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Aquatic Conservation: Marine and Freshwater Ecosystems

Southern right whale (*Eubalaena australis*), seasonal abundance and distribution at Head of Bight, South Australia

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Conflict of Interest: all authors confirm that there are no potential sources of conflict of interest

Abstract (300 limit, currently 266)

1. Seasonal trends in the distribution and abundance of southern right whales (SRW) *Eubalaena australis*, were assessed in Australia's largest calving aggregation ground at the Head of the Great Australian Bight, in the Commonwealth Marine Reserve, South Australia. Annual cliff-based surveys were undertaken between June and October from 1992 to 2016.
2. SRW were primarily distributed within a 15 km by 2 km area within the 10 m depth contour (with 95% of whale sightings made within a 10 km^2 area). The distribution of SRW at Head of Bight varied within an individual season but was consistent among the years. The composition of SRW sightings was 70% female-calf pairs and 30% unaccompanied whales.
3. Peak abundance occurred between mid-July and end-August for female-calf pairs and unaccompanied whales (juveniles or adults not accompanied by a calf), earlier than previously reported. A mean of 16% (range=8-28%, SD= 6.5, 95% CI=0.15) of calving females were present at the site in mid-June and a mean of 37% (range=13-61%, SD= 15.8, 95% CI=0.37) remained at the site at the end of September.
4. Based on nearest neighbour distances of 150 m the area occupied by 95% of SRW at HoB could reach carrying capacity at 68 female and calf pairs. Results suggest that the primary aggregation area at Head of Bight may have reached saturation capacity and that habitat expansion can be expected as the population increases.

5. This study provides information on SRW seasonal trends in distribution and abundance, timing of arrival and departure from the site and peak abundance periods relevant to application to conservation and marine park management.
6. As management requirements increase with a growing population, there is a need to complete an Australia wide assessment of SRW connectivity and habitat expansion.

Key words: Southern right whale; marine reserve; seasonality; abundance; distribution; conservation; management

1 Introduction

Southern right whales (SRW) *Eubalaena australis*, were reduced to near extinction globally from commercial whaling in the 19th (Dawbin, 1986) and 20th century (IWC, 2013; Tormosov et al., 1998). Although SRW became protected in 1935, signs of population recovery were not evident until the 1970s (Jackson et al., 2008; Tormosov et al., 1998). SRW occupy Southern Hemisphere latitudes of 16°S to 65°S and migrate between high latitude feeding grounds where they presumably spend most of the austral summer and low latitude breeding grounds where they spend the austral winter. Genetically distinct populations exist in South Africa, Argentina/Brazil, Australia, New Zealand and Chile-Peru (Galletti, Cabrera, & Brownell, 2014; Patenaude et al., 2007; Rosenbaum et al., 2000). While SRW are listed as least concern on the International Union for Conservation of Nature (IUCN) Red List, they remain listed as endangered under the Australian Commonwealth Environment Protection Biodiversity and Conservation (EPBC) Act (1999) (Figure 1).

The population of SRW that occurs seasonally off the coast of Australia is divided into two sub-populations; south-western and the south-eastern, based on genetic differentiation (Carroll et al., 2011; Carroll et al., 2015), and different rates of population increase and abundance (Bannister, 2017). The Australian population in 2017 was estimated to be 2,500 animals, with approximately 2,200 individuals in the south-western sub-population and less than 300 individuals in the south-eastern sub-population (Bannister, 2017). The south-western sub-population occurs off southern Western Australia (WA) and South Australia (SA) and the south-eastern sub-population occurs off Victoria, New South Wales (NSW) and Tasmania. The south-western sub-population occurs predominantly between Cape Leeuwin, WA and Ceduna, SA and comprises most SRW in Australian waters. SRW in Australia are distributed across 13 identified aggregation areas along the southern coast of Australia (Bannister, 2017; DSEWPaC, 2012). They are known to occupy shallow sandy bays that offer protection from south-westerly weather, within 2 km from shore and in 10 m water depth (Pirzl, 2008). The annual rate of increase of all animals in the south-western population between 1991 and 2016 was estimated at 5.55% (95% CI, 3.78, 7.36) per annum (p.a.) and 6.01% (95% CI, 3.49, 8.59) p.a. for females accompanied by a calf (Bannister, 2017). The south-eastern sub-population, found along the south-eastern coast, including Tasmania and rarely further north than Sydney, shows no signs of increase (Bannister, 2017).

Head of Bight (HoB), SA is a major aggregation area for SRW in Australia that is within the Great Australian Bight (GAB) Commonwealth Marine Reserve, established in 1995 to provide protection and sanctuary to recovering SRW. Over the past two decades, as much as 48% of the south-western population of SRW has been estimated to use the HoB aggregation area, but in more recent years it has decreased to around 25% (Charlton, 2017). Based on cliff-based surveys of SRW conducted at HoB annually during 1991-2016, maximum annual counts of between 18 (1992) and 81 (2016) female and calf pairs were recorded (Charlton, 2017). A maximum of 172 SRW were recorded on a single day at HoB in 2016, including 81 females accompanied by a calf (Charlton, 2017). There is high inter-annual variability in long-term abundance trends due to the average three-year calving cycles that SRW have throughout the Southern Hemisphere (Bannister

2001; Best, Brandao, & Butterworth, 2005; Burnell, 2001; Charlton, 2017; Cooke, Rowntree, & Payne, 2003; Payne, 1984; Payne, Rowntree, Perkins, Cooke, & Lankester, 1990).

Two long-term monitoring programmes have operated for the south-western sub-population of SRW: 1) annual aerial surveys between Cape Leeuwin, WA and Ceduna, SA undertaken since 1993 - present (Bannister, 2001, 2017), and 2) cliff-based surveys at HoB undertaken since 1991-present (Burnell, 2001; Charlton, 2017). While broad inter-annual trends are understood (Bannister, 2017; Burnell, 2001), current knowledge of within season trends in the distribution and abundance of SRW at HoB remains limited (Burnell & Bryden, 1997; Burnell, 2001). It is known that SRW are present off the Australian coast between May and October, however, how they are distributed and move between aggregation areas during their breeding season remains unclear. In addition, the timing of arrival and departure of whales and the peak abundance period in coastal aggregation areas is required to inform future planning and management. Thus, this study assesses the intra- and inter-seasonal trends in distribution and abundance of SRW, and peak abundance periods at HoB using 26 years of cliff-based research. Assessment of seasonal trends in the distribution and abundance of SRW inside the GAB Commonwealth marine reserve offers marine park management information on the effectiveness of the marine mammal sanctuary zone to manage potential human impacts. The resulting information also informs species management outside of protected areas through an improved understanding of the timing of arrival and departure and periods of peak abundance of whales in coastal aggregations. The likelihood of the aggregation area reaching saturation due to density resource (space) pressures is assessed using nearest neighbour estimates for female-calf pairs at HoB. As this key aggregation area reaches saturation, distribution expansion and coastal movements are expected, which has implications for habitat protection and the future management of the Australian population.

2 Methods

2.1 Study Area

The study area at the Head of the Great Australian Bight (31° 29' S, 131° 08' E) is in the broader region of the GAB and is located on the far west coast of SA, 300 km west of Ceduna and 200 km east of the WA border. The wider GAB is a multi-use area for commercial fisheries, marine parks, tourism and oil and gas activities offshore. Ongoing and planned oil and gas activities in the GAB include seismic exploration and exploratory drilling. Current oil and gas lease areas granted in the GAB cover approximately 115,000 km² (~750 km x ~150 km) and are located approximately 200 km offshore from the coastal aggregation area at HoB, on the continental shelf. HoB is within the Marine Mammal Protection Zone (MMPZ) of the GAB Commonwealth Marine Reserve that covers State and Commonwealth waters. The study area is also within the Far West Coast State Marine Park that covers the state waters out to 3 nautical miles (nm). HoB is adjacent to Yalata Aboriginal Land on the Nullarbor Plain. The MMPZ of the GAB Commonwealth Marine Reserve was established in 1995 to provide a sanctuary for these whales (Figure 2). All vessels and general access are prohibited in the MMPZ between 1 May and 31 October each year (there is a complete no access zone- no fishing or recreational activities). The MMPZ area covers approximately 9,000 km² (~100 km x ~90 km). The study area for this research is within the MMPZ and covers an area approximately 120 km² spanning approximately 15 km east to west along the coast and out to 8 km offshore (Figure 1).

