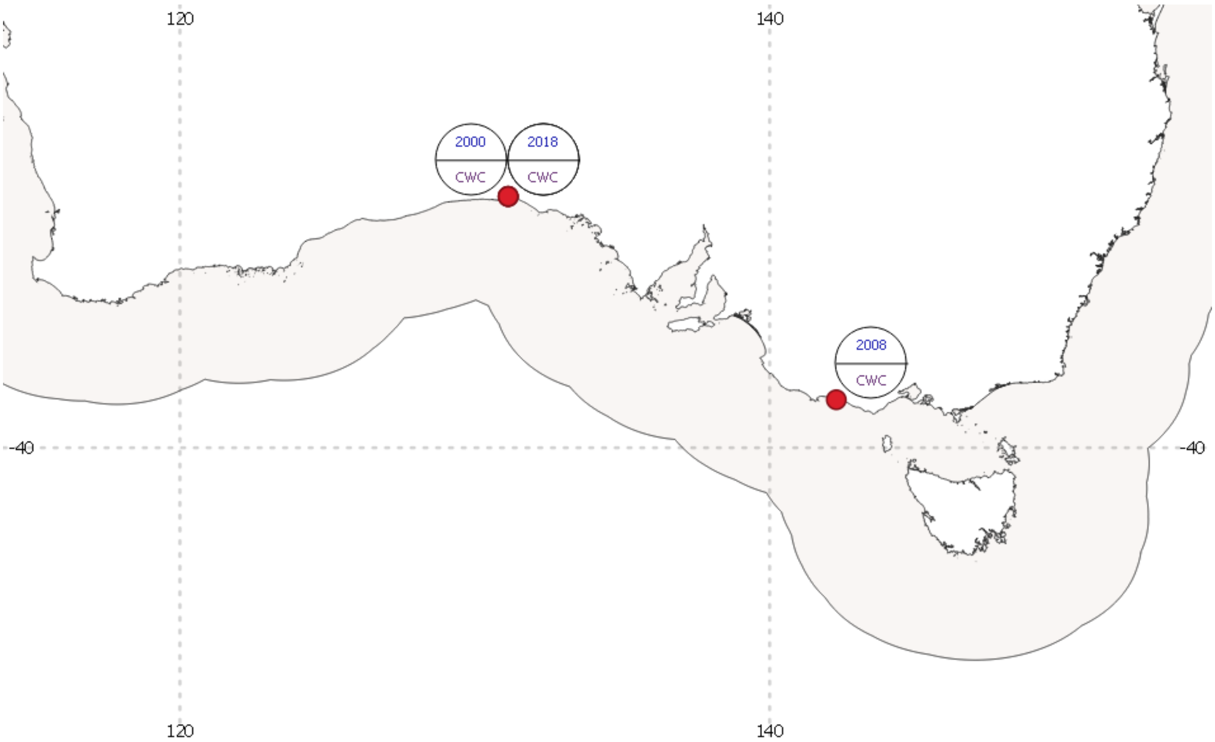
The spatial distribution of sightings (life stage and year) of ARWPIC ID 384 (female). A: adult; CWC: cow with calf.



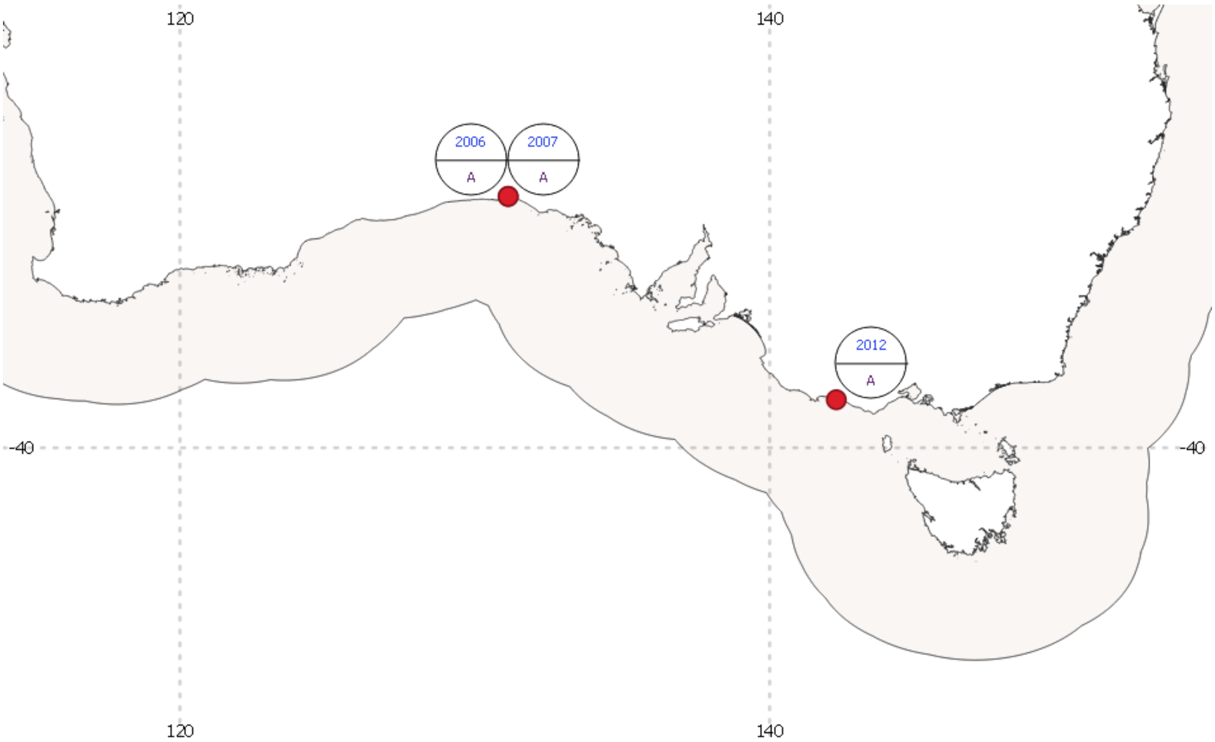
The spatial distribution of sightings (life stage and year) of ARWPIC ID 407 (female). A: adult; CWC: cow with calf.



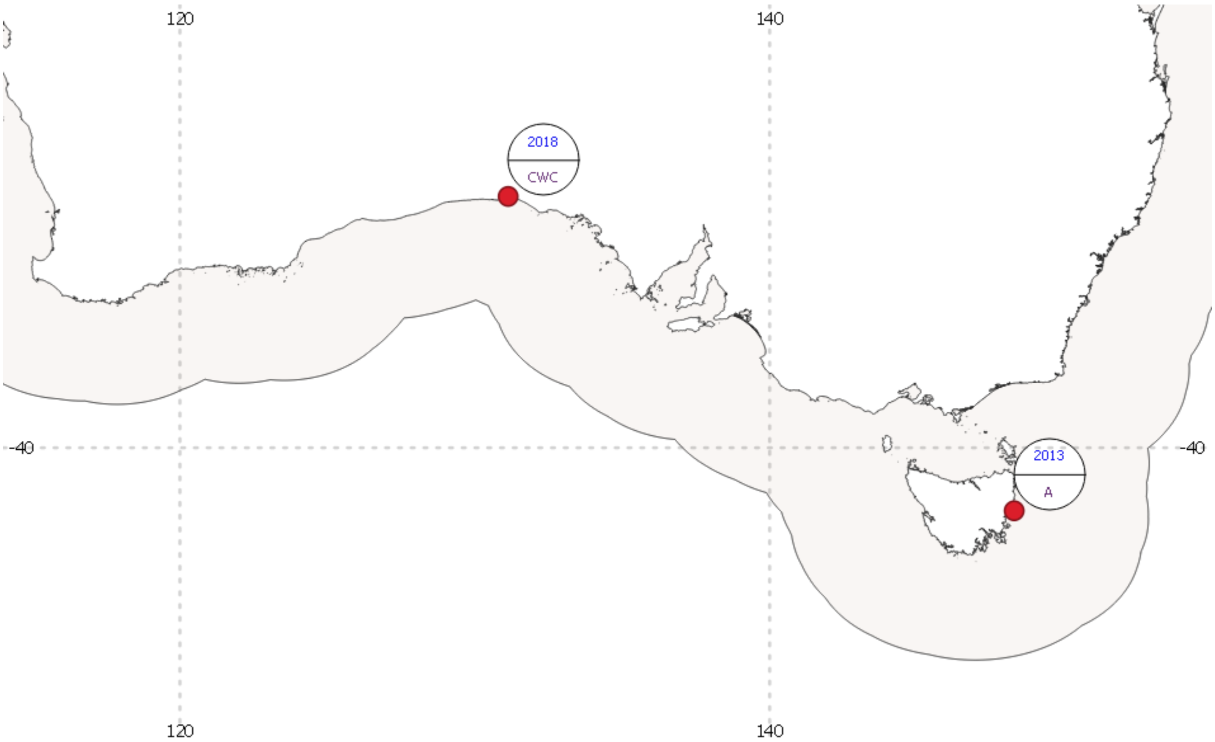
The spatial distribution of sightings (life stage and year) of ARWPIC ID 557 (female). A: adult; CWC: cow with calf.



