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A photo-identification study of southern right whales to update aggregation area classification in the southwest of Australia

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NESP Marine and Coastal Hub partners

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Cover images: Chris Burton (left) and Blair Ranford at Sharky Aerials (right)

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Executive summary

The population of southern right whales in the Southern Hemisphere has been recovering slowly from near extinction due to its decimation from whaling before its ban in 1935 and cessation in the mid-1970s. Due to the relatively small numbers of southern right whales that belong to the population that breeds off the Australian coast, the species is listed as endangered under Australian legislation. As the species recovers, there is increasing evidence of expansion of aggregation areas, including breeding grounds off the coast of Australia. Consequently, there is a need to update known southern right whale established aggregation areas recognised nationally as Biologically Important Areas (BIAs), as well as the national Southern Right Whale Conservation Management and Recovery Plan, which are both used in decision-making using new evidence.

This project collated over 2000 images and completed matching of individually identifiable whales in photos (i.e., Photo-ID) between 1991 to 2021 in the southwest corner of Australia to evaluate abundance, residency, site fidelity and connectivity in this historically data limited region. The new knowledge resulting from this study indicates that the Geographe and Flinders Bay regions within the Ngari Capes Marine Park fit the definition set out in the national Southern Right Whale Management and Recovery Plan of a small established aggregation "containing up to about 10 (usually less than five) calving females at the peak of the season". It is recommended that future research in the Geographe Bay region extends beyond the area of this study to capture wider ranging patterns within and between breeding grounds. This would be consistent with approaches recommended for effective conservation-based spatial planning.

This study used entirely opportunistic photos taken by researchers, volunteer citizen scientists, and whale watch operators. The continuation of future opportunistic efforts, given their clear benefits, is recommended. Photo-ID methods can be a cost-effective way of examining patterns in site-fidelity and movement of whales within and between habitats; to estimate demographic and biological parameters; and to estimate abundance. This includes photographs provided by researcher-led citizen scientists to contribute important information to research, particularly where funded is limited and sporadic. Moreover, community education and awareness are simultaneously achieved through citizen science participation.

In addition to opportunistic efforts, complimentary systematic surveys conducted at regular intervals are recommended, that cover a broader spatial area and capture the entire breeding season. While opportunistic photos used in this study provided knowledge essential for updating management plans and improving decision-making, the opportunistic nature of the study likely underrepresented abundance, residency, site fidelity and connectivity. Complementary systematic surveys should be designed to fill gaps in opportunistic efforts where required, and is more financially viable than relying completely on customary scientific surveys.

Finally, comparisons of photographs over the broader spatial range of the western sub-population are recommended for future research as they are required to evaluate connectivity and re-establishment of former breeding grounds across Western Australia and into South Australia. Movement over a range of scales is vital for genetic exchange, health, survival and recolonisation of former breeding grounds, and the recovery of the southern right whales. The extent of connectivity across regions is unclear, nor how much movement can be attributed to re-establishment of former breeding grounds. In addition, there are major knowledge gaps in regions across the vast coastline of Western Australia in which photos have already been taken by community-based citizen scientists and a range of researchers, and their evaluation to update a broader extent of the western Australian sub-populations is recommended for future studies.

Stakeholder representatives (72) were engaged during the execution of this project, including from government, industry, tourism, education and community sectors and cultural custodians. A stakeholder workshop was undertaken, and group activities with 20 participants provided information on how the knowledge from this project will be used by their sector. In additions, formats preferred for dissemination of the information from future such projects ranged widely, from peer-reviewed scientific papers and technical reports, to maps and spatial layers, physical presentation and meetings, and information packaged for mainstream audiences (e.g., infographics, a one-page summary, short videos, photographs, broadcast media, social media, project website and social media). The responses from participants highlighted the importance of stakeholder engagement in the communication of such results in the future to maximise impact and uptake.

1. Introduction

Effective conservation, management, and recovery of a threatened species is dependent upon knowledge regarding the species' biological and ecological attributes, its geographical range, habitats it uses, and threatening processes to its survival and reproduction. For example, by combining knowledge of important habitats in a species' population range, the proportions of the population using the habitats, and when and how individuals use them, the range of important habitats that require protection can be identified, as can overlapping threatening processes.

The identification of important ecological locations, in fact, is an increasingly used approach for defining areas in which to implement protective measures for marine conservation, although most marine protected area (MPA) efforts to date have been ecosystem-oriented (Hoyt 2018). For species such as marine mammals that commonly have large geographical ranges and are highly mobile, an MPA approach may only provide protection for a proportion of the population or during certain times of occupancy. This approach may not necessarily afford the protection required to meet the conservation needs of a marine mammal species or its populations.

In contrast, species-based planning efforts can result in a network of identified important areas in which to implement protective measures, thus having a better chance of achieving adequate protection to a population. Such efforts, however, are often restricted in the extent of protection afforded to wide-ranging species due to limits in geographic boundaries of governance. For example, state-based efforts may limit networks to state boundaries and federal efforts may limit networks to national boundaries. Species-based spatial tools designed to facilitate conservation at both state and federal levels of governance, however, can result in a coordinated approach that has better chances of providing adequate protection. Moreover, recent efforts are being focused on addressing needs beyond domestic boundaries, by creating tools that facilitate strategic planning of species-based protected areas covering important trans-boundary habitats, including migratory, breeding, and foraging habitats globally, such as important marine mammal area (IMMA) created by the IUCN Joint Species Survival Commission/World Commission on Protected Areas (SSC/WCPA) Marine Mammal Protected Areas Task Force (www.marinemammalhabitat .org; Hoyt & Notarbartolo di Sciara 2014; Notarbartolo di Sciara et al. and Hoyt 2020).

Regardless of the geographic governance-based boundaries at which protection is afforded, a sound understanding of important habitats is required to implement protective measures for a species. In addition, knowledge regarding the relative importance of habitats across a species' geographic range is necessary so that conservation efforts at all levels can be coordinated for optimal conservation outcomes.

The southern right whale (*Eubalaena australis*) is one such highly mobile and wide ranging species whose conservation requires knowledge on important habitats it occupies. Southern right whales have been in recovery since the decimation of their populations due to intense whaling over past centuries (Bannister, 1986; Dawbin,1986). While the species is now globally listed as Least Concern under the International Union for Conservation of Nature Red List of Threatened Species (IUCN 2022) because of its returning numbers, the populations that breed off the Australian coast is considered threatened. With an estimated ~3400 (Smith et al., 2020; Stamation et al., 2020) individuals in the population, the species is nationally listed as endangered under Australia's main environmental legislation, the Environment Protection and Biodiversity Conservation Act 1999 (EPBC, 1999), and is protected.

The population of southern right whales that overwinters off the coast of Australia between April and September is made up of two sub-populations; the eastern and western (Carroll et al., 2011), sometimes referred to as the south-eastern and south-western management units. The eastern is smaller than the western sub-population, and has recently been estimated at 268 individuals, with a population recovery rate of approximately ~4.7% per annum (based on analyses of data between 1996 and 2017; Stamation et al. 2020). The western sub-population was estimated at 3164 with an increasing trend of ~5.99% in 2019 (based on cow/calf pairs observed between 1993 and 2019; Smith et al. 2020). Despite progress in recovery, the southern right whale population size is still considered well below its historic size, with habitat occupancy constrained in comparison to historic occupancy (IWC 2009).

The southern right whale population that breeds off Australia is afforded a degree of international protection as well as protection within Australia. The species is listed under the Convention on International Trade in Endangered Species (CITES) and the Convention on the Conservation of Migratory Species of Wild Animals (CMS). In addition, Australia participates in international agreements that extend protection, either directly or indirectly, to southern right whales; including the International Whaling Commission (IWC), the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), and the Antarctic Treaty Consultative Meetings (ATCM). Southern right whales that breed in Australian waters may also be afforded some protection from commercial whaling by the Indian Ocean and Southern Ocean international sanctuaries established by the IWC and by the International Convention for the Regulation of Whaling (through the 1986 moratorium on whaling).