Habitat characteristics of the study area at HoB include a shallow, gently sloping, sandy bay in the east leading at the south-western end of the study site to the 33-53 m high Bunda Cliffs which provide some shelter from the dominating south-westerly wind and swell. Along these cliffs, water depths drop to around 20 m within approximately 300 m from the shore. Whales are often sighted directly below these cliffs within 100-200 m of shore (Figure 1).

2.2 Data collection

The study methods are consistent with the population census and photo-identification (ID) study completed annually at HoB between 1991 and 2016 described in Burnell and Bryden (1997), Burnell (2001), and Charlton (2017). Seasonal trends in abundance were assessed for SRW at HoB using daily counts over 25 years (1992-2016). Count data from 1991 were excluded because in that year the number of groups was recorded rather than number of individual whales, and therefore the data are not consistent with the rest of the dataset. Daily counts provide a snap shot of whale numbers and location on a given day. While the maximum value of the daily counts within a year was indicative of numbers using the site on any one day during that season, they are almost certainly an underestimate of the true maximum number of individual whales visiting the site since whales are known to immigrate and emigrate, to and from the site over the course of a season.

The within seasonal trends in distribution of SRW at the HoB study area were assessed using three years (2014-2016) when quantitative data on whale locations were recorded. Prior to 2014, the spatial distribution of whales was recorded at a coarse resolution and is not comparable to the distribution data collected from 2014 onwards. Across year abundance trends are presented in Charlton et al., (2018) (in review).

SRW within the study area were surveyed from 16 land-based observation stations (Figure 1) along a stretch of approximately 15 km of coastline and 8 km offshore. Observation stations on Bunda Cliffs ranged in height from 53 m towards the west to 33 m towards the east of the study area and were between 300 and 1000 metres apart. Observation stations were selected based on safety and topographic features to ensure full visual coverage of the study site (i.e. if the contour of the cliff line obstructed observer view, then the observation stations were closer together to allow unobstructed observations of whales along the 15 km stretch of coastline). Daily surveys, were conducted beginning at the western-most station and ending at the eastern-most station.

Observations at each station consisted of systematic scans using 10x50 Bushnell binoculars and the naked eye at an angle of approximately 180° east to west and as far as the eye could see offshore to the south from the horizon down to the cliffs. To avoid duplicate sampling between adjacent stations, only individuals in front or to the west of observation stations were recorded. To further reduce the risk of duplicate sightings, the location of sighted whales at each station was mapped in real time based on measurements of distance and compass bearing to whale, individuals were identified using photo-ID, and the location and ID was cross checked with sightings at a similar location at the next adjacent station. The time spent travelling (by vehicle) between stations ranged from two to six minutes. All surveys were completed in Beaufort Sea States of three or less and wind speeds less than 18 knots to reduce bias in counts due to weather conditions. Environmental conditions including wind speed and direction in knots, cloud cover in percentage, sea state using the Beaufort scale and swell height were recorded qualitatively at the start and end of each survey. Glare was not recorded as observations were timed to avoid glare. Daily cliff-based survey effort ranged from 2.9 hours to 4.9 hours (mean = 3.6 hours). Start times were roughly 08:30 and end times ranged between 12:30 and 16:00. Observations were timed to avoid glare in the early morning and sea breeze in the afternoon. Effort reported here excludes travel times between observation stations.

Most animals, particularly female-calf pairs, were easily observed in the relatively clear and shallow waters within a few hundred metres of observation stations, even when they were below the surface of the water. Thus, the probability of whales being available to be sighted within this distance of the observation stations was assumed to be 1 (Bannister, 2017; Burnell, 2001). A minimum of 10 minutes was spent observing at each station based on the assumption that at ranges beyond 5 km (where the larger incident angles of observation make detections of animals below the surface of the water more difficult), SRW were at the surface at some point during that period. The minimum 10 minutes survey period at each observation station improved the detection probability of animals at a distance from observation stations while ensuring that whale movements were visually tracked to avoid double counting. Female and calf pairs spend the majority of their time on the surface and in the absence of any published literature on mean surfacing intervals of SRW in a calving ground, a maximum of 10 minutes dive times for calves is assumed. Surface behaviour is common for young calves and dive times are generally less than a few minutes (Charlton, 2017). The data are biased towards potentially having greater detection probability for females and calf pairs than unaccompanied whales (juveniles or adults not accompanied by a calf). However, the overlap in observation stations and methodology moving west to east, increases the likelihood of sighting most animals. Longer time periods were spent at a location if additional time was required to capture photo IDs. A maximum of 50 minutes was spent at one location. In this instance, a dedicated observer watched the position of the whales to ensure that no animals had moved into or out of the observation station range. If a whale moved out of the observation station range to the east, it was instead counted at a later observation station. If it moved out of the observation station range to the west, there was no risk of double counting the individual, so it was still marked at the location station where it was first sighted. Photo-ID was abandoned if there was a risk of jeopardizing the accuracy of the count. Whale location and assessment of distribution in the study area is biased by the movement of whales into an area when longer than 10 minutes was spent at an observation station. The whales move around the area frequently, so the bias is not considered a limiting factor for the assessment of distribution and abundance.

Observer bias was reduced by using two trained and experienced observers during surveys and minimizing rotation of researchers across the duration of the long-term study. For each SRW sighting the following variables were recorded: date, time, observation station, group composition (number, age class, and group type which included female accompanied by a calf, unaccompanied adult or unknown status). Unknown status was recorded when the observer could not be sure if the individual had a calf or was unaccompanied. A group of whales was defined as one or more whales within 100 m of each other that were seen to be interacting or travelling together. Range and bearing of the whale to the observer was recorded using a Bushnell 1600 laser range finder and marine grade Bushnell 10x50 binoculars fitted with a compass. Compass readings were taken in the absence of any metal objects that could have interfered with the accuracy of the reading. In instances where the whale was outside the rangefinder detection range (typically greater than approximately 450 m), reticule binoculars fitted with a compass were used to measure increments below the horizon to the whale. Various handheld GPS units were used to log the position of each observation station, all using the WGS 84 chart datum (equivalent to GDA 90).

The research was completed under a South Australia (SA) Department of Environment Water and Natural Resources Scientific Permit (M26508-3, M26508-4 and M26508-5). Animal ethics approval was granted through Curtin University for observational and passive research (AEC_2013_27 and 28).

2.3 Analysis

2.4 Visual detection range

Visual detection range of whales was defined conservatively at the observation station with the lowest elevation. The visual detection range was estimated by calculating the range to each sighting over 2014-2016 using sightings to the south-east (< 150^{o}) from station 16, the south-easternmost observation station and establishing the range at which 95% of the whales were detected. At observation site 16 the shore line forms a boundary of the study area and the elevated Bunda Cliffs turn into lower elevation sand dunes. Thus at 33 m this site has the lowest elevation of the study sites.