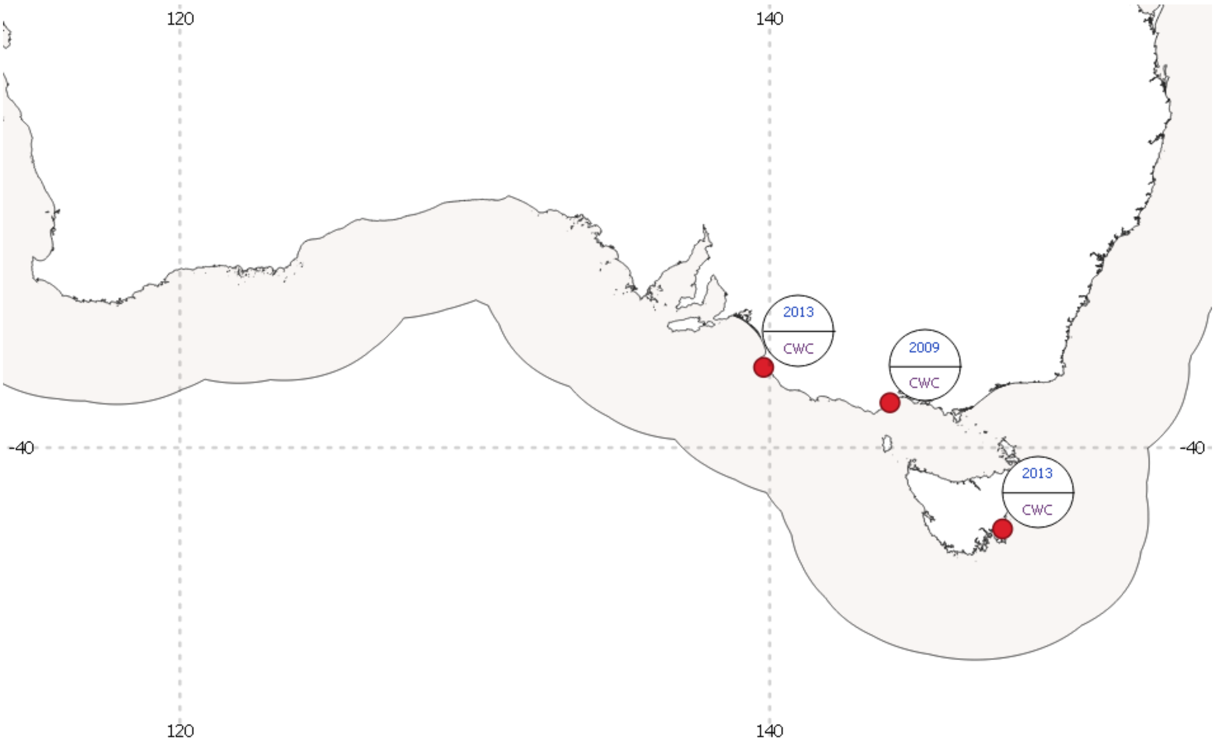
The spatial distribution of sightings (life stage and year) of ARWPIC ID 1110 (female). CWC: cow with calf.



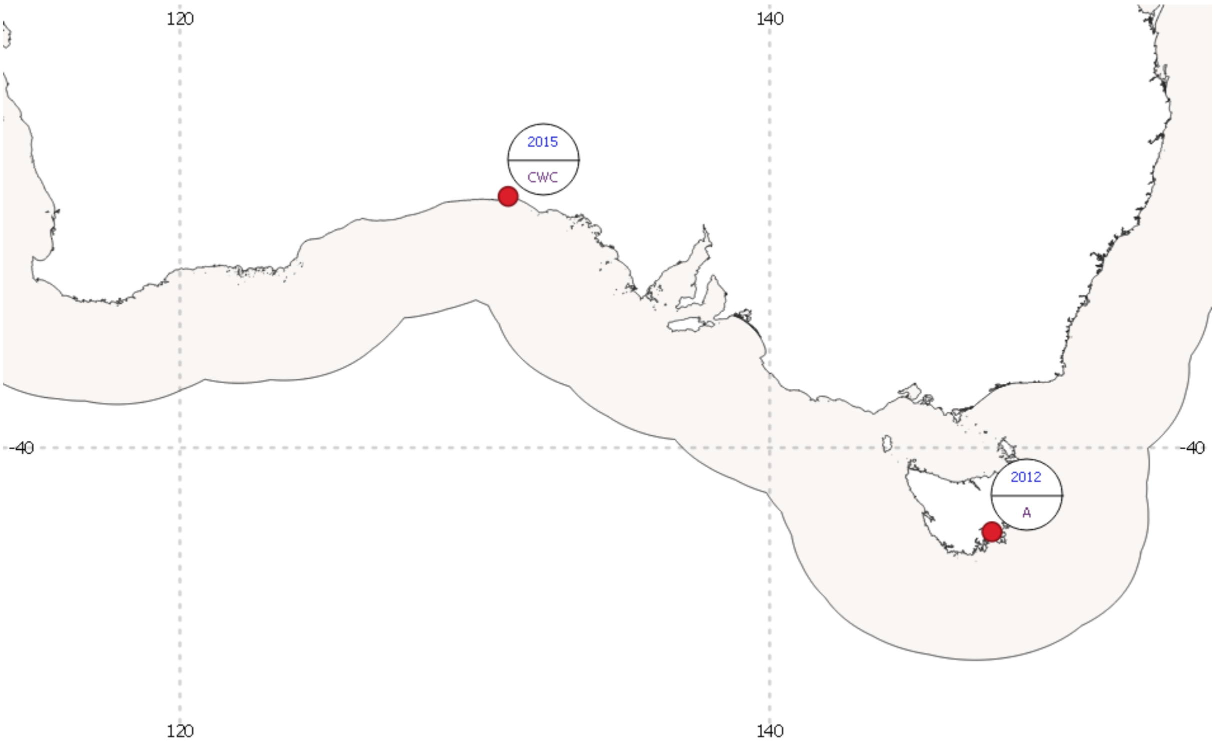
The spatial distribution of sightings (life stage and year) of ARWPIC ID 1765 (male). A: adult.