Within Australia, under the EPBC Act, all cetaceans in Australian Commonwealth (waters in the Australian Whale Sanctuary extending from the three nautical mile (nm) state waters limit out to the boundary of the Exclusive Economic Zone ~200 nm from the coast), state and territory waters are protected. In the Australian Whale Sanctuary, it is an offence to kill, injure or interfere with a cetacean. In addition, as a listed threatened and migratory species under the EPBC Act (1999) the species has a Recovery Plan. Recovery Plans are prepared for listed species that have “complex management needs due to their ecology, the nature of threats affecting them, and/or the number of stakeholders affected by or involved in implementing the necessary actions” (Parliament of Australia, 2013). Recovery Plans are designed to “provide for research and management actions necessary to stop the decline of, and support the recovery of” listed threatened species and maximise the chances of its long-term survival (Parliament of Australia, 2013). The Southern Right Whale Conservation Management and Recovery Plan stipulates objectives and targets to measure its performance at the culmination of the Recovery Plan’s life (2011-2021). Targets applicable to the western sub-population include: measurement and monitoring of the population and achieving an annual increase in abundance close to or at the maximum plausible biological rate; putting in place “robust and adaptive management regimes leading to a reduction in anthropogenically-induced southern right whale mortality in Australian waters”; and for management decisions to be supported by “high quality information and high priority research targets identified in this plan”.

An important example of high-quality information provided in the Recovery Plan is the location of Biologically Important Areas (BIAs), not defined under the EPBC Act. BIAs are areas “that are particularly important for the conservation of protected species and where aggregations of individuals display biologically-important behaviour” (DSEWPaC, 2012). BIAs are considered necessary for southern right whales’ essential life functions and include: aggregation and emerging aggregation areas used for calving and nursing; connecting habitats used by migrating or transiting whales; and habitat suitable for essential life functions, including historic high use areas currently not or only occasionally occupied that are potentially important to support full population recovery. Emerging aggregation areas and suitable habitats with no or low current occupancy are important for a recovering population to be able to expand into, for calf production to occur over a larger number of sites, and for genetic diversity to be maintained by allowing whales unrestricted dispersion. Restricted dispersion could lead to small scale genetic differences among aggregation areas.

The Recovery Plan stipulates that habitat occupancy can be evaluated by the level of use of aggregation areas. To facilitate the evaluation of habitat occupancy, the Recovery Plan currently defines aggregation areas as:

- *Large established aggregations*: contain some tens (usually greater than 50) of calving females at the peak of the season,
- *Small established aggregations*: contain up to about 10 (usually less than five). calving females at the peak of the season.
- *Emerging aggregation areas*: not occupied every winter, but in some winters contain a small number (around three) of calving females at the peak of the season. Emerging aggregation areas are those areas that have been used on and off (often more frequently in recent years) by a small number of calving females, and so may become established aggregation areas over time.

Aggregation areas currently identified for the western sub-population in the Recovery Plan include three large established (Head of Bight, Doubtful Island and Israelite Bay), two small established (Yokinup Bay and Flinders Bay) and four emerging aggregation areas (Twilight Cove; Hassel Beach; Cheyne, Wray, Dillon, and Bremer Bays; and Flinders Bay; DSEWPaC, 2012). These sites were identified using expert scientific knowledge regarding distribution, abundance, and behaviour, over a decade ago when the population was roughly 30% smaller. Due to the expansion into historic breeding areas expected to have taken place to accommodate the increased sub-population size since then, this requires updating. Indeed, expansion of population into historic breeding grounds has already begun to be documented (Burton et al. 2019; Charlton et al. 2019b) and may be expected to occur more rapidly for the western than the eastern sub-population due to its comparatively higher growth rate. With increasing anthropogenic pressures in many of these areas, a re-assessment and dissemination of knowledge will ensure management decisions are supported by high quality knowledge.

A region occupied by the western sub-population that has historically been knowledge poor is the southwestern corner of Australia, within which in recent years the Ngari Capes Marine Park has been gazetted (Figure 1). There are two embayments within Ngari Capes Marine Park with habitat suitable for southern right whales – Flinders Bay and Geographe Bay. While Flinders Bay was recognised by the Australian Commonwealth as an emerging calving ground at the time the Recovery Plan was prepared (DSEWPaC, 2012), Geographe Bay was not. The aim of this study is to evaluate the importance of the Ngari Capes Marine Park region, including the two bays, for breeding southern right whales and provide knowledge to update the Recovery Plan aggregation areas.

Specifically, this study aims to evaluate the minimum abundance, residency, dispersal, site fidelity and connectivity of southern right whales in the Flinders Bay and Geographe Bay regions using photos of individual whales collected between 1991 and 2021. Photos used in this study have been taken opportunistically through researcher surveys combined with citizen science observations. While opportunistic photographs come with inherent biases in effort and spatial coverage, in an environment where funding is often absent or limited, these observations can be vital for providing minimum estimates of important population parameters. The result of the opportunistic effort this study draws from has been the collection of several thousand (to date) land-based and vessel-based lateral and aerial drone-based photographs.

These photographs can be used for photo-identification (photo-ID) to identify individual southern right whales using recognisable, unique identifiable and persistent patterns of callosities that develop on their head region (Payne et al., 1983; Bannister, 1990). While the focus is on photos in the Flinders Bay and Geographe Bay regions, a small number of photos taken opportunistically in the broader southwestern Australian corner has also been included to gain insight on movements of southern right whales over longer distances during the 30-year period of this study.

While this study will provide recommendations for updating recognised aggregation areas identified in the Australian Southern Right Whale Conservation Management and Recovery Plan, it will also more broadly inform transboundary location-based conservation tools (e.g., IMMAs) and conservation-based decision making for the endangered population of southern right whales that seasonally occupies waters off Australia.

An important additional goal of this study is the upload of photographs of individual southern right whales observed in the Flinders and Geographe Bay regions each year to the Australasian Right Whale Photo-Identification Catalogue (ARWPIC; AMMC 2021) hosted by the Australian Marine Mammal Centre and Australian Antarctic Data Centre at the Australian Antarctic Division (archived at the Australian Antarctic Division Archives). This contribution to the ARWPIC will allow comparisons with regions beyond the southwest of Western Australia to be undertaken in future studies. Finally, this study also undertook a process of stakeholder engagement to evaluate needs in the context of this work and to communicate results. Stakeholders included federal, state and local government departments, industry (including tourism and fisheries), education and community sectors and cultural custodians. The feedback from engagement will inform the format of future outputs to improve communication and knowledge sharing.

2. Methods

2.1 Study area, effort and photo contributions

The project was undertaken in the southwest corner of Australia, with a focus on the Geographe Bay and Flinders Bay regions within Ngari Capes Marine Park (Figure 1).

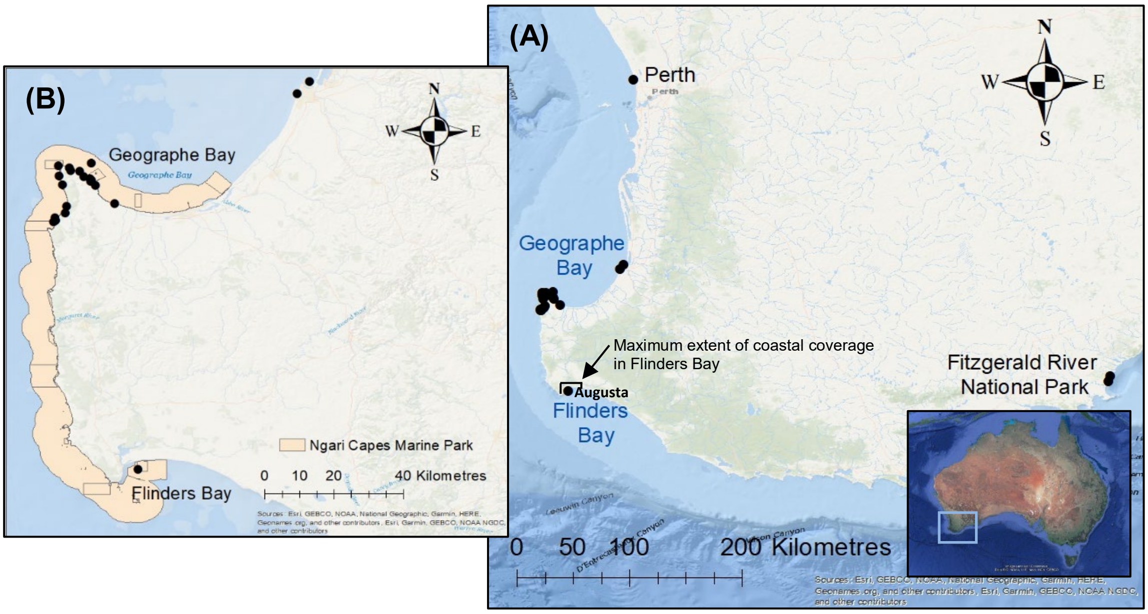

Figure 1 Locations (black points) from which southern right whale photo-ID images in the southwest corner of Australia (A) were available, including land-based vantage points located in the Geographe Bay region (including Cape Naturaliste and surrounds) and Flinders Bay in Ngari Capes Marine Park (B).