2.5 Distribution

Whale distribution was mapped using location data calculated from range and bearing of whale plus elevation of observer. The equivalent measure in degrees for vertical angles associated with binocular reticules was calibrated using the distances and heights of known targets. Whale ranges were calculated using reticules or theodolite assuming a spherical earth and allowing for observer-eye elevation. The height of the observation stations was determined using theodolite vertical angles to known objects at the water surface (a rock), for which the distanced was measured using a laser range finder. Geometry then gave the theodolite elevation. Whale positions were calculated using code developed at the Centre for Marine Science and Technology, Curtin University (CMST) using MATLAB (The MathWorks, Inc.). The MATLAB mapping toolbox was used to plot location of whales based on the range estimate and true compass heading (corrected for variation at the site). The error associated with tide was considered minimal given the tidal changes (<1.5 metres) relative to the distance that whales were sited (most within 1 km) and measurement errors. There was some error in the precision of sighting locations between 1° and 120° (horizontal angle) at observation station 16 caused by land blocking the horizon. In 2015 and 2016 the vertical angle of the horizon was estimated from which location data in this area were estimated to have an error in the range of 1-300 m. In 2014, locations were not collected between 1° and 120° at observation station 16. Count data were, however, collected and recorded in all locations.

Spatial data processing used purpose-built programs in MATLAB software to generate whale locations. Maps were generated in MATLAB using Australian Hydrographic Service charts under Seafarer GeoTIFF licence No 2618SG (Curtin University). Spatial data were normalized for effort (time spent at each observation station) and displayed as Kernel Density distribution plots (whales/0.5km²) using ArcMap v10. All times were presented in Australian Central Standard Time (UTC + 9.5 hours). Bathymetry was retrieved from the Geoscience Australia 0.00250˚ grid (Whiteway, 2009).

An estimate of the portion of the study area used by 95% of whales was made. To define the offshore 95% limit firstly the minimum range of each whale to the zero-m depth contour was calculated, with the zero-depth contour digitized from Australian Chart 341. The zero-bathymetry contour derived from the Geoscience

Australia bathymetry Atlas (Whiteway, 2009) was slightly incorrect according to the Australian Chart. The minimum ranges of each whale from the zero-m depth contour were sorted and the value which encompassed 95% of all values taken as the distance offshore for 95% of whales. To define the alongshore 95% bounds of whales, as the study area was aligned roughly east-west, the whale longitude values were sorted (smallest to largest) and the longitudes at which 0.025 and 0.975 of the total number of values found. This gave the 2.5% and 97.5% longitude bounds, which gave the alongshore bounds for 95% of whales. Using the offshore and alongshore 95% bounds in which whales were found gave the area used by most whales.

2.6 Abundance

Within seasonal trends in abundance between June and October (1992-2016) were analysed by plotting the abundance of female and calf pairs and unaccompanied whales and calculating the proportion of each group type that was present in the study area during each month surveyed. The variation in abundance of each group type (females accompanied by a calf, unaccompanied adult) was assessed to provide information on immigration and emigration into and out of the site. The timing of arrival and departure of whales to and from the site was assessed using daily counts and calculating the percentage of whales from each group type present at the site at the start and end of the study period.

2.7 Peak abundance

Inter-annual comparison of peak abundance periods was assessed using a 14-day period as that is the duration of the comparable study period consistently sampled throughout this 26-year study. To maintain comparability of inter-annual trends in abundance between years, the abundance study was always completed between August 15 and 30. Outside of that period, the study effort varied between years (1991-2016). There was a need to determine if the 14-day study period between August 15 and 30 was reflective of the peak abundance period. Therefore, a 14-day moving average with a 12-day overlap was selected for analysis of the peak abundance period. The maximum daily count for each year was normalized to a scale of 0-1. Estimates of 14-day peak abundance periods were calculated using 14-day sliding averages with 12-day overlaps using Julian Day as the time base. Changes to the mean peak abundance period were assessed. To account for variation in sampling effort across years a null value was given where there was a gap in sampling and the peak value data were presented with sampling effort. Analysis excluded years when only a two-week survey was completed (2007-2013). Normalized peak abundance periods and maximum annual counts were presented on a scatterplot for each year, 1992-2006 and 2014-2016.

3 RESULTS

3.1 Study period

Over the period 1992 – 2016, a total of 805 daily surveys were conducted at the HoB study area between the months of June and October. Effort was variable between the study years (1992-2016) and an average number of 35 surveys per year (range 8-112 survey days) were conducted (Table 1). Surveys resulted in 42,725 whale sightings over the 25-year study period.

3.2 Visual detection range

The maximum detection range was approximately 10 km, however, 95% of all sightings offshore of the cliffs were recorded within 1 km, with a drop off after this point (Figure 2). Whales were distributed within the 20 m depth contour and most whales were sighted in less than 10 m water depth. When considering only sightings recorded at observation station 16 to the south-east, the visual detection range for 95% of whales sighted extended to 4.5km, before dropping significantly (Figure 3).

3.3 Distribution

The distribution of SRW sighted in the HoB study area was recorded for 1,621, 1,069, and 1,955 adults in 2014, 2015, and 2016, respectively. The mean group size of SRW at HoB in 2014-2016 was 2.2 individuals (range 1-8; median 2). The mean group size for unaccompanied whales was 2.3 (range=1-7, SD=1.9, 95% CI=0.003) and was also 2.3 for females accompanied by a calf, (range 2-8, SD=1.8, 95% CI=0.003). The distribution of SRW was similar between years (Figure 4). In 2014 whales were not sighted as close to shore at the easternmost point as they were in 2015 and 2016 due to variation in the method, therefore the distribution in this area could not be compared. Within the study area, SRW were predominantly distributed along 15 km of the coast and within 2 km from the shore (95% were within 1 km of the shore) in water depths less than 20 m (Figure 4). Females accompanied by a calf were mostly distributed in the shallow sandy bay to the east, whilst sightings of unaccompanied whales were most frequently made along the cliff line in the centre and west of the study area (Figure 5).

The distribution of 95% of all SRW sightings recorded between 2014 and 2016 occurred within an area 10.16 km wide from east to west and within 1.04 km from shore. Assuming a minimum preferred spacing distance between female and calf pairs of 150 m, the area occupied by 95% of all whales sighted would reach capacity at 68 female and calf pairs, assuming a perfect packing density. If a minimum spatial requirement of 100 m is tolerated by SRW at HoB, the area occupied by 95% of whales sighted would reach capacity at 155 female and calf pairs, assuming a perfect packing density.

SRW displayed within season variation in distribution at HoB (2014-2016). At the beginning of the season in June, when calves were very young or females were still pregnant, whales were commonly distributed in the shallow bay area in the east of the study area. As the season progressed, the distribution of female and calf pairs increasingly extended along the Bunda Cliffs to the west of the study area (Figure 6). Unaccompanied whales were predominantly distributed along the cliffs in the centre of the study area throughout the season.

3.4 Abundance

A total of 805 counts resulted in 24,806 SRW sightings at the HoB study area over the 25 years between 1992 and 2016. Sightings of female and calf pairs, unaccompanied whales and unknown status represent 67%, 27% and 6% of all sightings, respectively. SRW displayed within season variation in abundance at the HoB study area (Figure 7). Generally, whales arrive at the site between May and July, reach their peak in July/August and then depart the site in September and October.

Female and calf pairs occupy the site between May and October. Based on the proportion of female and calves recorded within season, across the study period, during 2014-2016 (when the study period was June-Sept) a mean of 16% (range 8-28%, SD= 6.5, 95%CI=0.15) of the females that were sighted with calves during the season were present in the study area in mid-June, and a mean of 27% (range 13-61%, SD= 15.8, 95% CI=0.37) of females with calves remained in the area in late September (Figure 8).

Unaccompanied whales occupied the site in the greatest abundance between July and August, with few sightings before mid-June or in September. The percentage of unaccompanied whales sighted within the HoB study area throughout the season was 8% in June, 23% in July, 44% in August, 18% in September and 7% in October.