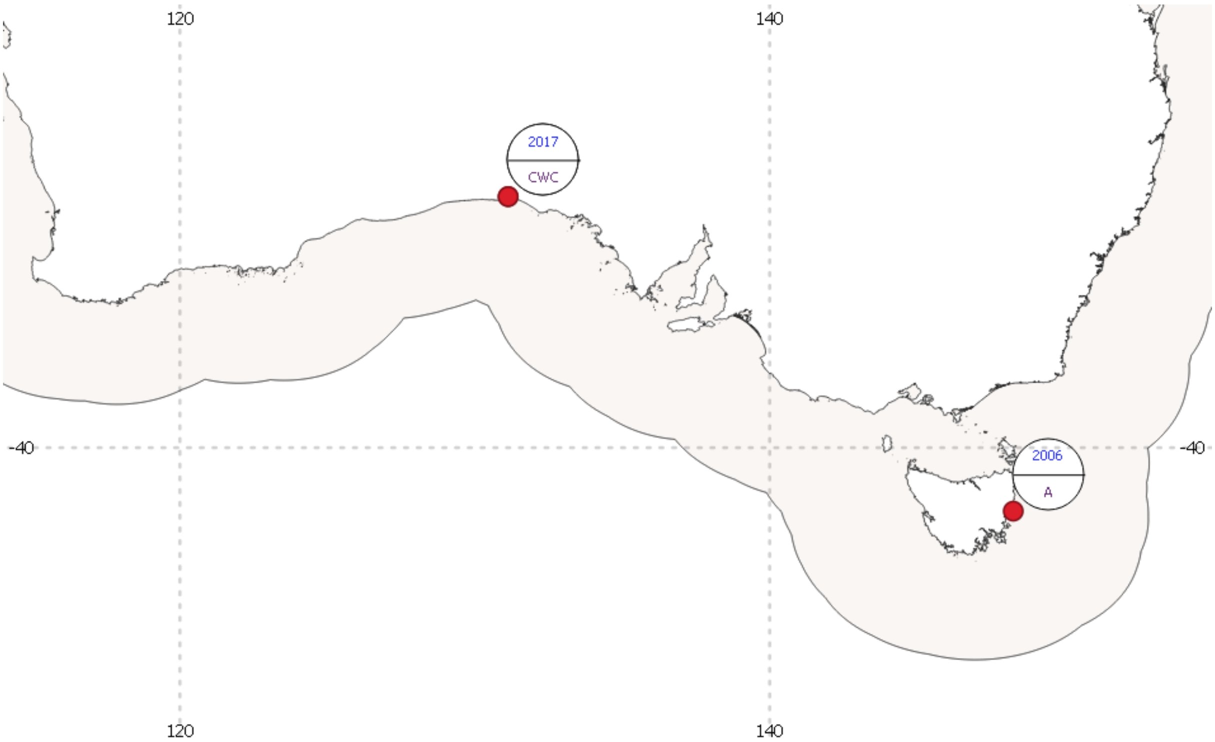
The spatial distribution of sightings (life stage and year) of ARWPIC ID 1942 (female). A: adult; CWC: cow with calf.



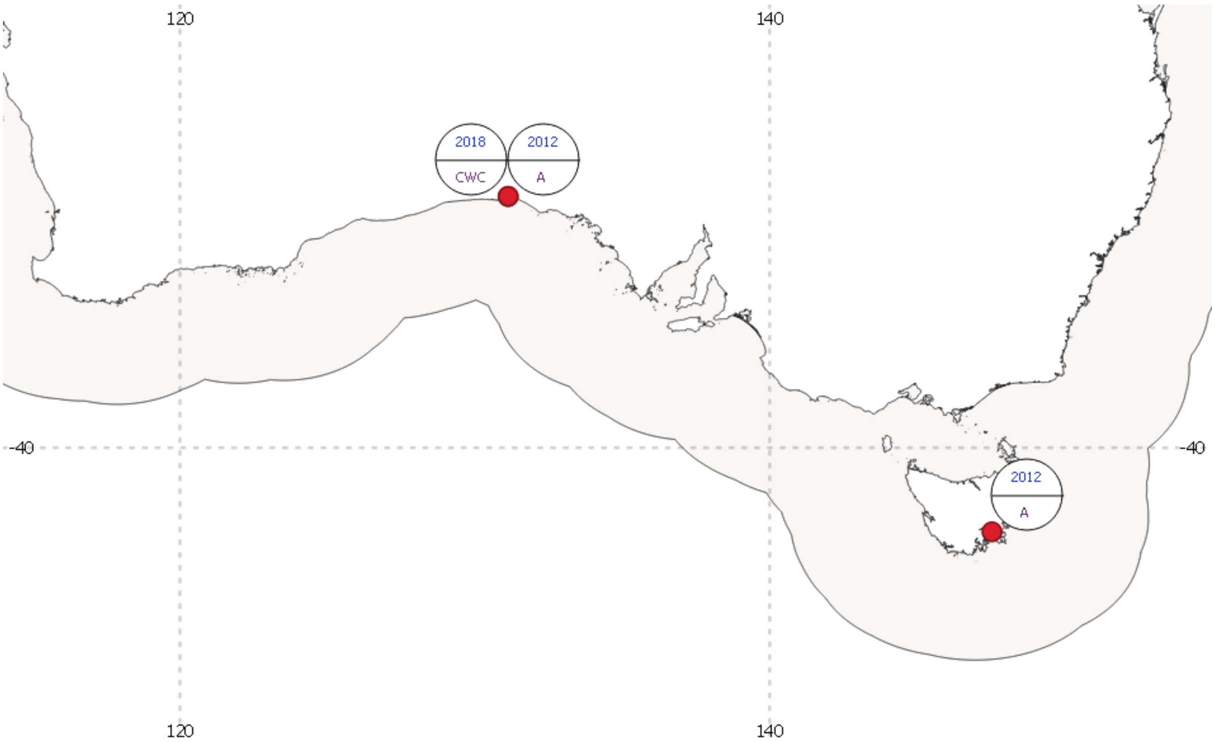
The spatial distribution of sightings (life stage and year) of ARWPIC ID 1943 (female). CWC: cow with calf.



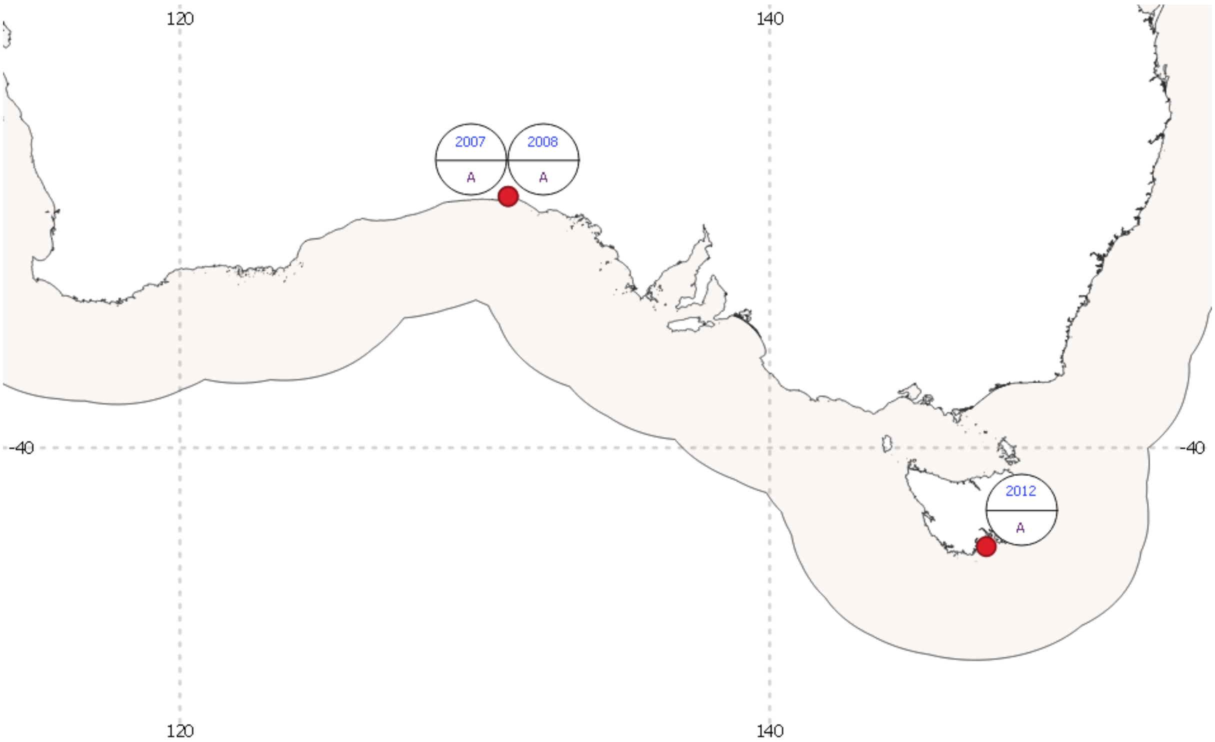
The spatial distribution of sightings (life stage and year) of ARWPIC ID 1979 (female). A: adult; CWC: cow with calf.