Photos used in this study were taken from vantage points from land, vessels and drones launched from land. Vessel and land-based photos consisted of lateral images of the bodies, while drone images consisted of aerial overhead shots of whales. Photographs were contributed to the SouWEST (Southwest Whale Ecology Study; http://souwest.org) Southern Right Whale catalogue (curated by C. Burton at Western Whale Research since 1991). Contributors include authors of this report, and those listed in the Acknowledgements including whale watching operators and volunteers that are part of the long-term citizen science program established and coordinated by Western Whale Research and is part of SouWEST.

As a result of photos being taken from a range of platforms and contributors, there was high variability in spatial coverage, temporal effort within seasons and across years, and locational information associated with the photos. Search effort (in space and time) was not available for most photos. Photos taken from land-based vantage points or drones launched from land had the nearest land feature from which the whale was sighted as the location of sighting, while photos taken from vessels generally had the name of the bay as the location of the sighting, or in some cases the location of a nearby water or land feature. During two of the years, researchers (authors of this report) conducted dedicated survey effort which resulted in vessel-based photos with detailed information including the GPS positions of sighted whales. Since the main aims of this report, however, were to evaluate the minimum abundance, residency, site fidelity and connectivity within regions through comparisons with photos over all years available, the detailed GPS positional information of this subset of data are not reported on here. In this study, interpretation and qualifications of results that may have been biased by varying effort is provided, based on the authors' insight (qualitative) on activities over the years at different locations.

Within the Geographe Bay region, most photos were taken from land-based vantage points or from drones launched from land, with a smaller number of photos taken from vessels. Land-based vantage points and drone launching locations included the coastline from Indjidup, to the southwest of Cape Naturaliste to Quindalup in Geographe Bay, with most effort from Pt. Picquet (Figure 4). The maximum detection range from the coastline in the Geographe Bay region is expected to have been approximately 2 km in good weather conditions. All photos from Flinders Bay were from vessels operating mostly within an area of approximately 10 km (6nm) radius of Augusta (i.e., whale watch operations). In one of the years (2016) a dedicated systematic survey effort by the authors of this report extended the spatial coverage to 20 km along the coastline east from Augusta (Figure 1). Photos from the Perth, Bunbury and Fitzgerald River National Park regions were all taken from a vessel.

In the Geographe Bay region, photos were available from 16 years over a 25-year period (1996-2021; Table 1). In Flinders Bay, photos were available from 10 years over a 22-year period (1997-2019; Table 1). Photos from Perth were taken in 1991, 2004 and 2019 from Bunbury in 2012 and 2021, and Fitzgerald River National Park 1994.

Table 1: Region, platform, and source of southern right whale photos; years in which they were taken, and the total number available for analysis after removal of 1000 of the poorest quality photos (FB = Flinders Bay, GB = Geographe Bay region, FRNP = Fitzgerald River National Park).

Location	Platform	Source	Years of photos	Number of photos available
GB	Land, drones, vessels	Researcher, volunteer citizen scientists, whale watch operator	1996, 1998, 2003-2005, 2010-2021	1560
FB	Vessels	Researcher, whale watch operator	1997, 2003-2004, 2013, 2015-2017, 2019-2020	1070
Bunbury	Vessels	Researcher	2012, 2021	5
Perth	Vessels, drones	Researcher	1991, 2004, 2019	12
FRNP	Vessels	Researcher	1994	15

Seasonal effort in the Geographe Bay region began in September and ended in December until 2012, as the whale season at that time was focused on monitoring humpback and blue whales that seasonally migrate through the bay between August and December. After 2012, an earlier start to seasonal observations began to capture more southern right whales; and since 2017 a higher level of temporal coverage has been achieved, with regular observations undertaken between July and December.

In Flinders Bay photos were mostly from June to September, and mostly limited to a period of less than two months for most years, due to the absence of funding and high dependency on whale watch operators working in the area at the time.

In total, over 2600 photographs of southern right whales were available for this project, the majority of which were from Flinders Bay and Geographe Bay regions (Table 1). Photos consisted mostly of adults (mothers accompanied by a calf or adults without a calf), since callosity patterns do not normally stabilise until after 6 months of age (Kraus et al. 1986). In a few cases calves were re-identifiable due to the presence of white dorsal pigmentation anomalies.

2.2 Photograph processing and matching

All photographs (either in electronic format from DSLRs or scanned from SLR camera slides) were imported into an Adobe Lightroom Classic CC Version 6.12 (2017) Library created for curation, processing and matching. *Collections* within the Library were created for each location, and folders were created for each date within each *collection*. After importing photographs into the relevant folders within their respective *collections*, all very poor-quality photos in which distinguishing features of southern right whales were not discernible were removed. Each photograph in the Library was then labelled using the *key word* feature available in Lightroom to code the following attributes: Group Encounter Number (beginning with 1 to the last for each survey day), Individual Number (for each group, beginning with 1 to the last within the group), Image Quality Criteria (see Appendix A), and southern right whale features including Gender, Colour of Body, Dorsal Blaze Presence and Colour, Coaming shape and texture, Bonnet erosion, the Number of Right and Left Island Callosities, Left and Right Bar Island Callosity Presence/Absence, Left and Right Lip Callosity Presence/Absence, Central Feature Callosity Presence/Absence and Type, Complex Presence/Absence, Sub-blowhole Callosity Presence/Absence and Post Blowhole Callosity Shape. Southern right whale features coding was consistent with that used in Australasian Right Whale Photo-Identification Catalogue (ARWPIC) briefly described in Appendix A.

To identify matches of the same individual photographed on different days and locations, photos of individuals within each date in each *collection* were compared to photos from every other date in the same *collection* and all dates in all other *collections* in the Library, after applying a filter to view only Excellent and Good Quality photos. Feature filters were used to aid with matching. Comparisons were undertaken by an experienced researcher, and any suspected matches were checked independently by a second experienced researcher. The dates and locations of all matches for each individual were recorded on a Microsoft® Excel® v14.7 for Mac (2011) spreadsheet.

2.3 Analyses

Minimum abundance of identified individuals was quantified as the number of individuals identified in photos, while minimum abundance was quantified as all adults identified plus calves of mothers that were not photographed. Minimum abundance was reported over the entire period of the study as well as for each location and year. Abundance values here are defined as ‘minimums’, as effort varied and was not available for many of the photos included in this study and could not be used to account for poor effort at certain times and locations. A discovery curve (of new individuals over each season) was created as a visualisation of the rate at which new individuals were discovered. In addition, the number of individuals identified at different locations was mapped using the location of first sighting to visualise the distribution.

Residency was quantified as the time between the first and last sighting within a breeding season for each whale. This approach assumes that emigration outside of the regions did not take place between sightings, and is considered likely valid for most whales given the large size of the regions and relatively large distances between regions, however exceptions are discussed further in the Discussions and Conclusions section of this report. Residency was also considered a minimum, with many whales likely occupying a region over a longer period than that documented here.

Site fidelity was quantified by resights of whales within the same region over different breeding seasons, and connectivity as resights of whales in different regions, either in the same breeding season or in different breeding seasons (as a measure of functional connectivity between regions).

Further quantification of these characteristics for southern right whales occupying the southwest corner of Australia using additional statistical tools is anticipated for preparation of this work for peer-reviewed publication.

All analyses and associated visualisations were produced using R v4.1.0 (R Core Team 2021) in RStudio Version 1.1.463 - © 2009-2018 RStudio, Inc. or Microsoft® Excel® for Microsoft 365 MSO (Version 2204). ArcGIS® and ArcMap™ v10.7.1 (© Esri) was used to create all maps.

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3. Results

3.1 Minimum abundance and distribution

A total of 237 individuals were identified (including four calves); 141 in the Geographe Bay region, 88 in Flinders Bay, 4 off Perth, 2 off Bunbury, and 2 off Fitzgerald River National Park. When comparing individuals identified between the Geographe Bay, Flinders Bay, Perth, Bunbury and Fitzgerald River National Park regions, there were 3 individuals that were the same sighted at different times in different regions (see connectivity in Section 3.3). Consequently, accounting for these, the total number of unique individuals across all regions over the study period was 234.