3.5 Peak abundance period

The overall mean peak abundance period for a 14-day moving average with 12-day overlap occurs between August 3 to 17 for total individuals, and July 20 to August 3 for females accompanied by a calf at HoB (1992-2016, excluding 2007-2013). Inter-annual variation in peak abundance was recorded for female and calf pairs. The peak abundance period was recorded between early July and early September, with most variability occurring between 1992 and 2006 (Figure 2-9). Between 2014 and 2016 there was no significant difference in the 14-day peak abundance period, which was recorded in August. No apparent patterns in the variability of peak abundance periods is evident without further analysis. The seasonal abundance period analysis used the Gregorian calendar which is based on the southern hemisphere summer solstice with an offset. There was no evidence in the SRW seasonal timing that alternative calendar reference points applied. Julian Day is used in the Gregorian calendar.

The peak abundance period for unaccompanied whales was not significantly different across all years and was recorded between mid-August and early September, except for 1991 and 2016 (Figure 9). In 1991 the 14-day period of peak abundance was recorded in early-mid September and in 2016 in late-July to early-August.

4 Discussion

Within and among seasonal trends in distribution and abundance for SRW at the major aggregation ground at HoB were investigated using 25 years (1992-2016) of count data collected during annual cliff-based surveys. The distribution of SRW at HoB showed variability within season and among seasons in the HoB study area. Female-calf pairs were typically more densely distributed in the shallow sandy habitat in the eastern end of the study site during June, becoming more widely distributed to the west along the deeper, cliff lined coast in July/August. Unaccompanied whales were more densely distributed towards the west of the study site. Consistent with findings from Burnell (2001) for the years 1991-1999, SRW at HoB were distributed across the whole study area, along approximately 15 km stretch of coast and predominantly within 2 km of shore at HoB.

Within season variability in abundance occurs at HoB as SRW arrive to the site in June/July, peak in abundance between late-June and mid-August and depart the site in late September/October. Unaccompanied whales were more transient into and out of the site and their within season abundance was more variable than females accompanied by a calf. Within season variation in abundance indicates immigration and emigration of individuals into and out of the study site, particularly for unaccompanied whales.

Within season abundance varies for different populations of the species in the Southern Hemisphere. Peak periods of abundance were recorded earlier in the year for SRW in South Australia compared with Argentina, South Africa and Brazil. SRW migrate to waters off Australia, South Africa, Argentina, Brazil, New Zealand and Chile during the austral winter (IWC, 2013). In South Africa, SRW are sighted all year round, however, mothers with calves are only sighted between June and December, with numbers peaking in September (Best & Scott, 1993). At Peninsula Valdes, Argentina, the calving season is between May and December, with the maximum number of whales present from August to September (Crespo et al., 2017; Payne, 1984, 1986; Rowntree, Payne, & Snell, 2001). In Patagonia, Argentina SRW dispersed into a new area in San Matias Gulf, near Peninsula Valdes. Whales were observed from August to October with a peak in late August-early September (Arias et al., 2017). Off the coast of Chile, sightings of eastern South Pacific SRW were recorded between July and October with resident times of up to three months, and within season movements of up to 159 km (Galletti et al., 2014). Similarly, in southern Brazil sightings occur from May to December, with most recorded between July and September (Camara & Palazzo, 1985; Simoes-Lopes, Palazzo, Both, & Ximenez, 1992). An earlier peak in calving in Australia (late-July to early-August) may be influenced by the shorter distance travelled from feeding grounds but is more likely attributed to shifts in prey abundance. Triggers for arrival and departure to wintering aggregation areas also include weather and climate factors such as local storm events or air and water temperature which influence thermoregulation (Burnell and Bryden, 1997) and physical condition (Lockyer, 1981).

Information on timing of arrival and departure of SRW to the HoB coastal aggregation area is important for species management in Australian waters and risk minimization. Considering the proportion of the breeding population recorded at HoB from mid-June to late-September, and the maximum percentage of breeding females at HoB remaining at the end of the study period (61%), SRW and their newborn calves may be sensitive to potential impacts in the broader GAB area between May and October or beyond. The number of breeding females present at the start of the season is an underestimate because pregnant females are not recorded as part of that season's breeding cohort until they are sighted with a calf. For example, of the five unaccompanied whales photo-identified between 16 and 19 June 2016, three were sighted later in the season with a calf.

There is some variability in the peak abundance period for female and calf pairs, ranging from mid-July to early September. There is less observed variation in the peak abundance period for unaccompanied whales, ranging from late July to early September. Although the study period August 15 to 30 is not always inclusive of the 14-day peak abundance period, the maximum daily count was always recorded during August 15-30 and it is considered the most representative period to sample female and calf pairs and unaccompanied whales.

Females have calved by mid-August; therefore, it is assumed that counts completed during August 15-30 include all breeding females that select the HoB study area as a calving/nursing habitat for that season (Burnell, 2001; Burnell & Bryden, 1997). It is recommended that future monitoring programmes consider the peak abundance period and that field studies are undertaken over a six-week period between between mid-July and late-August, whilst maintaining comparability with the long-term time-series.

Distribution and abundance reported here may have had biases associated with lower detectability with range at the south-eastern end of the study area. However, aerial surveys conducted through the Western Australian Museum (Bannister, 2017) within the HoB study area following the coastline at a range of approximately 1 km indicate that the cliff-based surveys compare favourably. For example, in 2016, 66 females with a calf and 11 unaccompanied whales were counted from the aircraft on one day. On the same day, the cliff-based team counted 66 females with calves and 10 unaccompanied whales. Similarly, comparable counts were recorded throughout the duration of the studies (Pirzl, 2008).

Saturation capacity of SRW at the primary aggregation area at HoB may be reached in years of abundance greater than 68 female and calf pairs, assuming a maximum packing density and a spatial requirement of 150m between pairs. Therefore, saturation capacity at the site may have already occurred in years of high abundance, . Helicopter surveys completed by the South Australian Research and Development Institute (SARDI) in 2014 (Mackay et al., 2015) of the broader region between the WA border in the west and Fowlers Bay in the east showed that up to 17% of whale sightings occurred outside of the HoB cliff-based study area. Density resource pressures (i.e. space) will cause SRW to disperse outside of the primary aggregation area at HoB. It can be expected that habitat expansion outside of HoB will occur with an increasing population.

The HoB aggregation area represents approximately 25% of the overall south-western population (Charlton 2017). SRW habitat selection is influenced by environmental factors and preferred habitat generally includes shallow sloping sandy bottom bays that provide protection from prevailing wind and weather (Elwin & Best

2004; Pirzl, 2008). Distributional shifts across suitable habitat along the southern coasts of Australia and established and emerging aggregation areas should be investigated.

While this study provided a clear indication of the consistency and timing of abundance of SRW in the study area, daily surveys provide a snap shot of SRW distribution and abundance on a given day within the study area, and do not consider immigration and emigration of whales to and from HoB. Therefore, the maximum daily count is an underestimate of the true maximum number of individuals using the HoB aggregation area in a season. Photo-ID mark recapture shows that the number of individuals photographed in a season often exceeds the maximum daily count, implying immigration and emigration across a season (Burnell, 2001; Charlton, 2017). Unaccompanied whales were more transient than females accompanied by a calf, displaying greater immigration and emigration from the site, as indicated by variation in within season abundance.

Information on the timing of arrival and departure of whales to and from HoB highlights that May through to the end of October are sensitive periods for SRW migration to and from the coast of Australia. The female and calf pairs that migrate south from nursery grounds late in the season are likely to be the most sensitive of the cohort because they are often the youngest calves that are at higher risk of mortality from malnourishment (Rowntree et al., 2013). Best and Ruther (1992) found that multiparous females (having borne more than one offspring) calve before primiparous females (bearing young for the first time), supporting that female and calf pairs that remain at the site towards the end of the season may me more sensitive.