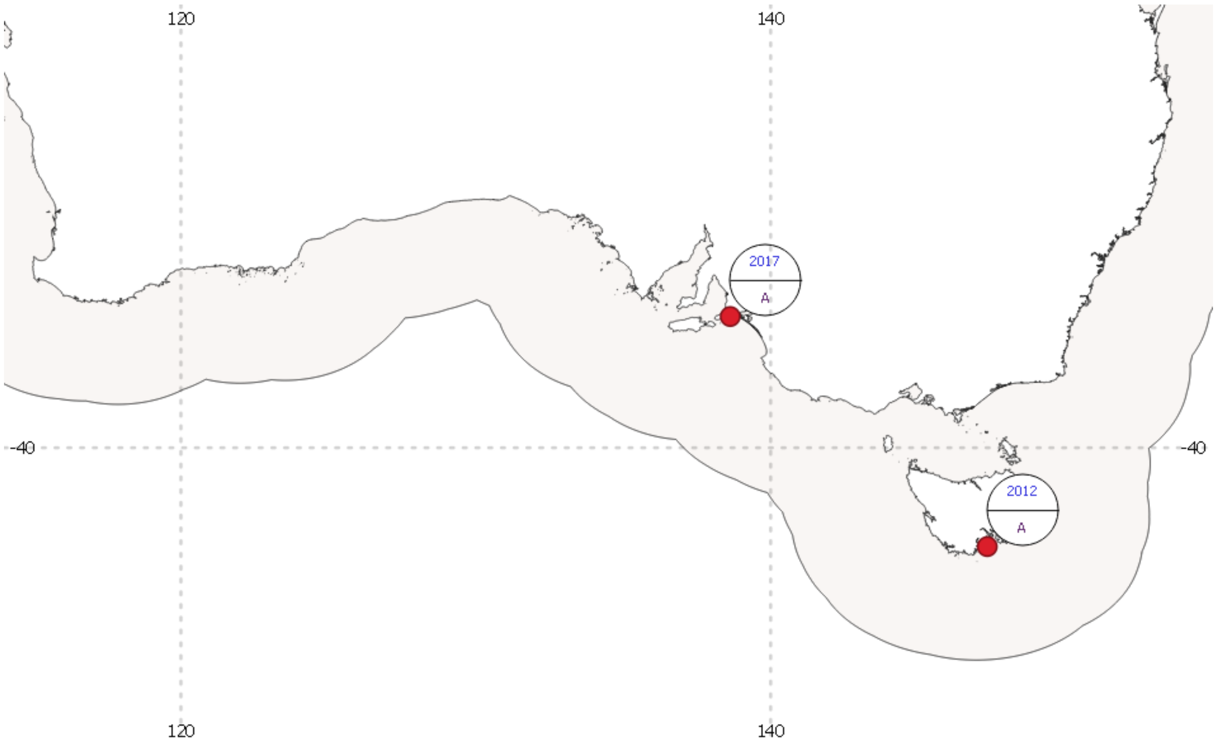
The spatial distribution of sightings (life stage and year) of ARWPIC ID 1980 (female). A: adult; CWC: cow with calf.



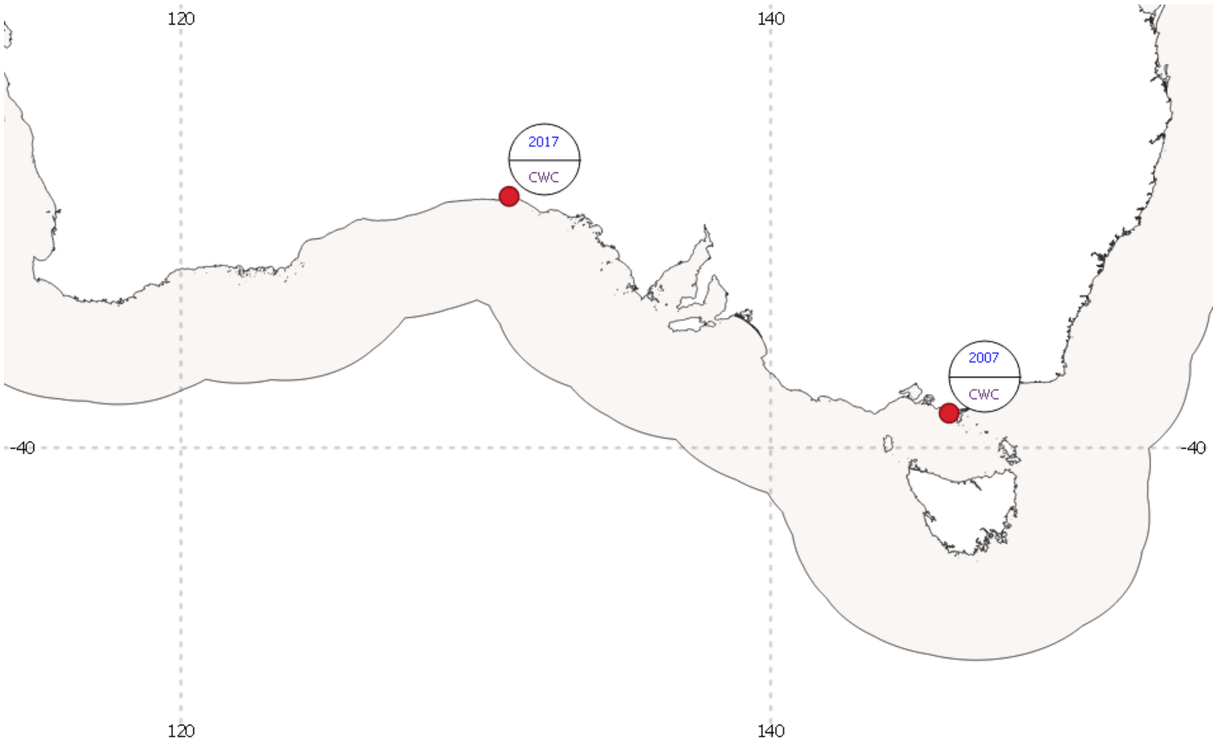
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2003 (female). A: adult; CWC: cow with calf.