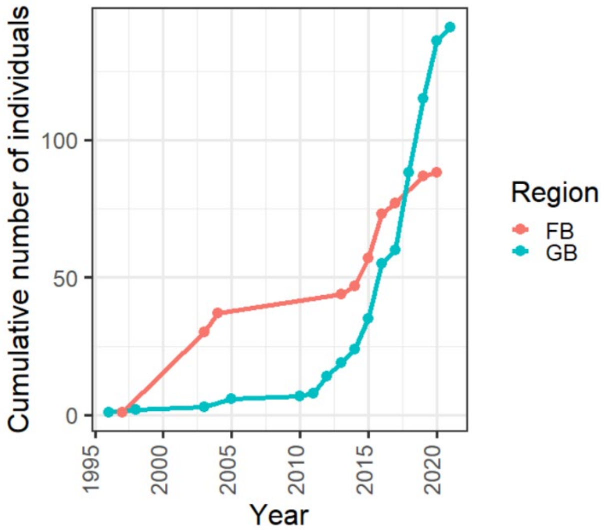

Figure 2 Discovery curve for individual southern right whales identified from photos from the Flinders Bay (FB) and Geographe Bay (GB) regions between 1996 and 2021.

Discovery curves indicated a continued 'discovery' of new individuals between 1996 and 2021. No plateau was observed in either the Geographe Bay or Flinders Bay regions (Figure 2). A marked increase in discovery rate was observed at times of known greater relative effort (e.g., since 2017 in the Geographe Bay region and in 2003 and 2016 in Flinders Bay).

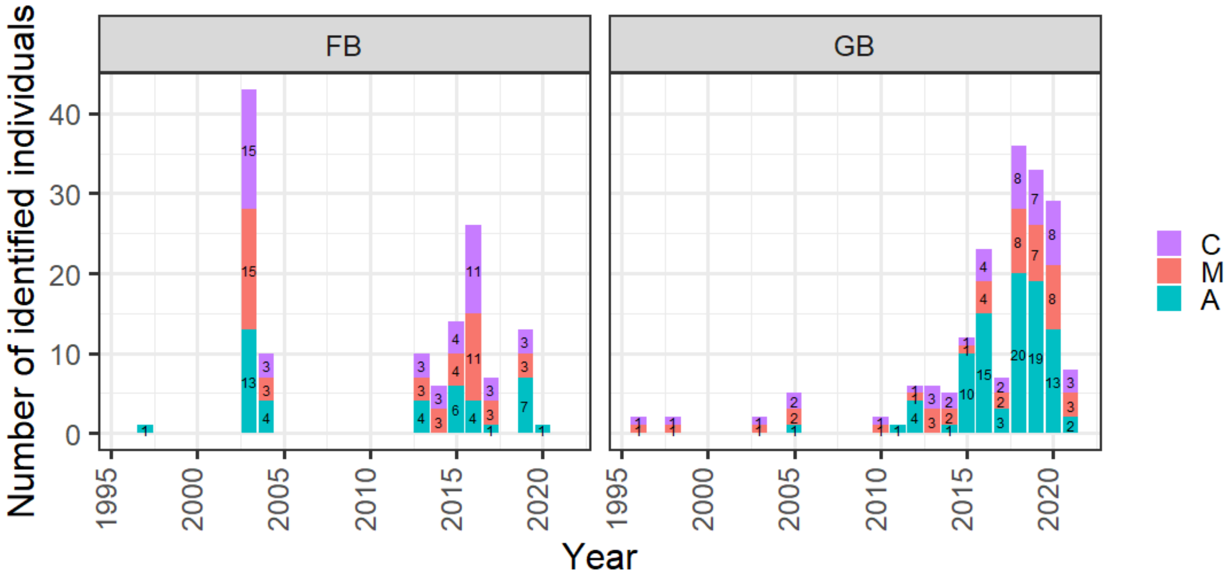

Figure 3 Total number of individual calf (C), mother (M), and unaccompanied adult (A) southern right whales identified from photos from the Flinders Bay (FB) and Geographe Bay (GB) regions between 1996 and 2021.

On average, the number of whales observed per year in the Geographe Bay region was 11.2 (SD = 12) and ranged from 1 in 2011 to 36 in 2018 (Figure 3). In Flinders Bay the average was 13.1 (SD = 12.7) and ranged from 1 in 1997 to 43 in 2003 (Figure 3). In the Geographe Bay region, the average number of mother-calf pairs was 3 and ranged from 1 (in years prior to 2005) to 8 (in 2018), while the average number of unaccompanied adults was 8 (SD = 2.6) and ranged from 0 (in the 1990's and early 2000's) to 20 (in 2018; Figure 3). In Flinders Bay, the average number of mother-calf pairs was 5.6 (SD = 4.7) and ranged from 0 (in 1997) to 15 (in 2003; Figure 3), while the average number of unaccompanied adults was 4.5 (SD = 3.8) and ranged from 0 (in 2014) to 13 (in 2003; Figure 3).

While the specific position (latitude and longitude) within the regions where individuals were sighted were not recorded for most whales, in all regions except for Flinders Bay, the land features proximal to where individuals were seen were recorded. In the Perth region, three individuals were recorded off northern beaches (Hillarys) and one was recorded as generally off Perth, off Bunbury one was recorded in Koombana Bay and the other recorded in a general location off the 'back beach', and off Fitzgerald National Park one was recorded off Boondaldup River and the other off Trigalow Beach from a research vessel (Figure 4). In the Geographe Bay region, individuals were recorded from a range of vantage points from Busselton (~15 km east of Quindalup) to Indjidup (Figure 4), with the greatest number recorded at first sighting was off Pt. Picquet (49) where there was known to be most effort, followed by Bunker Bay (12), Rocky Pt. (11), Meelup (10), and fewer sightings at all other vantage points. In Flinders Bay, where sightings were from vessels and most positions not recorded, the western and eastern most extent of sightings was from Augusta to a maximum of 20 km eastward (Figure 1).

3.2 Demographics and minimum residency

Of the individuals identified in the Geographe Bay and Flinders Bay regions, 130 were adults unaccompanied by a calf, 79 were mothers (with a calf with no photo-ID obtained), 18 were mother-calf pairs (9 mothers with their 9 calves), and 2 were calves (with mothers with no photo-ID obtained). Of the total individuals identified, 68 were sighted over multiple days. For the cohort of whales that were sighted more than once, the distribution of minimum residency periods varied between the two regions (FB: median = 14, max = 42, n = 25; GB: median = 12, max = 72, n = 20; Figure 5), as did the average (FB: mean = 13.6, SD = 10.3; GB: mean = 18.6, SD = 20.1). In addition, a greater percentage of mother-calf pairs (31%) were sighted over multiple days than adults without a calf (10%), and this occurred in both the Flinders Bay and Geographe Bay regions (19% and 45% of mother-calf pairs in the Geographe Bay and in Flinders Bay regions, respectively; compared with 7% and 14% at the two locations for adults without a calf).