When managing marine based industries in the Great Australian Bight, human activities that could cause disturbance to the whales during the sensitive life stages (pregnant or with newborn calves) should be avoided between early May and the end of October. Results show that whilst the MMPZ effectively provides protection for the whales at HoB, the movement of whales outside of this area has increased with population growth. The primary area occupied by SRW at HoB is likely to reach saturation in years of abundance greater than 68 female and calf pairs and therefore expansion outside of the primary aggregation area can be expected. It is important that recovery goals prioritise the management of SRW outside of the MMPZ, along the coastline and in small and emerging calving grounds.

Future research planning will consider the peak periods of abundance at HoB between mid-July and late-August. This study provides a baseline for detecting changes in population dynamics over time. The continuation of long term annual monitoring of SRW is critical to species management. Research is underway to assess SRW abundance and connectivity for the Australian population.

I. Acknowledgements

Scholarships for PhD Student Claire Charlton were granted through Commonwealth Australian Postgraduate Award (APA) and Curtin University Postgraduate Scholarship (CUPS). Research funding and PhD scholarship stipend was provided by Murphy Australia Oil Pty. Ltd. and Santos Ltd. for 2014-2016 under project number RES-58756. The Australian Marine Mammal Centre (AMMC) provided funding for the land-based research in 2009, 2012 and 2013 under grant number 12/21. In-kind support was provided by South Australian Department of Environment Water and Natural Resources, the Aboriginal Lands Trust and the South Australian Museum to varying degrees over the 26-year study. The research was completed under a South Australia (SA) Department of Environment Water and Natural Resources Scientific Permit (M26508-3, M26508-4 and M26508-5). Animal ethics approval was granted through Curtin University for observational and passive research (AEC_2013_27 and 28). Sacha Guggeheimer contributed to photo identification catalogue maintenance and provided field assistance in 2013 and 2014. Many volunteers contributed over the years and their assistance was invaluable to the study. In particular, Richard Twist, Alice Morrison and Ana Costa provided extensive volunteer support. In 2016, Murdoch University contributed drone images for photo identification.

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iii. Tables

Table 1: Southern right whale abundance and distributional study effort at the Head of Bight study area, South Australia between 1992 and 2016.

Year	Survey days	Survey period
1992	60	25 Jun - 10 Oct
1993	112	18 Jun - 13 Oct
1994	88	19 Jun - 12 Oct
1995	46	27 Jun - 10 Oct
1996	41	7 Jul – 9 Oct
1997	41	7 Jul - 6 Oct
1998	22	30 Jun – 2 Oct
1999	30	2 Jul - 7 Oct
2000	32	3 Jul - 7 Oct
2001	33	3 Jul - 4 Oct
2002	32	13 Aug - 9 Oct
2003	36	1 Jul -7 Oct
2004	36	3 Jul -3 Oct
2005	33	4 Jul - 30 Sept
2006	26	5 Jul - 29 Sept
2007	15	16 Aug - 30 Aug
2008	12	13 Aug - 25 Aug
2009	12	21 Aug - 2 Aug
2010	9	24 Aug - 1 Sept
2011	13	15 Aug - 26 Aug
2012	9	14 Aug - 29 Aug
2013	8	18 Aug - 30 Aug

2014	41	19 Jun - 28 Sept
2015	41	18 Jun - 25 Sept
2016	33	16 Jun - 25 Sept

iv. Figure legends

Figure 1: Study area and shore-based observation stations at Head of Bight in the eastern Great Australian Bight, South Australia. Observations sites on the cliffs are labelled west to east.

Figure 2: Distributions of southern right whale, *Eubalaena australis* distance from 0 bathymetry contour (left) and depth (right), for sightings at Head of Bight, South Australia recorded between June and September 2014-2016.

Figure 3: Detection range of southern right whales, *Eubalaena australis* with distance from observation station 16 to the south-east of the study site at Head of Bight, South Australia.

Figure 4: All sightings of southern right whale, *Eubalaena australis* recorded within the Head of Bight study site in the Great Australian Bight, South Australia between 19 June and 28 September 2014 (A), between 18 June and 25 September 2015 (B) and between 16 June and 25 September 2016 (C), showing females accompanied by a calf in open circle, unaccompanied whales as X.

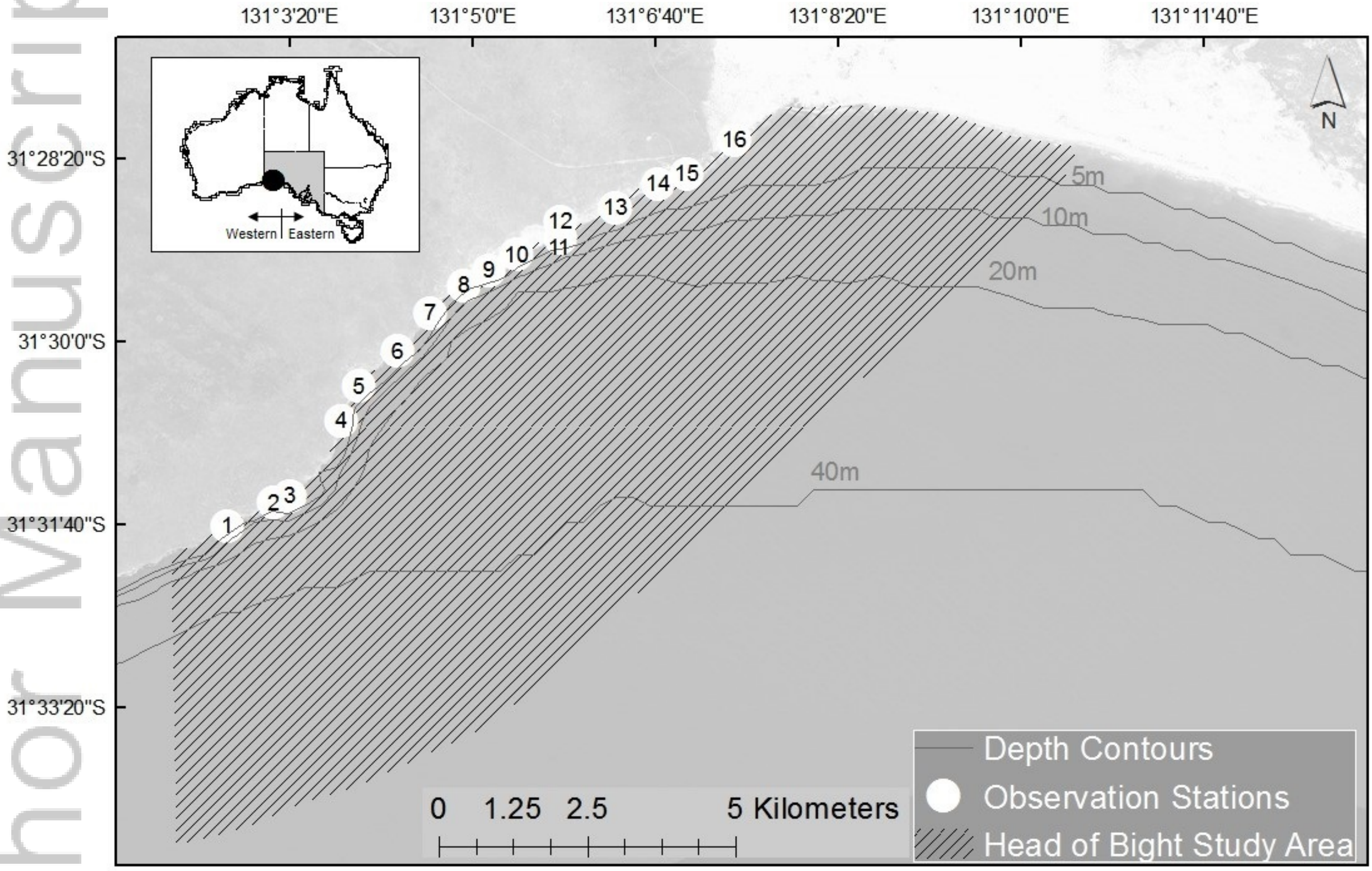
Figure 5: Kernel density plot of southern right whale, *Eubalaena australis* female and calf pairs (top) and unaccompanied whales (bottom) at Head of Bight study site, South Australia between June-September using pooled data collected between 2014 and 2016.