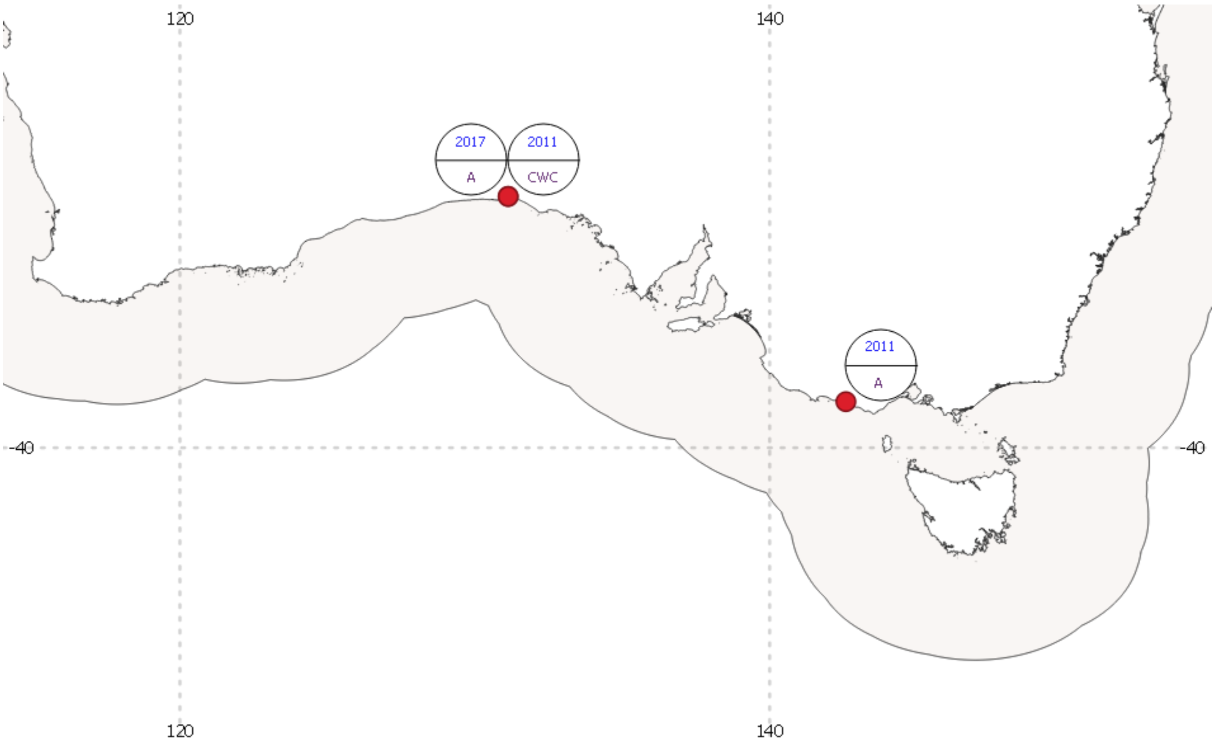
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2005 (unknown gender). A: adult.



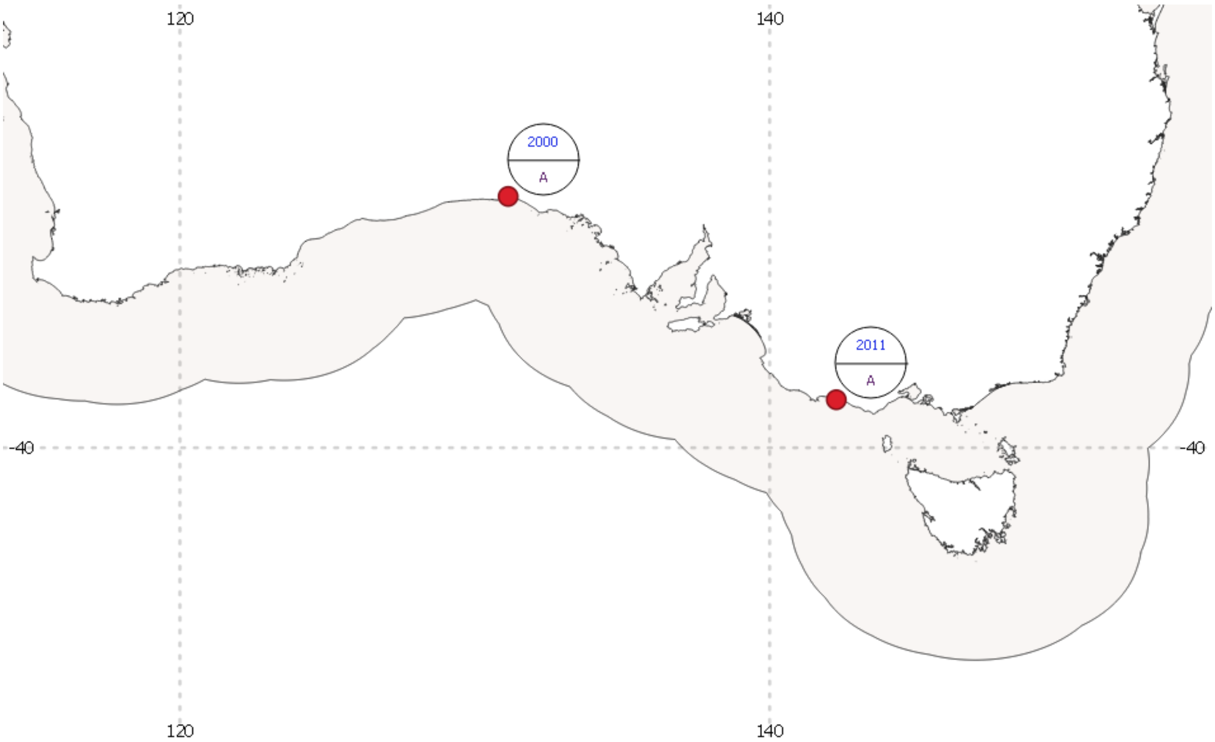
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2015 (unknown gender). A: adult.



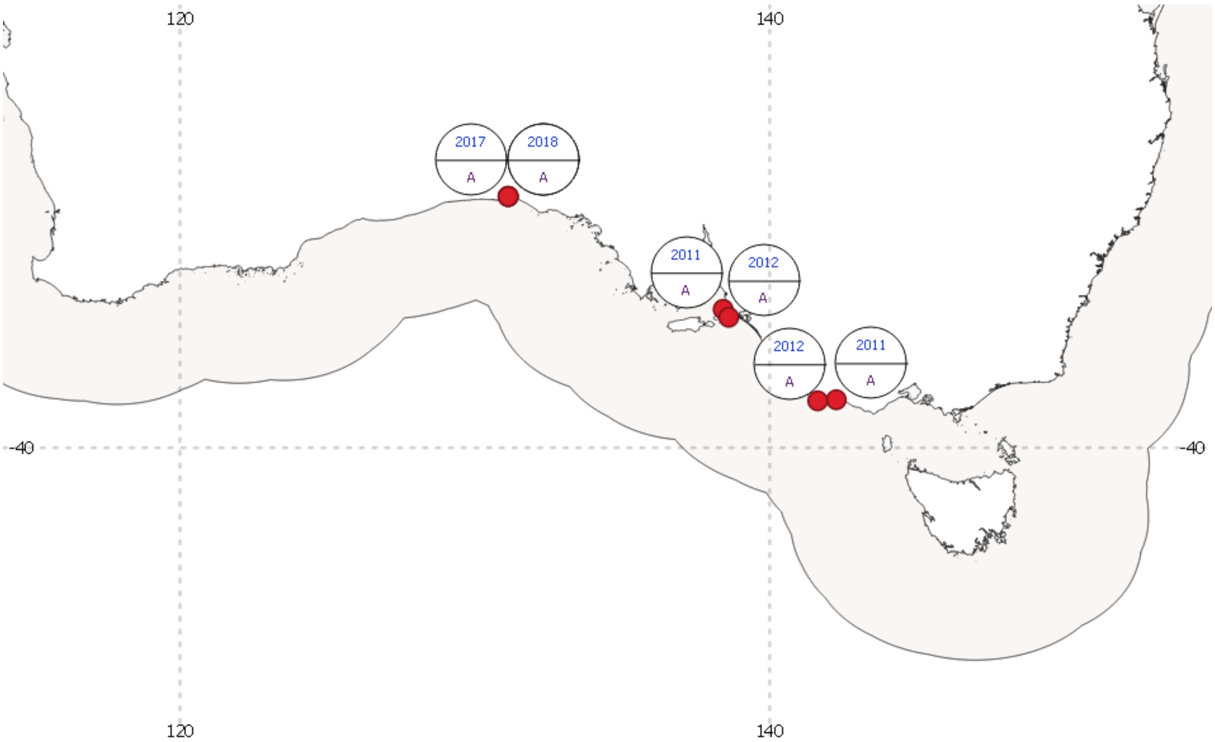
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2107 (female). CWC: cow with calf.