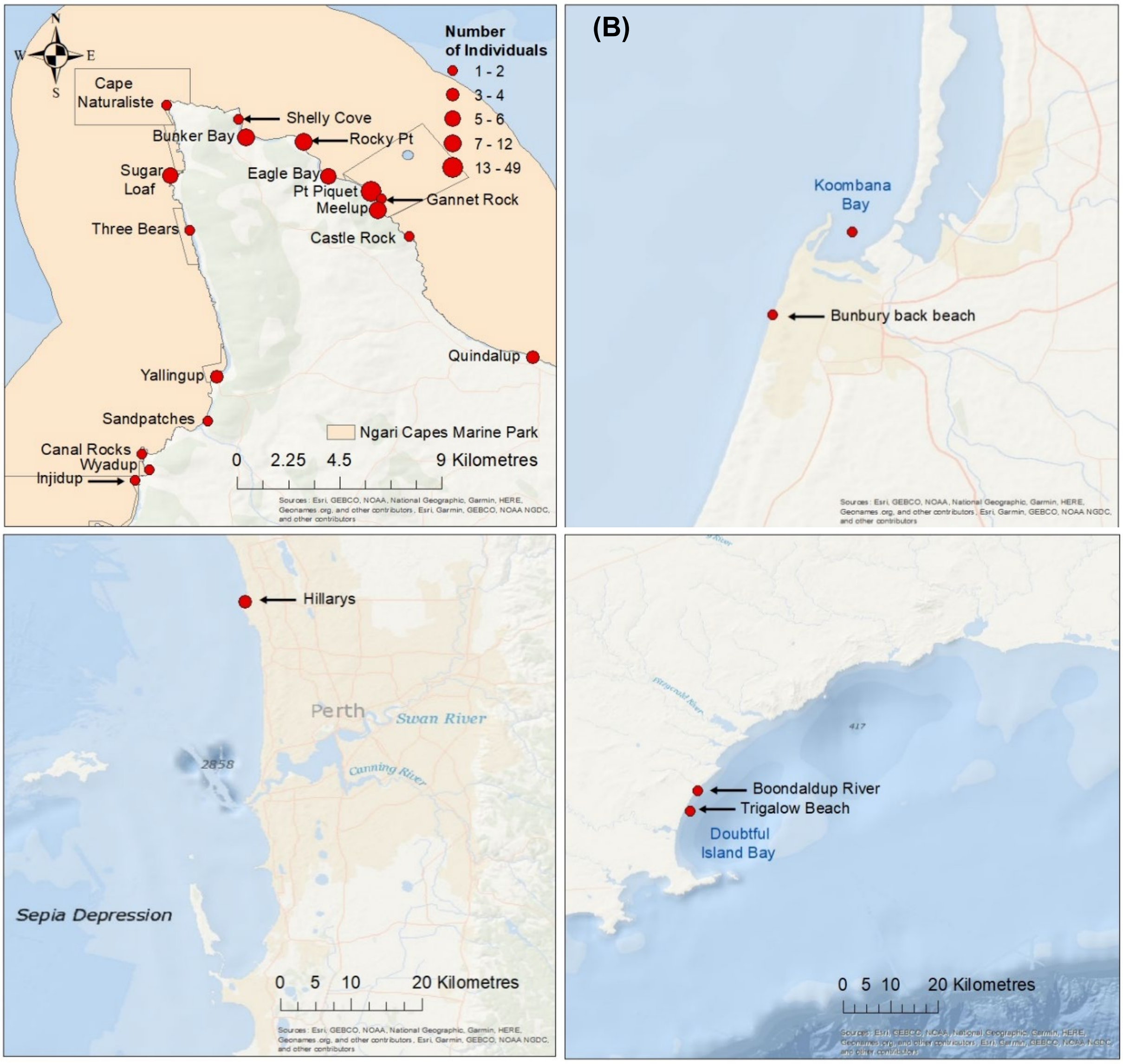

Figure 4 Numbers of individual southern right whales sighted at the vantage point they were first recorded in; in the Geographe Bay region including Cape Naturaliste down to Injidup (A), in the Bunbury region (B), in the Perth region (C) and the Fitzgerald River Nation Park region (D).

The average minimum residency was greater for mother-calf pairs than for adults unaccompanied by a calf. The average minimum residency for all mother-calf pairs recorded in Flinders Bay was 7.5 days (SD = 10.1) and in the Geographe Bay region was 6.7 days (SD = 15.5). For adults unaccompanied by a calf, the average residency was 2.4 (SD = 4.1, n = 29) in Flinders Bay and 1.4 (SD = 2.1, n = 59) in the Geographe Bay region.

In the Geographe Bay region, during 6 of the 15 years with photos available, mother-calf pairs were recorded in the area over multiple days; including in all four of the most recent years (2018-2021; Figure 6). In 2013, 2016, 2018, 2019, 2020, and 2021, 1-2 pairs were resighted 2 to 18 times over ≥16 to 72 days. In 2016 and 2018, a pair was resighted two times over 8-12 days. In 2018, one pair was resighted twice over 4 days.

In Flinders Bay, in all eight years with photos available, with the exception of 2013, mothers and calves were recorded in the area over multiple days (Figure 6). In 2003, 2004, 2014, 2016, and 2017, 2-4 pairs were resighted 3-12 times over ≥14 to 42 days; in 2004

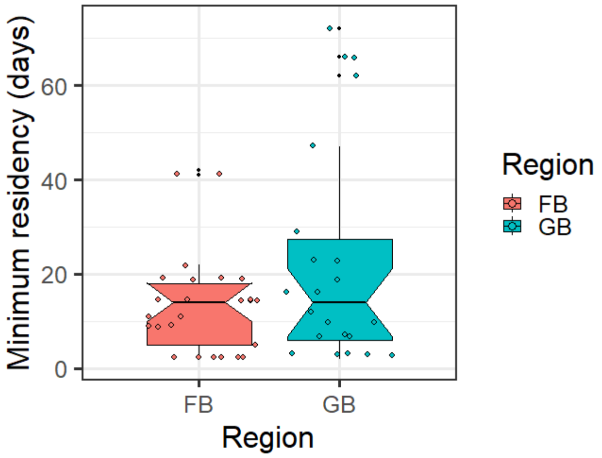

Figure 5 Box plots of minimum residency for southern right whales sighted more than once in the Flinders Bay (FB) and Geographe Bay (GB) regions between 1996 and 2021.

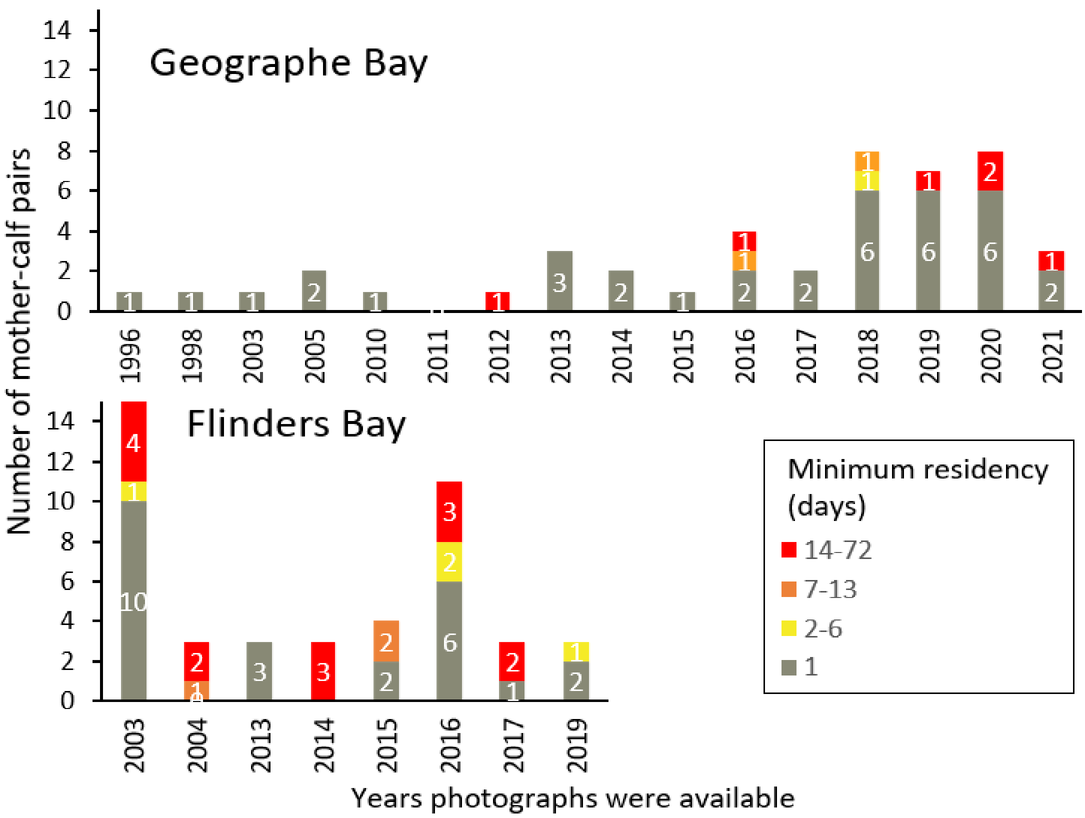

Figure 6 The number of mother-calf pairs sighted over 1 day, 2-6 days, 7-13 days and over 13 (and up to 72) days in the Geographe Bay and Flinders Bay regions during years between 1996 and 2021.

and 2015, two pairs were resighted 2-4 times over ≥9 to 10 days; and in 2003, 2016, and 2019, 1-2 pairs were resighted 2-4 times over ≥2 to 3 days.

Residency was not recorded for photos from the Bunbury, Perth, and Fitzgerald River National Park regions, and consisted of a single sighting. One mother-calf pair was sighted in each of these regions – one off Bunbury (Koombana Bay) in 2021; one off Perth (Hillarys) in 1991, and one off Fitzgerald River National Park (Trigalow Beach).

3.3 Site fidelity and connectivity

One individual was confirmed to have returned to the same region in different years. This was a female (GB 001) sighted in Geographe Bay 9 years apart. When first sighted on 7 October 1996 off Eagle Bay GB 001 had a calf, as she did when sighted the second time on 19 October 2005, again off Eagle Bay.

During the study period, three individuals were resighted in a different region at a different time (Table 2). All three were confirmed as mothers accompanied by their calf. Two had calves both times they were sighted while one was recorded as an unaccompanied adult the first time and subsequently was confirmed as a female with a calf the second time she was sighted. The duration between times of resights ranged between over 80 days (within the same breeding season) and 5.1 years. All three were individuals first sighted in Flinders Bay that were subsequently resighted in Geographe Bay. None of the individuals that were sighted off Perth, Bunbury or Fitzgerald River National Park were resighted.