Figure 6: Within season distribution of southern right whales, *Eubalaena australis* at the Head of Bight, South Australia using pooled data 2014-2016: A) June; B) July; C) August; D) September**.**

Figure 7: Mean percentage of southern right whale, *Eubalaena australis* female and calf pairs observed at Head of Bight, South Australia between June and October 1992-2016.

Figure 8: Abundance of (a) the total southern right whale, *Eubalaena australis* and (b) females accompanied by a calf sighted at the Head of Bight study area between 1992 and 2016 using a 14-day moving average with 12-day overlap (presented as proportion of overall sightings). The dotted lines represent the 95% confidence limits.

Figure 9: Mean peak abundance of southern right whales, *Eubalaena australis* recorded within the Head of Bight, South Australia study area between May and October 1992-2016, using a 14-day moving average with 12-day overlap (top) with female and calf pairs in black and unaccompanied whales in red. The maximum daily relative abundance count recorded per year is presented below with black circles showing female and calf pairs and red circles showing unaccompanied whales.



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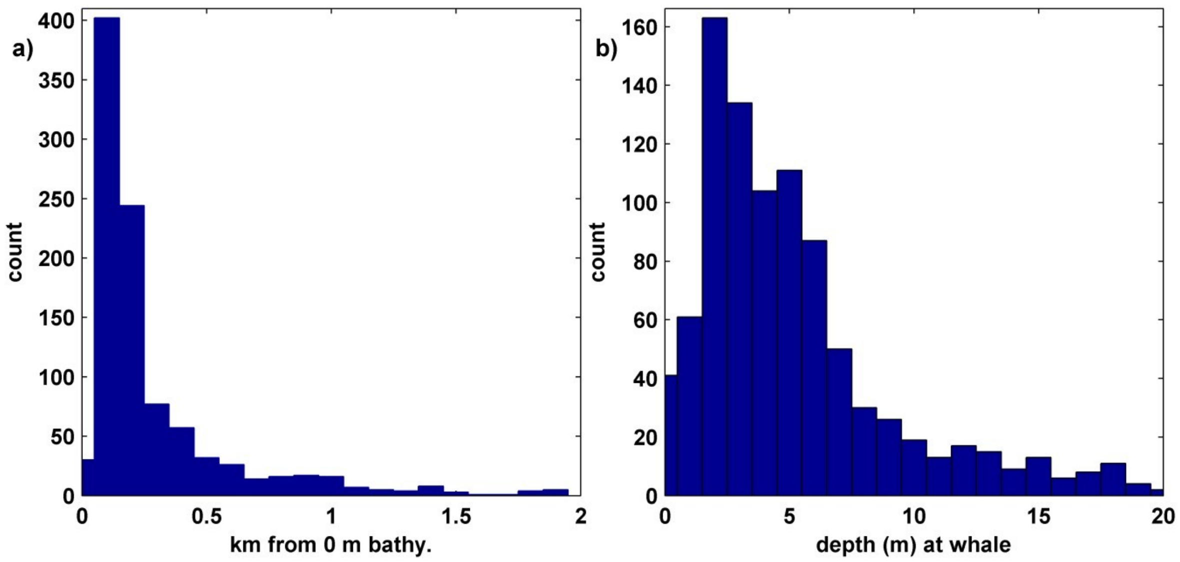

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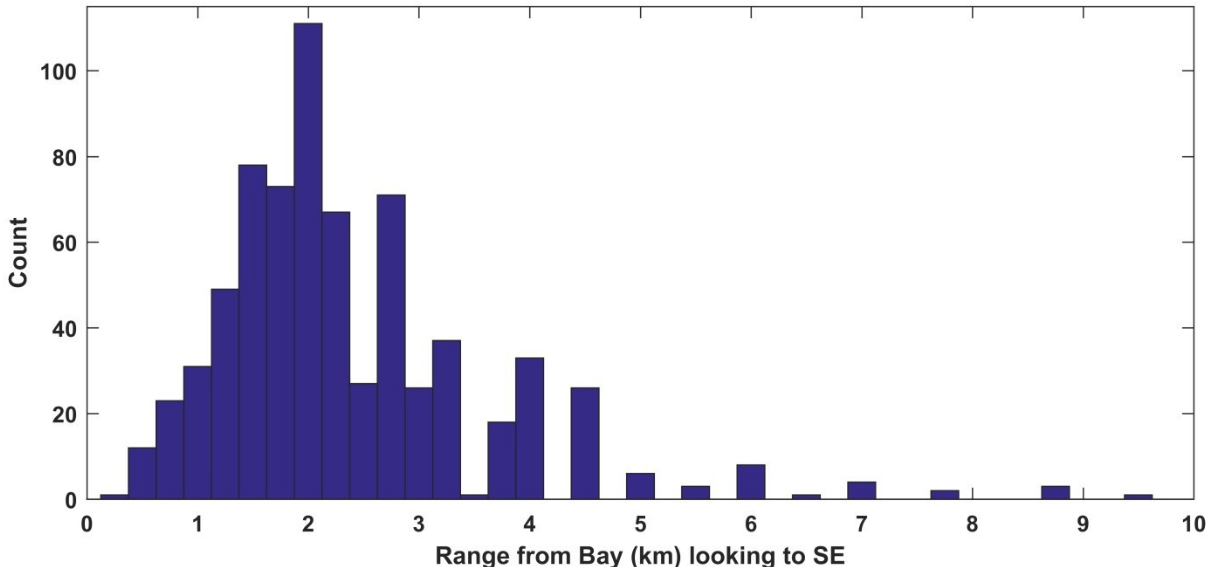