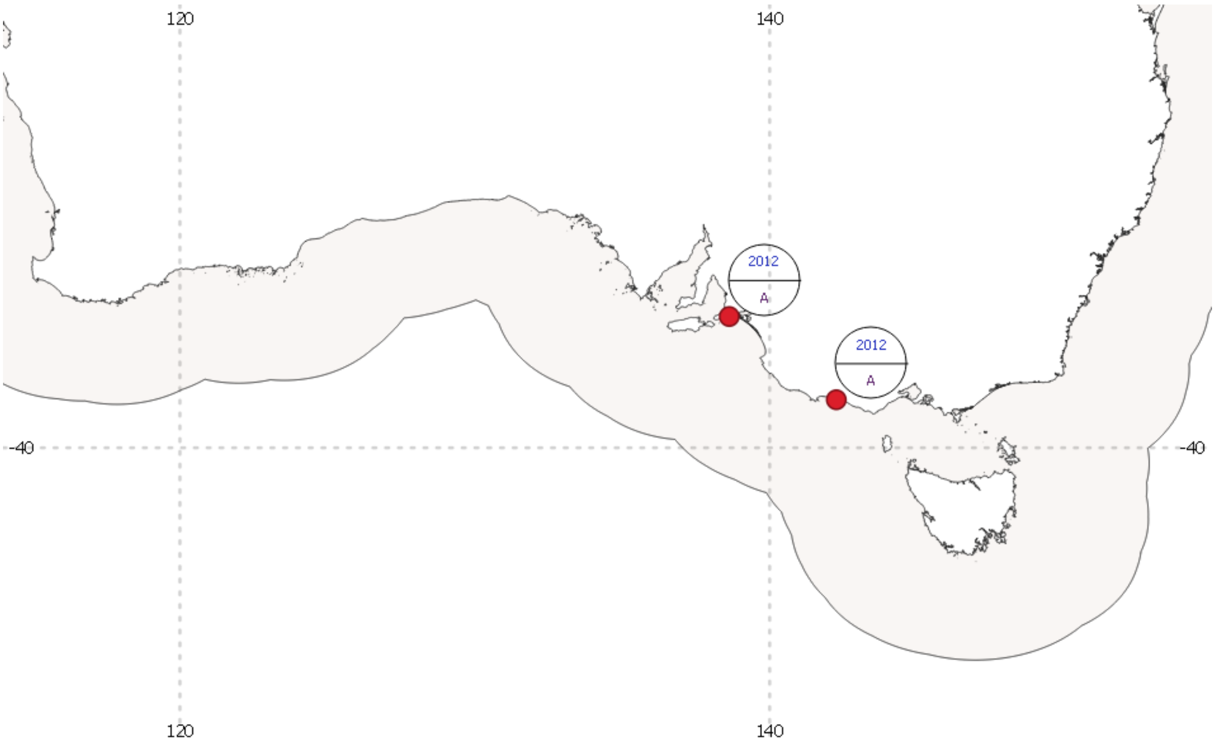
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2176 (female). A: adult; CWC: cow with calf.



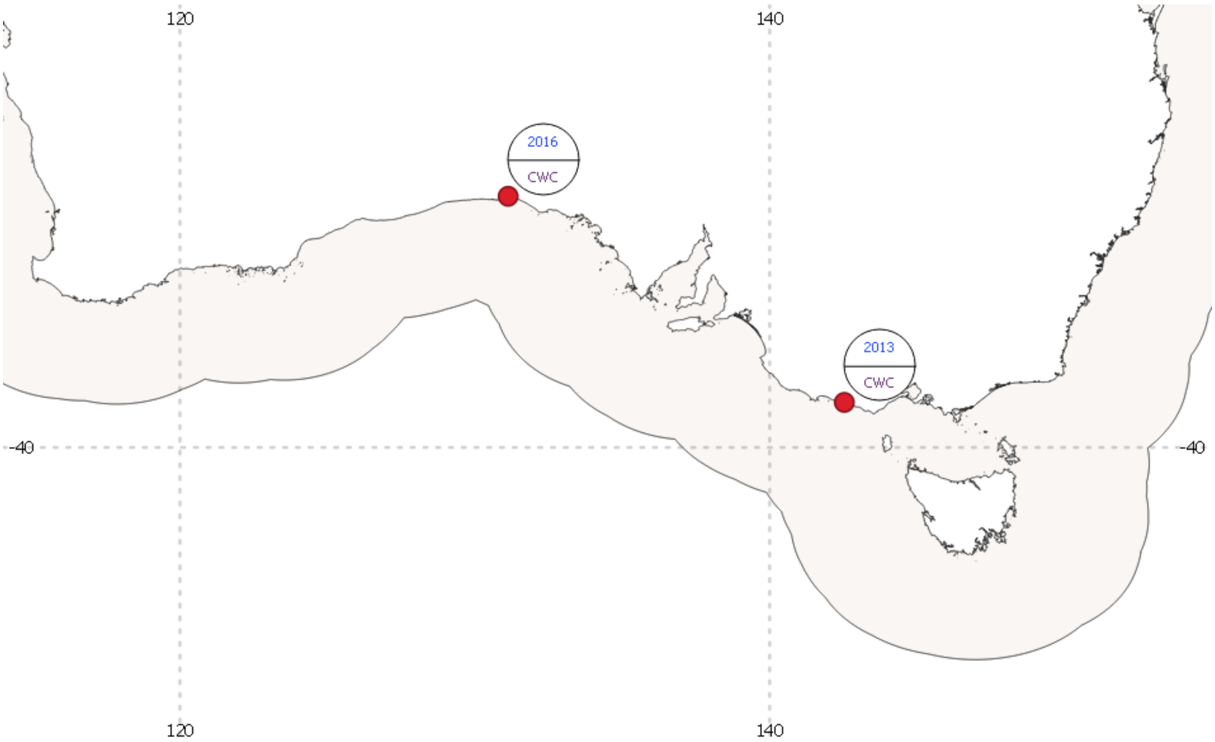
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2180 (male). A: adult.



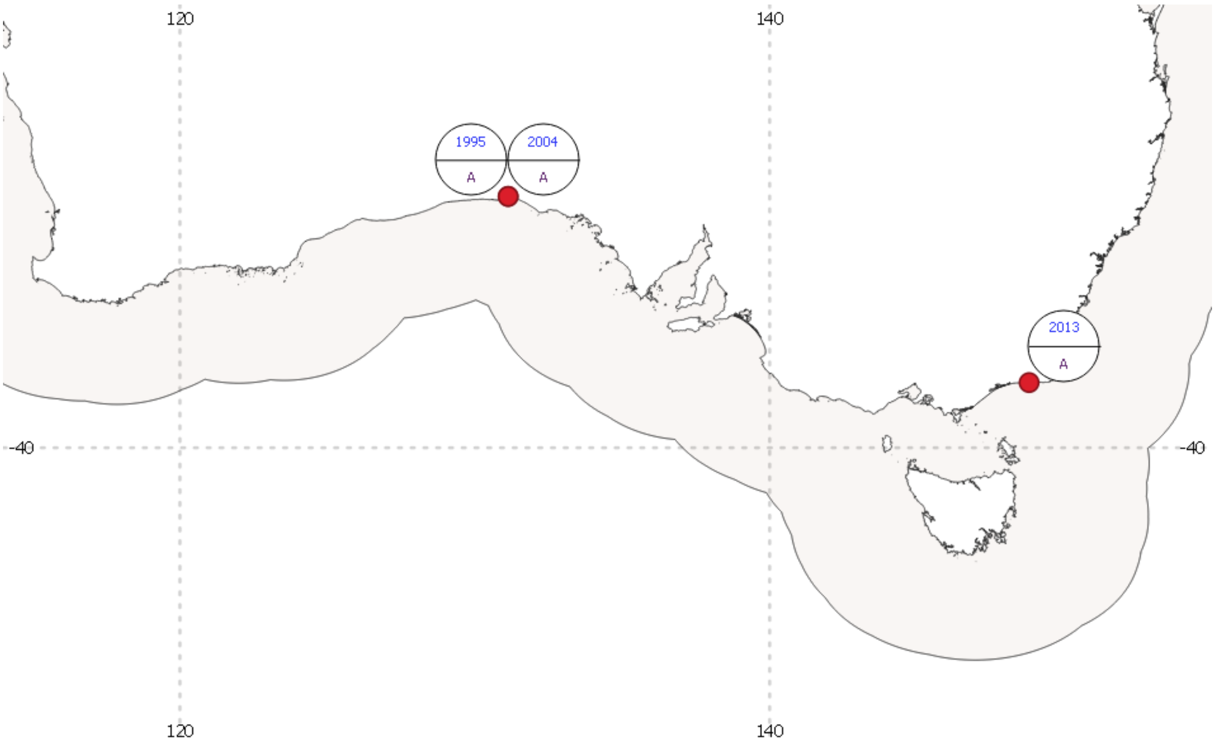
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2182 (male). A: adult.