Table 2: Southern right whales resighted in different regions and corresponding dates of the first sightings within each region and the duration between resights (FB = Flinders Bay, GB = Geographe Bay).

ID	Cohort	Region		Date		Time between sightings (years)
		First sighting	Resighting	First sighting	Resighting	
SW055	Mother	FB	GB (Pt. Picquet)	2015/08/26	2020/09/27	5.1
SW057	Mother	FB	GB (Rocky Pt.)	2016/08/02	2016/10/21	0.2*
SW062	Mother**	FB	GB (Pt. Picquet)	2016/08/05	2018/09/15	2.1

Note: *Within season resight of 80 days. **First sighted as an adult in a group of two adults and two years later was resighted accompanied by a calf.

4. Discussion and conclusion

4.1 Abundance

This study provides supporting evidence for an increasing return of southern right whales to formerly occupied habitat in the southwest corner of Australia. The numbers of whales identified in the region during this study on average was approximately 5 to 10-fold greater than in previous studies; with a mean of ~11 and ~13 in the Geographe Bay and Flinders Bay regions, respectively, and up to at least 49 individuals in any one year identified across both locations (i.e., number summed over both bays in 2016). In a previous study by Bannister (1990), the number identified in the southwest corner from Flinders Bay to Perth over the period of 1980 to 1982 was approximately 1 and between 1983-87 was 10. While effort was highly variable among years in the present study and differed from effort in the study by Bannister (1990); the average discovery rate of individuals between 1996 and 2021 here was 7.5 per annum, while between 1983 and 1987 it was reported as 2 per annum. The continued discovery of new individuals over the 30 years of this study is indicative of, either new individuals arriving to the region or whales not having been recorded previously occupying the region despite their presence, and is likely a result of a combination of the two.

The intensity of effort reported by Bannister (1990) was more limited than some years in this study; with approximately three surveys a season in the 1980's study (one per month from August to October), however, there was much better spatial coverage due to an aircraft being used as the survey platform. A comparison with numbers reported by Smith et al. (2020) and previous reports from that same program is not made here since that study aimed to produce a total western sub-population trend estimate, and not total numbers within any one location, hence consisted of one flight per year that covered Flinders Bay and eastward, and did not include the coast from Cape Leeuwin northward.

Despite the low numbers observed in the 1980's study, Bannister (1990) identified the Augusta area as one of several areas off the Western Australian coast favoured by southern right whales. Bannister's (1990) findings regarding the favoured area near Augusta and the increasing numbers of whales reported in this study are consistent with the sense of the region bestowed by reports from the 18th and 19th century whaling period, providing further evidence to the southwest corner of Australia as providing important habitat for southern right whales.

The Western Australian coast, in general has historically been understood to have plentiful whale 'stocks', with reports from as early as the 17th and early 18th century (Gibbs, 2010). The abundance of whales off Australia's coast supported French, British, and American (and, albeit to lesser extent, Dutch and German) pelagic whaling since the late 1700's. However, due to a range of geopolitical reasons the development of so called 'bay' whaling by early colonists that targeted whales in sheltered waters, including southern right and humpback whales, did not gain momentum until the early to mid-1800's. Bay whaling was considered to be a cost-effective operation, where whaling stations could operate with limited resources, often involving only a few small boats (Gibbs, 2010). Despite the limited capabilities, southern right and humpback whales breeding in and migrating through sheltered bays in the Austral winter (Gibbs, 2000; Gibbs, 2010) could be targeted. Once shore-based whaling stations gained momentum, over a dozen shore-based whaling stations were established in Western Australia (McIlroy, 1986). Shore-based whaling in the southwest of Western Australia were reported from the following locations: Toby Inlet (probably operating in 1847), Minninup (probably operating in 1862-1863) and Castle Rock (operating over 19 years, including 1846-1862,1866, and 1871-1872) in the Geographe Bay regions; Bunbury (operating over 20 years, including 1838-1839,1843-1844, 1846, 1849-1853, 1855-1865, and 1867); Safety Bay (1838); Bathers Beach (operating over 22 years, including 1837-1841 and 1843-1861); Carnac Island (operating at least 9 years, including 1937, 1845, 1853-1860, and probably in 1863, 1865-1866, and 1868-1875; Gibbs, 2010); North Fremantle (in 1856 and probably in 1865); Rottnest Island (in 1850); and Marmion (in 1849) (Gibbs, 2010). Flinders Bay was never established as a whaling station, despite it being highly regarded for the fishery, as a result of the limited size of the population of the colony, and because the cape was deemed a difficult passage to navigate, and transport expensive. Hence, Geographe Bay was considered as a simpler location in which to continue operations (Gibbs, 2010).

During early shore-based whaling, American and French vessels continued to operate and directly compete with colonial whaling, with American vessels particularly active in Flinders Bay, Busselton, Koombana Bay and Cockburn Sound in the early to mid-1800's (Gibbs, 2010). Consequently, it is thought that the large numbers of American vessels operating near and along the Western Australian coastline in the early 1840's immediately before colonial shore-whaling began, had likely already significantly driven down the numbers of southern right whales in the region (Gibbs, 2012), and the addition of colonial whaling pressure further depleted the stock. Indeed, while the Fremantle Whaling Company reported to have generated the largest export commodity in the colony of 100 tons of oil and 5 tons of whalebone in 1837, by 1840 a decline in productivity due to depleted whale stocks and a drop in overseas oil and bone prices seriously impacted the industry (McIlroy, 1986).

With likely already depleted whale numbers in the region, during the earliest days of colonial settlement at Augusta in the 1830s, seasonal whaling by American and French vessels continued with yearly visits to the settlement. Two American vessels reportedly caught 30 and 31 whales (either southern right or humpback whales or both, as the species were not reported) inside Flinders Bay in the winters of 1839 and 1840 (respectively; Shire of Augusta-Margaret River, 2021). This is the only record for the region of few available on American and French catches. Colonial station catches were also rarely reported. In Geographe Bay, between the years 1846 and 1852, the Castle Rock Whaling station (which evolved into the establishment of the town of Dunsborough in 1845) reported 16% of all whales chased being southern right whales, with anywhere from 4 to 23 southern right whales chased per season (Gibbs 2012). Between the years of 1845 and 1865, up to 12 southern right whales were reported to have been caught in Fremantle, up to 5 in Bunbury, up to 11 at Castle Rock, and 2 as far as Port Gregory (north of Geraldton) by the local newspaper at the time (Gibbs, 2012).

While the historical records on Western Australian whaling are insufficient to determine the abundance of southern right whales seasonally occupying the southwest corner of Australia before whaling commenced, including in the sheltered waters of Geographe and Flinders Bays, they provide evidence that southern right whales occupied the region every season reliably and with extended distribution well north of Geographe Bay. They also lend evidence of depletions of southern right whales in the region. With whales observed in all years in which photographs were available in this study, and a maximum number of up to 43 in Flinders Bay and 36 in Geographe Bay identified in a single year, this study supports the premise of re-emerging occupancy within the region, which is consistent with re-establishment of former breeding grounds observed in other locations (Charlton et al. 2019b).

Relatively high numbers of individuals identified per season during this study were in more recent years of the 30-years period. Not only might there have been increasing numbers of whales occupying the region in recent years, but more recent years are also known to have had relative high effort searching for whales and collecting photographs. Years in which there was low effort corresponded with few individuals identified. In the Geographe Bay region, search effort by researchers and volunteers since 2017 has been particularly high, with a consistent search effort based at Pt. Picquet where volunteers spend time blocks of 2-hour shifts searching the area from land and recording all species and numbers of whales they observe. The total daily search time ranged approximately from 2 to 8 hours a day. The researcher that leads this effort (C. Burton), conducts approximately two to three 2-hour shifts a day and takes lateral photographs of whales as they travel past Pt. Picquet. In addition, an increased drone effort by trained volunteers (listed under C. Burton's research permit) has been undertaken, whereby volunteers travel to land-based vantage points and search opportunistically, taking drone photos and video if a whale is within drone-flying range. In addition, sightings of any whales observed by volunteers on shift at Pt. Picquet are communicated to the researcher and volunteer drone operators with information on the whale's direction of travel so that a drone operator (if available) may attempt to obtain images of the whale. In Flinders Bay, effort was very different and the seasonal extent more limited than that in the Geographe Bay region in recent years, with most effort from a whale watch vessel (Naturaliste Charters). Two of the years (2003 and 2016) in Flinders Bay, however, had relatively high effort over a two-to-four-week period as dedicated surveys were undertaken by researchers. The dedicated effort coincided with greater numbers of identified individuals.