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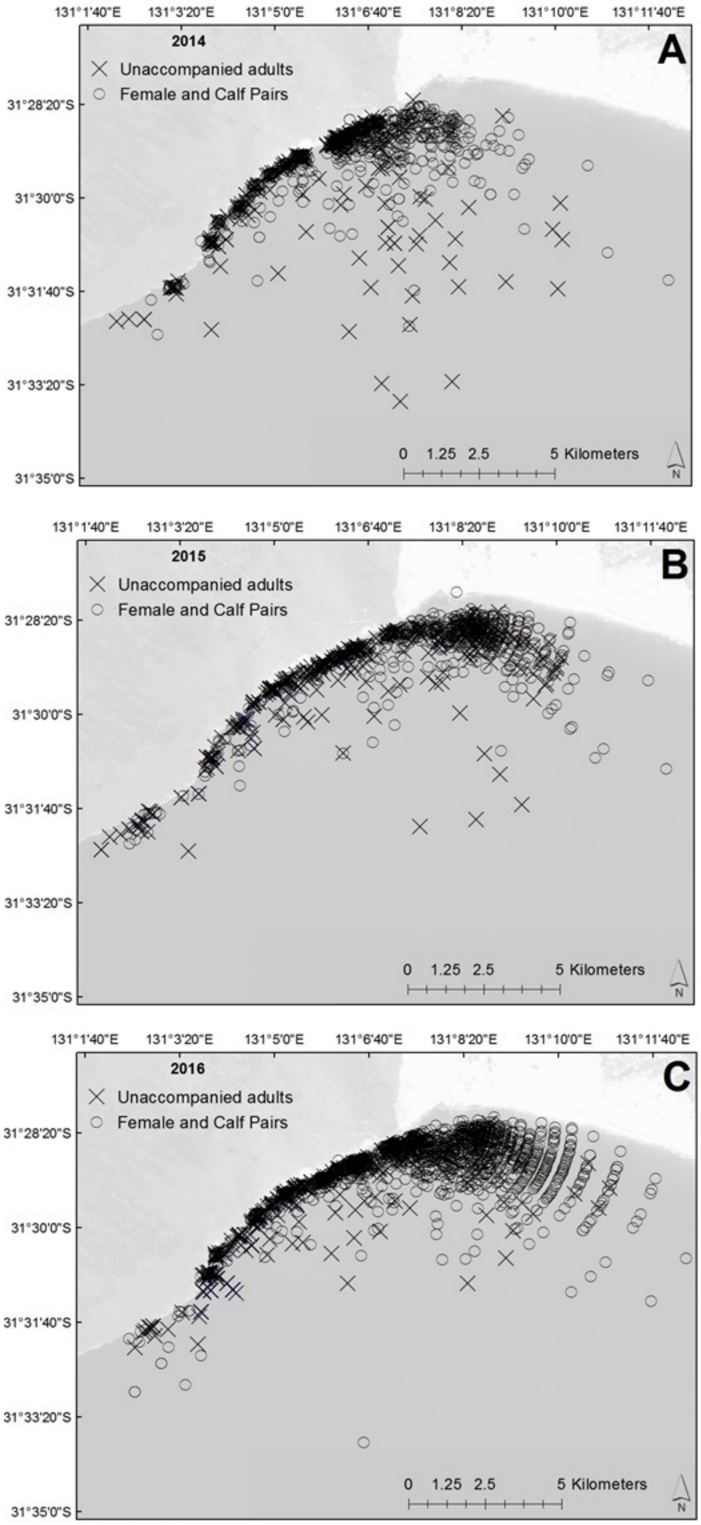

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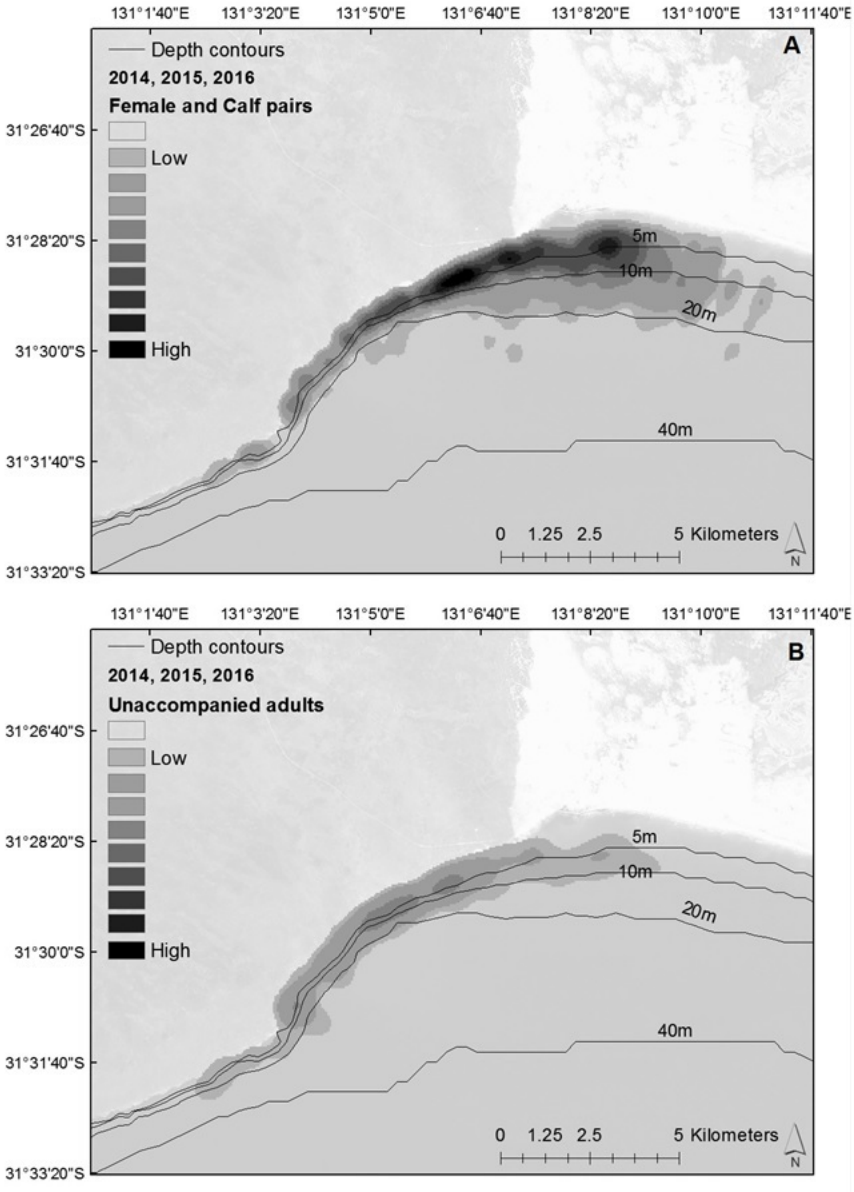

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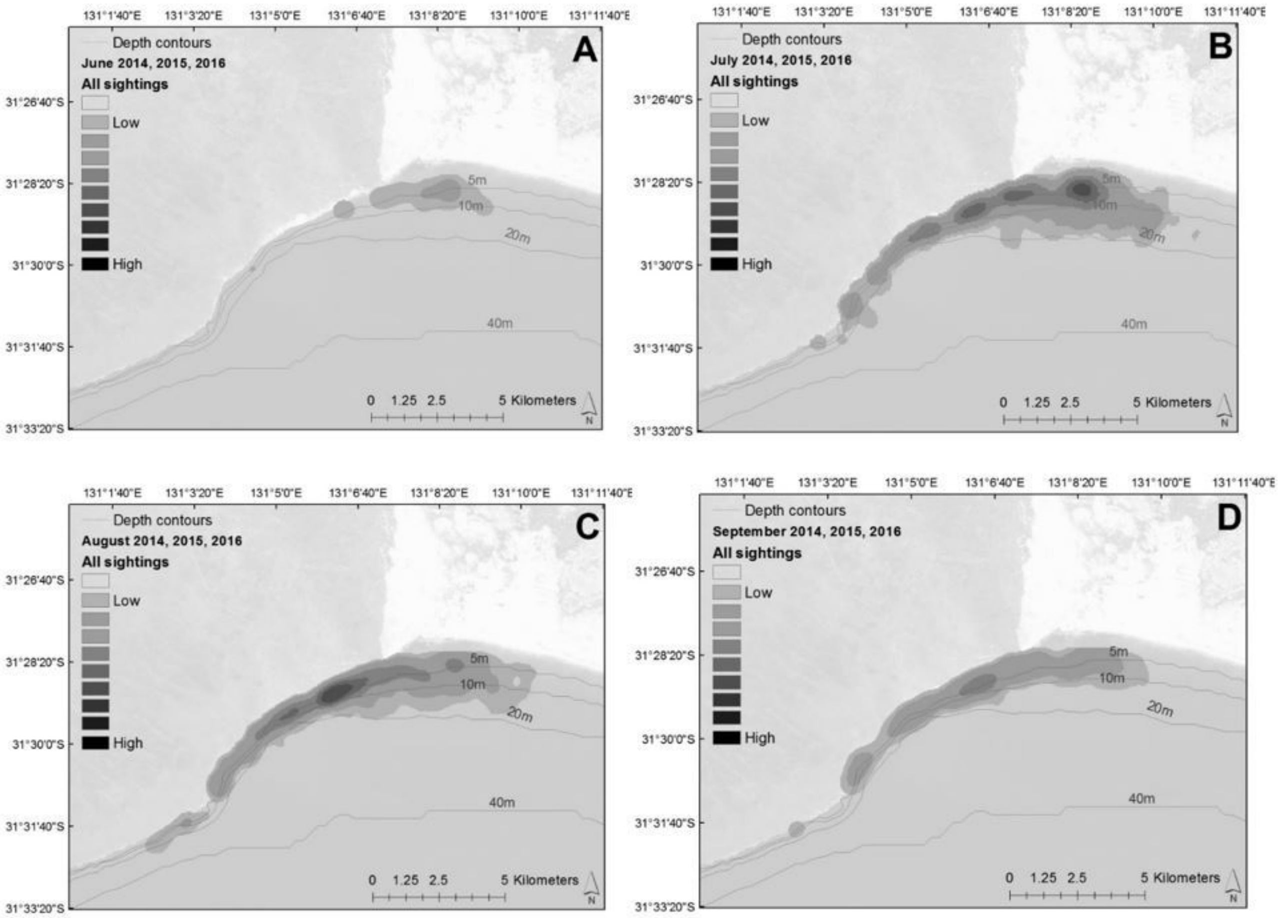