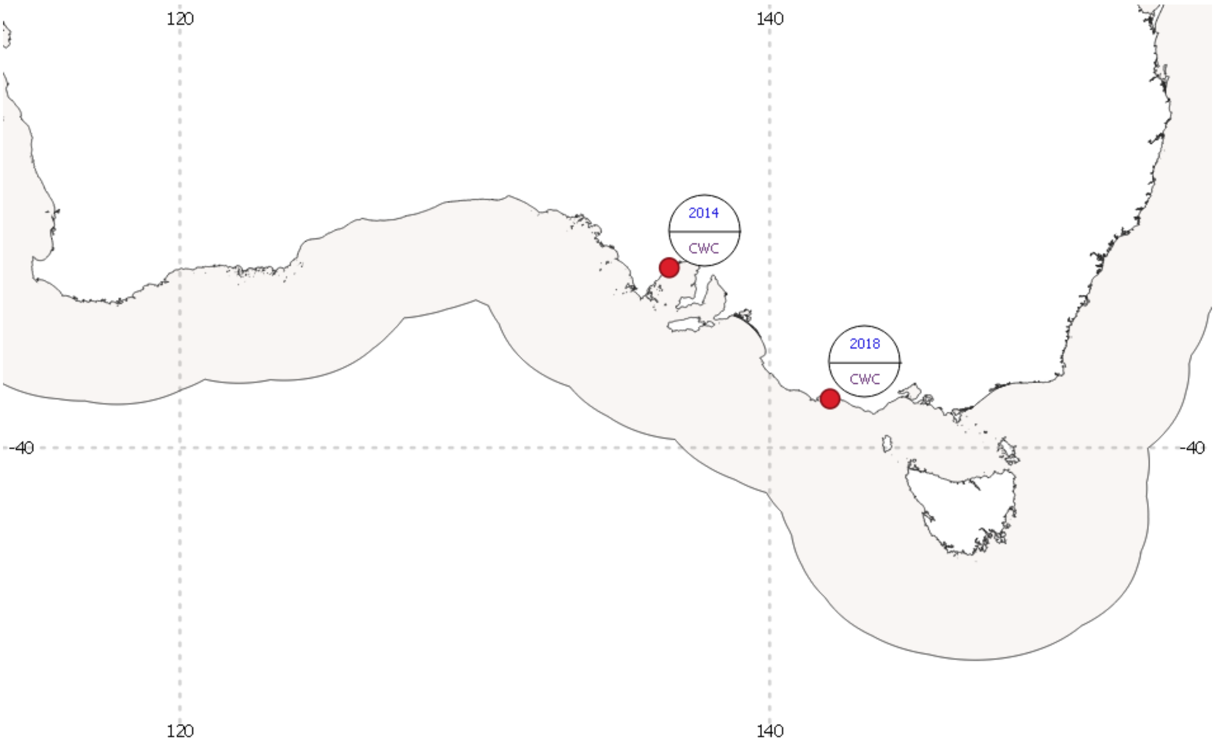
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2190 (unknown gender). A: adult.



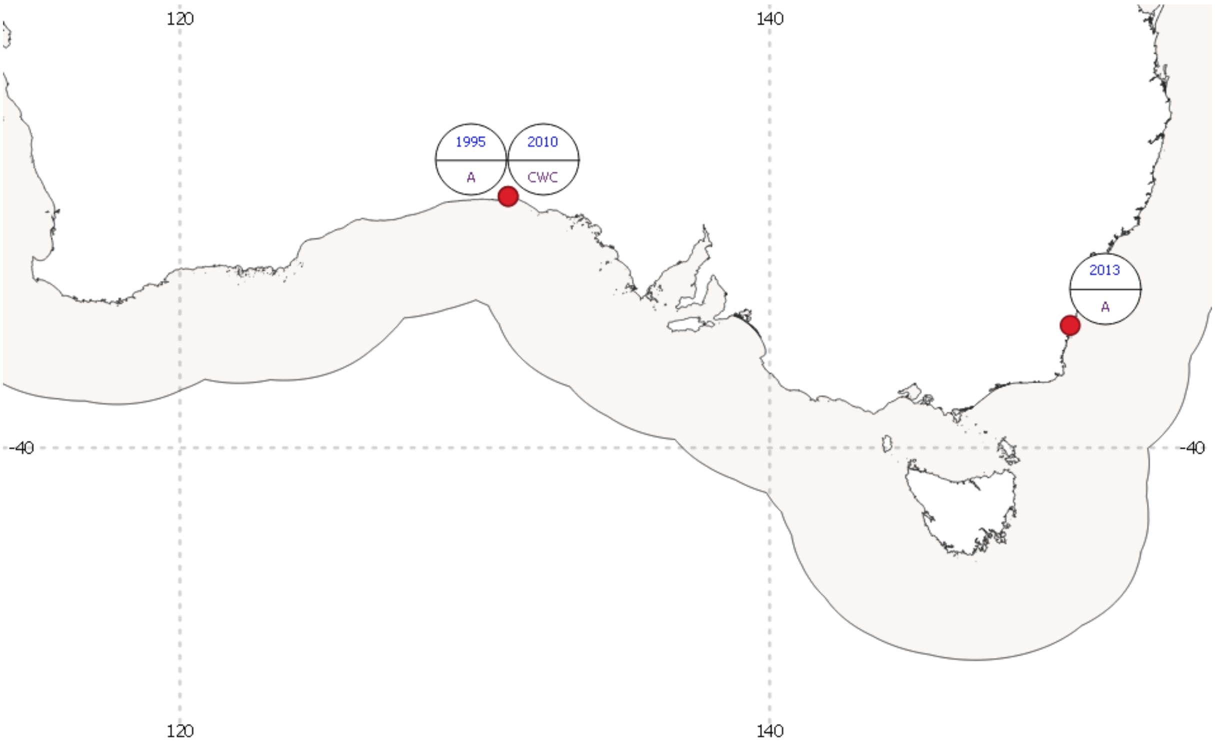
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2225 (female). CWC: cow with calf.