4.2 Demography and residency

The demography and residency of whales recorded in this study also provides supporting evidence for recolonisation of a southern right whale breeding ground in the southwestern corner of Australia, including in the Flinders and Geographe Bay regions. In Flinders Bay the number of mothers with their calves ranged from 1 to 15, while in the Geographe Bay region, the number ranged from 1 to 8. As was true for the total number of individuals identified each year, greater numbers of mother-calf pairs were observed in more recent years and when there was greater-known effort in searching for whales and obtaining photographs. Numbers, however, also are likely to have varied as a result of more females occupying inshore calving grounds in years that they were calving, which has been recorded as commonly occurring every three years (Payne et al., 1990; Bannister, 1990; Charlton et al., 1999a). The high variability in effort in this study, however, precluded a clear evaluation of such temporal patterns in calving.

In most years the number of adults without calves identified was greater than the number of mothers with their calves, and the difference was particularly prominent in the Geographe Bay region from 2016 onward. The number of unaccompanied adults in any one year ranged from 1 to 20 in the Geographe Bay region and 1 to 13 in Flinders Bay. It may be that with re-colonisation of former breeding areas, while mothers with calves are arriving to the sheltered bays to rest and suckle their young, adults without calves are travelling more widely, and males in particular are doing so to maximise mating opportunities. Indeed, a mating event was documented on video by one of the volunteer drone operators (I. Wiese) in 2018 in Geographe Bay. The average minimum residency of around 2 days for unaccompanied adults (also observed at the established and recovering breeding area of Fowlers Bay; Charlton et al. 2019b) compared to that of around a week for mother-calf pairs supports this assertion, as does the wider ranging of unaccompanied adults documented in past studies in the region.

The locations of resights of unaccompanied adults within the same breeding season off the coast of Western Australia documented in the 1980's were between 100 (~93 km) and 300 nm (~555 km) away from the location of first sighting (Bannister, 1990). Having said this, in this study a relatively high number of mother-calf pairs in the Geographe Bay region were documented to have been sighted only once, including in more recent years when the extent of seasonal coverage in effort was significantly greater. These mother-calf pairs would have been using the region much more broadly than the area where concentrated effort along the coastline between Pt. Picquet and Bunker Bay of not much more than 5 km in distance occurred, and resights within the region would have been missed. The few individuals off Bunbury and Perth identified in this study (in addition to others reported anecdotally and in media coverage) indicate that indeed mother-calf pairs travel through the Geographe Bay region to locations further to the north. Moreover, a mother and her calf in this study were observed to move broadly within Geographe Bay over a four-week period. She was first sighted at Pt. Picquet (on 26 August), then at Meelup (28th August), then 16 days later off Bunbury (on the 14 September), then 9 days later off Dunsborough (23 September), then 5 days later off Meelup (27 September), and finally off Castle Rock the following day, after which she was not sighted again. In fact, even broader within season movement was recorded in this study with a mother-calf pair sighted in Flinders Bay and then 80 days later in Geographe Bay (in 2016) providing direct evidence of within-season ranging over 100 km. Such ranging has been reported in Western Australia in the past (in the 1980's), with 68% of mother-calf pairs resighted within the same year within 50 nm (~93 km) and 28% resighted at greater ranges up to 200 nm (~370 km; Bannister 1990).

Of those mother-calf pairs sighted over more than one day, most were seen to have stayed for at least almost 2 weeks and over, regardless of whether it was in the Geographe Bay or Flinders Bay region, with the longest period being 72 days in the Geographe Bay region and 42 days in Flinders Bay. This period constitutes anywhere from almost 20% to the full period mothers are expected to seasonally occupy breeding grounds off the coast of Australia to suckle their young in preparation for the migration to feeding grounds. Most residency periods reported here are thought to be underestimated at both locations – in Flinders Bay, mainly due to the limited extent of seasonal coverage (and limited effort in general) and in the Geographe Bay region due to the limited seasonal and spatial coverage in years prior to 2017 and in more recent years due to the limited spatial coverage. Despite this, mean calving occupancy periods are somewhat comparable to the mean occupancy of 23 days and ranging from 1-75 reported at the small established aggregation area of Fowlers Bay (Charlton et al. 2019b), and more so to observations from the 1980's off Western Australia with most mothers and calves reported to have been resighted over 2 to 5 weeks (Bannister 1990). The mean occupancy in this study, however, is less than the mean occupancy of between 40 and 71 days reported at the Head of Bight in Southern Australia (Burnell 2001, Charlton 2017).

The numbers of mother-calf pairs that were resighted over one week to over two months increased over the years in the Geographe Bay region. Over the most recent four years of the study there were at least 1 to 2 mother-calf pairs consistently occupying the area. In Flinders Bay there were consistently from 1 to 5 documented over 1 week to over a month.

As indicated for the total number of whales identified, it is highly likely that the number of total mother-calf pairs and those staying over an extended period have been underrepresented. In Flinders Bay a relatively small area of the habitat available in the bay was covered, thus, it is expected that surveys further east along the coast would have resulted in greater numbers documented. In the Geographe Bay region, as indicated before, a greater spatial coverage in effort across the region may have resulted in further individuals identified and a greater number of resights.

Despite the limited time spent at breeding grounds, southern right whale mothers in the Geographe Bay and Flinders Bay regions are fasting and lactating, and are transferring an enormous amount of energy to their calves (Christiansen et al. 2018). Mothers are spending significant amounts of time nursing their young. Consequently, mothers and their calves are particularly vulnerable to disturbances that may disrupt the nursing time required for calves to gain weight and strength. In addition, the shallow coastal habitats of Flinders Bay and Geographe Bay may well be important as refuges where calf predation risk is decreased (Corkeron & Connor 1999; Ford & Reeves 2008, Nielsen et al. 2019). Hence, it is important that such breeding areas are protected so that mothers that require low energy expenditure during the breeding season remain undisturbed and calves protected so that their survival is not impacted (Nielsen et al. 2019).

4.3 Site fidelity and connectivity

The resight of a female that was first identified in Geographe Bay with a calf in 1996 and was confirmed to have returned 9 years later in 2005 to have another calf provides the first reported direct evidence of long-term site fidelity specific to Geographe Bay. Site fidelity has been reported for southern right whale females with a calf off Western Australia previously, with almost 30% of resighted animals sighted one to six years apart within 50 nm (~93 km) of the first sighting location, and 76% recorded not more than about 150 nm (~278 km; Bannister, 1990). In the same study, unidentified adults were reported to have greater dispersal with ~11% of individuals resighted in different years within 50 nm (~93 km), and 50% within 150 nm (~278 km; Bannister, 1990). Such site fidelity has been recorded previously, with southern right whales returning to the same coastal areas to calve (Payne 1986; Burnell 2001; Pirzl 2008).

Two other females were resighted in different years; one of which was sighted 5 years apart and had a calf both times she was sighted, and the other which was resighted two years apart and had a calf only on the second time she was sighted. A single mother-calf pair was also observed in Flinders Bay and then in Geographe Bay within the same breeding season (80 days apart). Notably, all resights occurred in Geographe Bay after having been first identified in Flinders Bay, and not the other way around; coinciding with increased numbers of individuals identified in Geographe Bay in addition to increased effort in the bay. Consequently, it is unclear whether the resights between the Flinders Bay and Geographe Bay regions represent broader regional site fidelity within Ngari Capes Marine Park (and perhaps beyond) or a re-colonisation of Geographe Bay of individuals that have used Flinders Bay previously for calving. It may well be that both are occurring. None of the individuals identified off Perth, Bunbury or Fitzgerald River National Park were resighted in other locations. Given past recorded ranging patterns and known dispersal of southern right whales off the Western Australian coastline (Bannister 1990), it is not unreasonable to expect that some of these whales may have travelled through the Ngari Capes Marine Park Region and perhaps would have been identified if there had been greater spatial and temporal survey effort coverage.

4.4 Marine protected area planning

The capacity of animals, such as southern right whales, to move freely across a range of scales is vital for the health and survival of its populations (Singleton and McRae, 2013). In fact, the study of "metapopulation dynamics has demonstrated that the persistence of many species across broad landscapes is influenced by their ability to move and recolonize areas when local sub-populations become extinct” (Singleton and McRae, 2013). Habitat connectivity also ensures that genetic exchange can occur, which reduces the risk of extinction of local populations. Individual movements identified through photographic resights, such as in this study, provide insight into movement, functional habitat connectivity and recolonisation. The locations and scales required to allow adequate protection of vital life processes are essential in underpinning conservation-based spatial planning for successful conservation management. This study has identified the region within the Ngari Capes Marine Park and further eastward within Flinders Bay as a breeding location for endangered southern right whales that overwinter off the Australian coastline. Adequate protection afforded to southern right whales in this region will improve their conservation outcomes and support recovery of the population; both of which are consistent with the objectives and targets of Australian Southern Right Whale Conservation Management and Recovery Plan.