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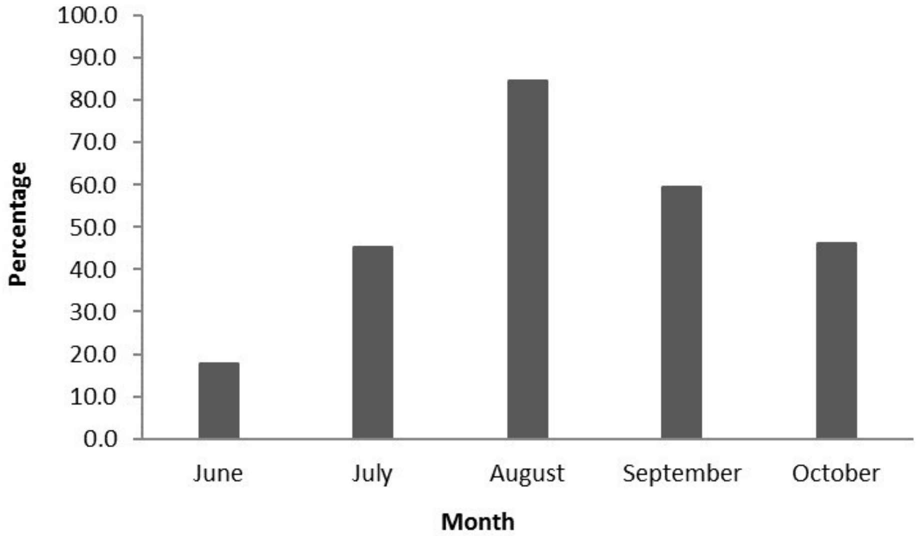

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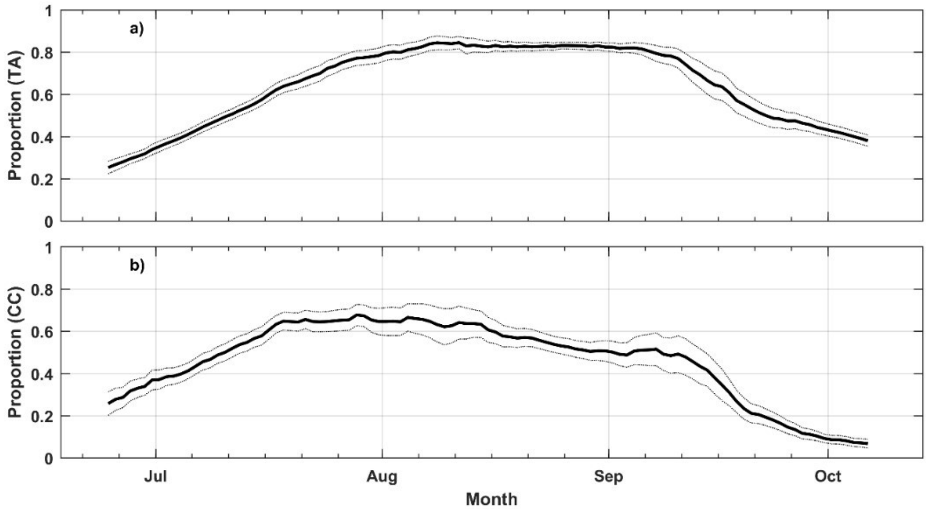

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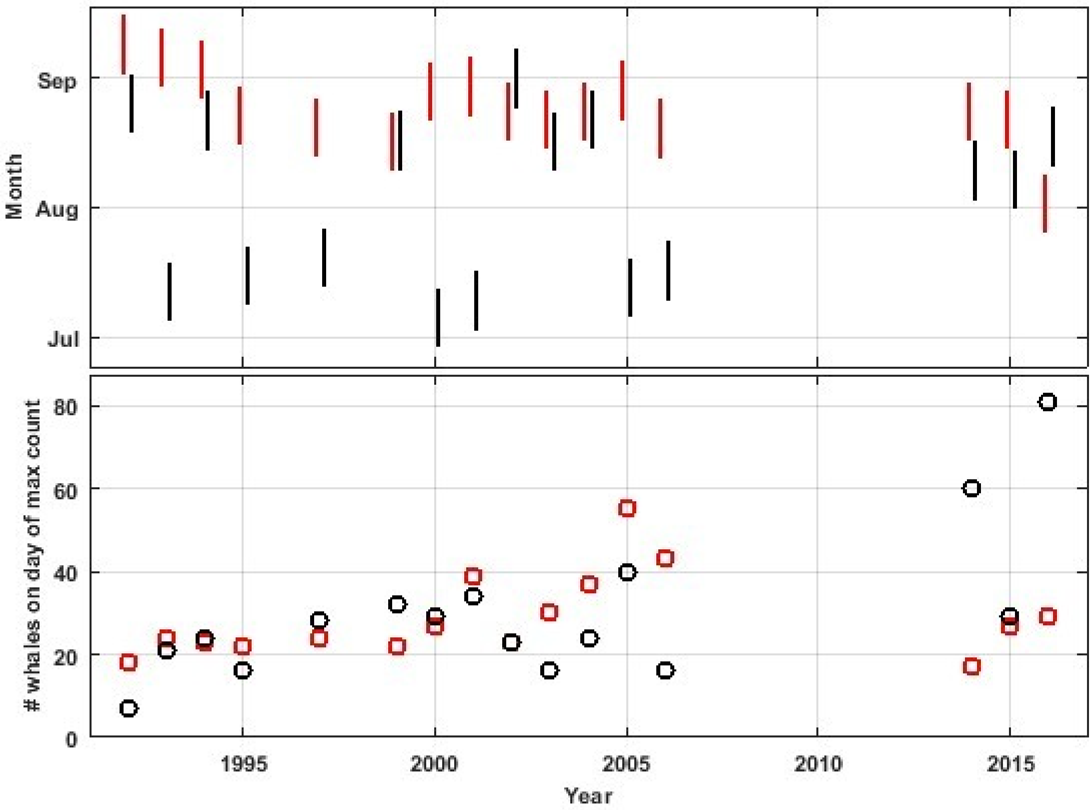

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