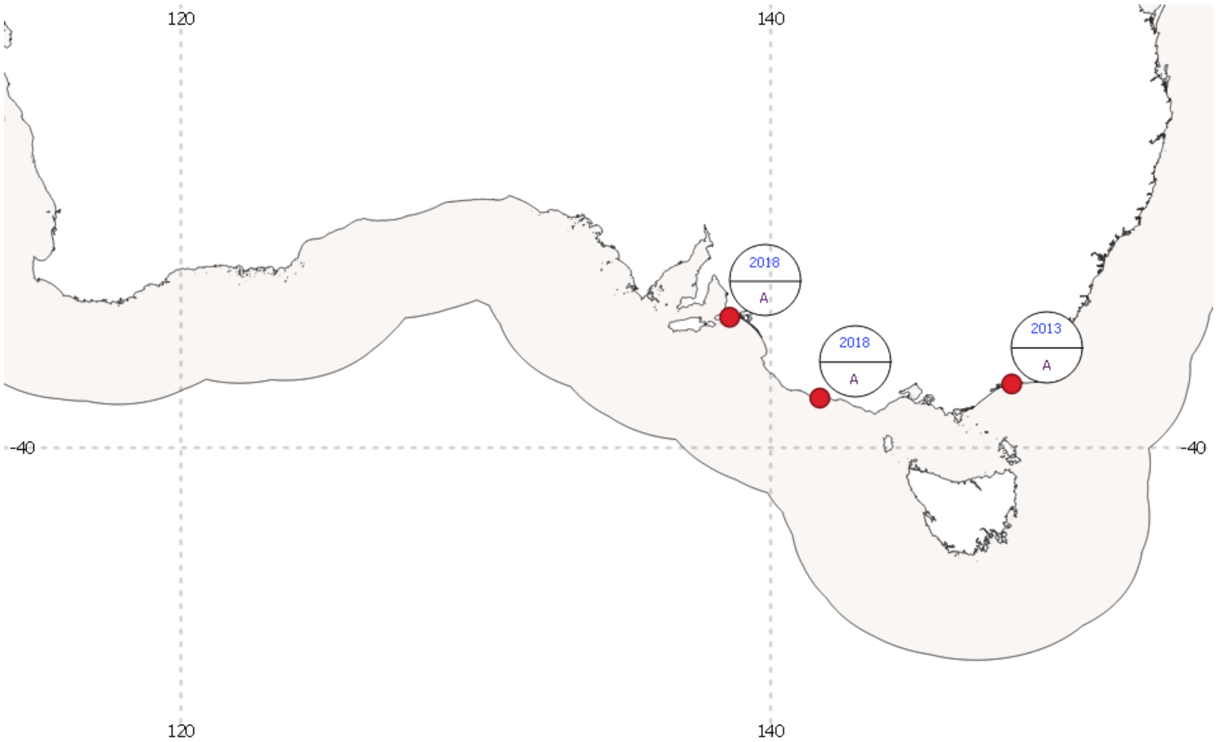
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2241 (male). A: adult.



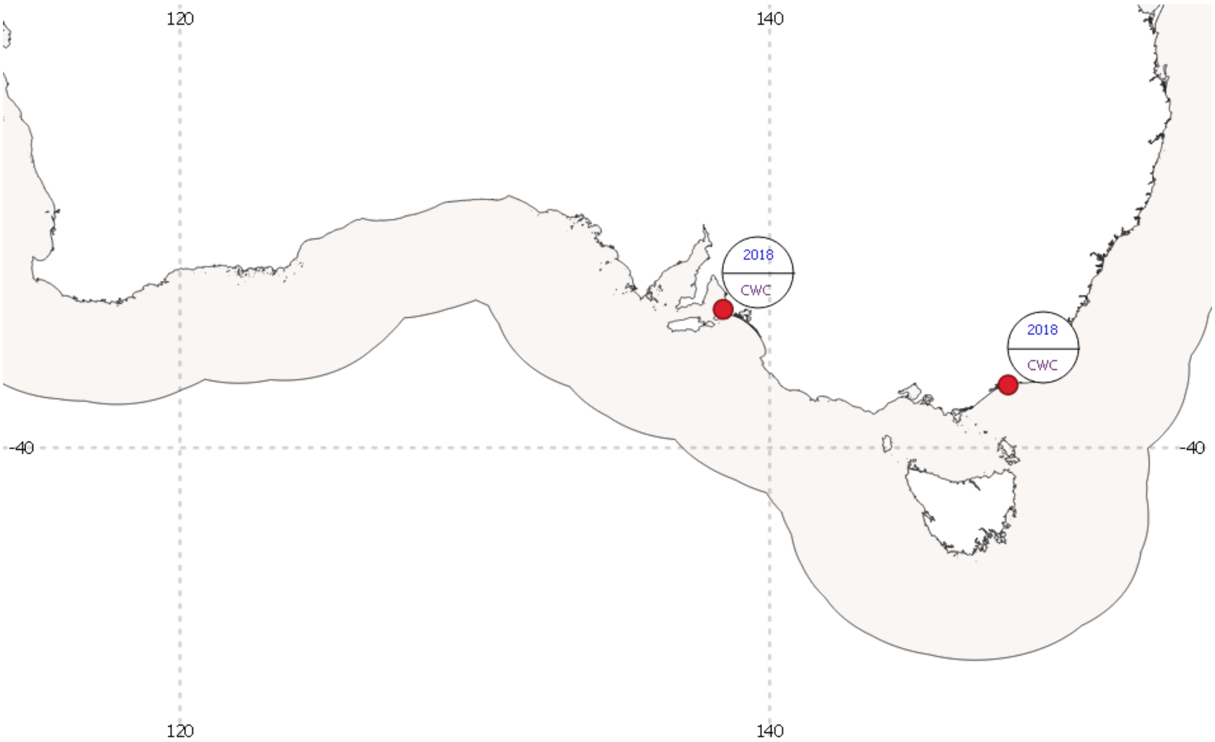
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2256 (female). CWC: cow with calf.



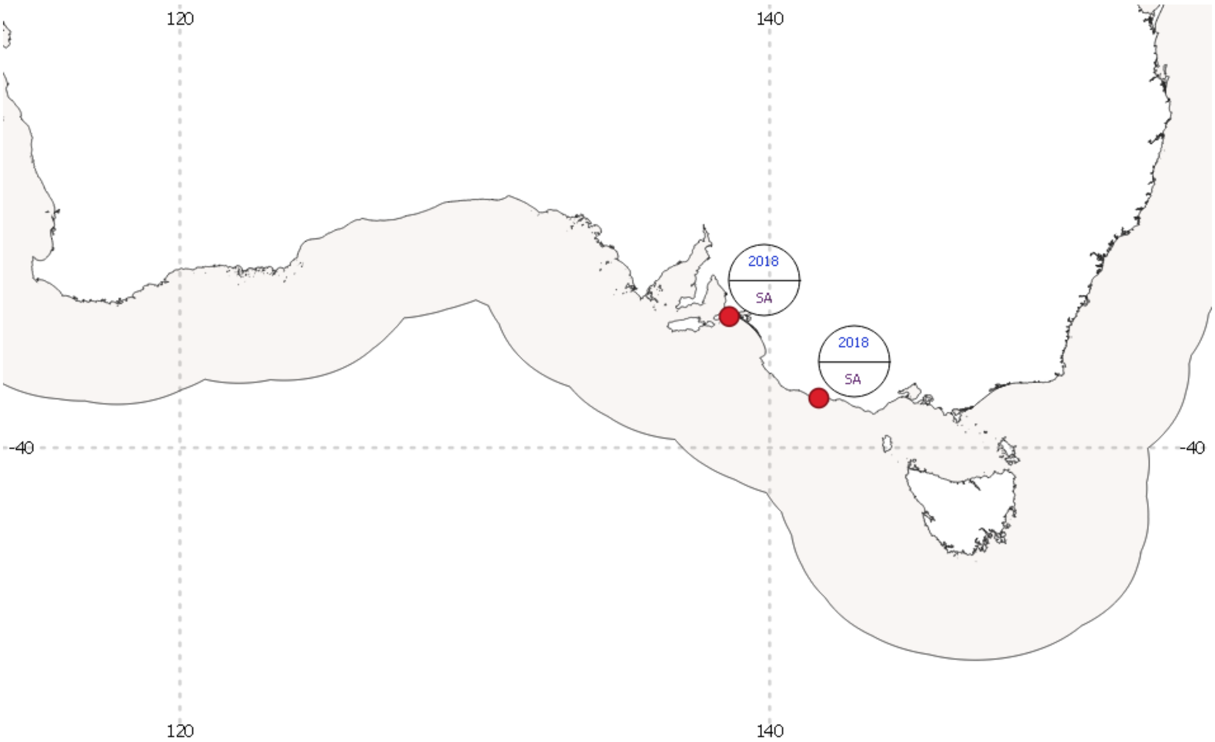
The spatial distribution of sightings (life stage and year) of ARWPIC ID 2384 (female). A: adult; CWC: cow with calf.



The spatial distribution of sightings (life stage and year) of ARWPIC ID 2390 (unknown gender). A: adult.



The spatial distribution of sightings (life stage and year) of ARWPIC ID 4986 (female). CWC: cow with calf.



The spatial distribution of sightings (life stage and year) of ARWPIC ID 5604 (male). SA: sub-adult.

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