While there is much work to be done to achieve the government’s commitment to establishing a national network of whale (and dolphin) sanctuaries to provide them with further protection (DAWE 2022), this study identifies a suitable area for inclusion in the network, in addition to future species-based transboundary spatial planning.

4.5 Stakeholder engagement

As well as conducting the southern right whale research presented in this report, the team for this project compiled an extensive stakeholder list for communicating the outcomes of this research, including 72 representatives across government, industry, education and community sectors and cultural custodians. The team reached out to each person with an introductory email and request for a method of engagement that suited them. Over 25 responses were received, including 20 that requested a workshop and/or meeting and the remaining requesting email and or social media updates.

On 16 March 2022, a virtual workshop with 18 participating organisations represented, including state and federal government agencies, local community groups, cultural custodians, marine researchers, tourism operators, environmental consultants, authorities and educators from around Australia was undertaken. At the workshop, participants were provided a welcome and acknowledgement of the traditional custodians in all areas in which the research was conducted in and where participants came from, followed by a background to the engagement process and update on the project itself. The workshop was concluded with two group activities in which participants provided information on what they require the results of the project for in their roles, and what formats of outputs would be most useful, with the aim of informing project planning and resources required in future projects.

Participants indicated that they required the information to;

- inform Environmental Impact Assessments (EIAs) for industry
- develop joint management plans with indigenous groups
- evaluate marine park key performance indicators (KPIs), to inform management
- update Biologically Important Areas (BIAs) and the Southern Right Whale Management and Recovery Plan
- stay informed on monitoring the broad population across the state waters where they overlap with federal interests

- raise awareness amongst community
- increase community engagement by being involved directly with the project
- understand how southern right whales use their habitat
- understand threats to southern right whales
- increase personal knowledge.

The formats in which the information is preferred (from most to least frequent response) included: technical reports, maps, infographics, one page summary pitched at community, peer-reviewed and published papers, spatial layers, short videos, photographs, broadcast media, social media, physical presentation/meetings, project website and social media.

The responses from participants highlighted the importance of stakeholder engagement in the communication of results of such a study, and that a wider range of formats is required to maximise communication impact and uptake. While the project scope for this study has been able to produce some of the requested formats, the authors endeavour to include resources required for producing the wide range of formats in the planning process of future studies.

5. Recommendations

The outcomes of this study have resulted in the following suggested updates to Biologically Important Areas (BIAs) for southern right whales as defined by breeding aggregation areas identified in the Southern Right Whale Conservation Management and Recovery Plans, so that the new knowledge on the Flinders Bay and Geographe Bay regions is reflected, including:

- Flinders Bay be classified as a small established aggregation, consistent with its definition of "containing up to about 10 (usually less than five) calving females at the peak of the season".
- Geographe Bay also be classified as a small established aggregation, as "containing up to about 10 (usually less than five) calving females at the peak of the season". Sightings in this study indicate that the Geographe Bay region was occupied consistently every year at least over the last nine years, and with the increased temporal effort mostly in the relatively restricted area of Pt. Picquet to Bunker Bay since 2017 some mother-calf pairs and unaccompanied adults have been confirmed to occupy the area over the entire or majority of the breeding season. In addition, between-year returns to Geographe Bay of the same female indicate site fidelity specific to the location, and resights between Flinders Bay indicate either an expansion of the breeding area from Flinders Bay to the broader Ngari Capes Marine Park Region (including Flinders Bay) and beyond, re-establishment of the breeding grounds within Geographe Bay, and or functional connectivity between Flinders Bay and Geographe Bay. It is recommended that future research in the Geographe Bay region extends beyond the area of this study to capture wider ranging patterns within and between breeding grounds. This would be consistent with approaches recommended for effective conservation-based spatial planning.

The new knowledge obtained in this study was undertaken entirely from opportunistic, unfunded efforts. The following future work is recommended:

- Future opportunistic efforts to continue given its clear benefits. Photo-ID methods are invaluable as cost-effective methods of examining patterns in site-fidelity and movement within and between habitats; to estimate demographic and biological parameters such as reproductive age, age at mortality, and reproductive periodicity; and to estimate population size, among other applications. In a chronically underfunded field of research, citizen scientists led and coordinated by researchers can provide a wealth of photographs that can be used for these purposes and can continue to be collected during periods when the political environment results in funding being unavailable. In addition, community education and awareness are simultaneously achieved through citizen science engagement. We recommend that where possible the documentation of this opportunistic effort be encouraged, to aid in disentangling the effects of effort from those of natural seasonal and interannual variability and a recovering southern right whale population in future analyses.
- Opportunistic efforts should be complimented by systematic surveys conducted at regular intervals that cover a broader spatial area and capture the entire breeding season. While this study provided important information that would have otherwise been unavailable and that can improve on current management and decision making, the opportunistic nature of the study likely underrepresented abundance, residency, site fidelity and connectivity in the regions. Complementary systematic surveys

should fill gaps in opportunistic efforts where required. This approach is more financially viable than full traditional surveys since they are supplemented by cost-effective citizen-science.

- Comparisons of photographs over the broader spatial range of the western sub-population be undertaken to evaluate connectivity and re-establishment of former breeding grounds across Western Australia and into South Australia. Movement over a range of scales is vital for genetic exchange, health, survival and recolonisation of former breeding grounds, and recovery of the southern right whales. It is unclear how much connectivity there is among regions where breeding occurs off the coast of Western Australia, and how much movement can be attributed to re-establishment of former breeding grounds. In additions, there are major knowledge gaps in regions across Western Australia in which photos have already been taken by community-based citizen scientists. Future research, including the evaluation of photographic resights from photos already taken across Australia not evaluated in this study, is recommended.

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Appendix A

Southern right whale image quality and feature coding (consistent with the Australasian Right Whale Photo-Identification Catalogue).

Image Quality and Feature characteristics	Codes	Additional information
Photo quality	1,2,3 (poor to excellent)	Focus and exposure
Angle quality	1,2,3 (poor to excellent)	With respect to 90 degree lateral or aerial angle to the whales head.
Features visible	1,2,3 (poor to excellent)	The degree of feature uniqueness and identifiability.
Gender	male, female, unknown	
Dorsal Blaze	Presence, absence, not seen	Dorsal Blaze Colour was not ascribed to calves since their colour may change over time.
Dorsal Blaze Colour	Grey, white, mixed grey/white, absent, not seen	
Colour of Body	Yes, no, not seen	'Yes' was designated if the whale was grey or white, and 'no' if the whale was black. Whales were required to be grey all over to be classed as grey. Because grey whales derive from white calves that have darkened during the first few years of life, white calves were coded 'yes'.
Bonnet Eroded	Yes, no, not seen	Describes whether the anterior (near nose tip) margin is even and fully formed, or eroded.
Bonnet Complex	Yes, no, not seen	Identifies features that are difficult to code because of their complex nature

Number of Right and Left Island Callosities	[0…9], not seen	The number of distinct, separate islands (including bars) on the whale's right and left sides of the rostrum, respectively. Islands evenly bisected by islands that fell on an imaginary centre line running through the coaming and down through the bonnet, but that were disproportionately on one side of the rostrum were included in the count on that side, while islands that were evenly bisected were scored as a central features.
Left and Right Bar Island Callosity Presence/Absence	Presence, absence Not seen	If there were two (or more) bars present on one side a presence score was allocated. Bars that were evenly bisected by the central line were coded under 'central feature'.
Left and Right Lip Callosity Presence/Absence	Presence, absence, short, not seen	'Short' was allocated for lip callosity patches that were no more than three times as long as they were wide, or a series of tiny broken callosities. Longer lips were coded as 'present'.
Central Feature Callosity Presence/Absence and Type	Presence, absence, not seen	Describes the presence or absence of callosity features (islands and bars) that are not attached to features on the bonnet and are evenly bisected by the central line of the rostrum.
Coaming	continuous, elongated, none, not distinctive, not seen	Describes the shape and texture of the coaming.
Post Blowhole callosity Shape	Fused, separate, not seen	Post blowhole describes the shape of the callosity material posterior to the blowholes. 'Separate' was allocated if the callosities behind the blowholes were two separate islands, one behind each blowhole, and 'fused' if they were joined to form a single continuous callosity.
Right and Left sub-blowholes	Presence, absence, not seen	Describes whether there is a callosity patch below the left or right blowhole.

Note: see ARWPIC (https://data.marinemammals.gov.au/arwpic/) for further description of feature coding.

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