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Inshore Cetacean Survey between Ceduna and Coffin Bay, eastern Great Australian Bight

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GREAT AUSTRALIAN BIGHT RESEARCH PROGRAM

The Great Australian Bight Research Program is a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University. The Program aims to provide a whole-of-system understanding of the environment, economic and social values of the region; providing an information source for all to use.

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ACKNOWLEDGEMENTS

The Great Australian Bight Research Program is a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University. Administrative support for this project was provided by Flinders Partners Pty Ltd, SARDI and CSIRO. Logistical support was provided by *Observair* and its Chief Pilot Brad Welch. We thank Shae Small and Juliette Coudert for field assistance.

EXECUTIVE SUMMARY

Little is known about the occurrence and distribution of cetaceans in the region between Ceduna and Coffin Bay in the eastern Great Australian Bight (GAB), South Australia. The importance of the eastern GAB for cetaceans, and in particular for the endangered southern right whale, is currently unknown. This study provides the first systematic aerial survey of cetaceans, including southern right whales, between Ceduna and Coffin Bay in the eastern GAB. For shelf waters, a line transect survey design consisting of 12 transects aligned north to south from the coastline to the 100m depth contour and spaced 15 km apart was used. In addition, two transects were designed for coastal regions, which covered the area 1 nautical mile from shore and the 40-m depth contour. Between July and August 2013, 2,236 km were flown in the region, covering an area of 29,822.4 square kilometers. Altogether, five cetacean species were detected, with seven southern right whales, three humpback whales, one minke whale, and approximately 71 schools of short-beaked common dolphins and 14 schools of bottlenose dolphins. Common dolphins were the only species that resulted in a large number of sightings, which enabled estimates of abundance to be calculated using distance sampling methods. Calculations of relative abundance of common dolphins resulted in estimates of N = 21,366 (95% CI = 12,221 - 37,356) and density of D = 0.72 dolphin/km^2 (CV = 0.28) when using Conventional Distance Sampling (CDS); and N = 19,735 (95% CI= 10,747 - 36,241) and D = 0.66 dolphin/km^2 (CV = 0.31) when using Multiple Covariate Distance Sampling (MCDS). Numbers of detected southern right whales between Ceduna and Coffin Bay were relatively low compared to those previously reported to coastal regions west of Ceduna (i.e. between Cape Leeuwin in Western Australia and Ceduna in South Australia) (Bannister 2011). Results suggest that the region is principally used by whales transiting from feeding grounds to aggregation sites at the Head of the Bight and/or Fowlers Bay, although the sighting of a female with calf suggests that the region may also be occasionally used for calving and nursing.

INTRODUCTION

Overview

We conducted aerial surveys across coastal and shelf waters of the Great Australian Bight (GAB), between Ceduna and Coffin Bay, to assess the occurrence, distribution and relative abundance of southern right whales and other shelf water cetaceans. This study is part of the project *Status, distribution and abundance of iconic species and apex predators*, which aims to provide baseline data on the status and distribution of several iconic and apex predator species in the GAB.

The GAB is a region of major oceanographic importance off southern Australia linking tropical western waters of the Indian Ocean and temperate waters of the Pacific Ocean (Petrusevics et al. 2009). In this region, a minimum of 27 cetacean species potentially occur, including the endangered southern right whale (*Eubalaena australis*) (Kemper et al. 2005). Southern right whales are known to aggregate in several regions along the coast of the GAB, with the Head of Bight being recognized as an important breeding ground (DSEWPaC 2012).

This study provides information on the occurrence, distribution and abundance of cetaceans in the eastern GAB region, which is relevant for an assessment of risk to threatened and protected cetacean species in the region.

Background and Need

Southern right whales were subject to commercial whaling in the 19th and 20th centuries, resulting in substantial declines in abundance (DSEWPaC 2012). Although protected in Australian waters in 1935, populations were further depleted by illegal Soviet whaling in the 1960s (Tormosov et al. 1998). Since then, the southwestern Australia population has undergone some recovery, with annual aerial surveys between Cape Leeuwin (WA) and Ceduna (SA) (undertaken since 1976) indicating that the population is recovering at or near the species maximum biological rate (6.9% per year) (Bannister 2011, DSEWPaC 2012).

Southern right whales are currently listed as endangered under the *Commonwealth Environmental Protection and Biodiversity Act 1999* (EPBC Act).

Although southern right whales are increasing in numbers (Bannister 2011), they are currently still well below estimated historical abundances (Bannister 2011, DSEWPaC 2012, Torres et al. 2013). The current population estimate off southern Australia is approximately 3,500 individuals (Bannister 2011). Furthermore, southern right whale habitat occupancy is still constrained in comparison to their known historical occupancy (DSEWPaC 2012). Threats to southern right whales include human induced impacts such as vessel collisions, anthropogenic noise (shipping, industrial and seismic surveys), commercial fishing entanglements and coastal development (DSEWPaC 2012). They are also likely to be impacted by climate variability and change (DSEWPaC 2012).

To date information on southern right whale distribution and abundance off southern Australia is mainly derived from two long-term studies; an aerial program from Cape Leeuwin to Ceduna (Bannister 2011), and a land-based program in the Great Australian Bight Marine Park (GABMP) (Burnell 2008). Both studies have not covered the region to the east of Ceduna. In particular, little is known about the distribution of southern right whales between Ceduna and Coffin Bay. This region may be of increasing importance for southern right whales because it may include 'emerging areas of use' for these whales as the population recovers from past exploitation (i.e. whales may start using adjacent areas for aggregation, calving and nursing purposes). Moreover, southern right whales may travel through coastal and shelf waters between Ceduna and Coffin Bay as part of their migration cycle between offshore foraging areas during summer and coastal wintering grounds used for calving and nursing. Main aggregation sites for calving and nursing in South Australia are located in coastal waters at the Head of Bight and at Fowlers Bay (Bannister 2011, DSEWPaC 2012). Other known calving grounds are located west of the Head of Bight in southern Western Australia (Bannister 2011, DSEWPaC 2012). Foraging by southern right whales appears to occur mainly during the austral summer, south of the Australian continental shelf in regions of the Subtropical Front (approximately 35°-45°S) (Torres et al. 2013).

In southern Australian waters, bottlenose dolphins (*Tursiops* spp.) and short-beaked common dolphins (*Delphinus delphis,* hereafter referred to as common dolphins) are also regularly sighted, including in the eastern GAB (e.g. Kemper et al. 2005, Bilgmann et al. 2007a, Bilgmann et al. 2008, Bilgmann et al. 2014). The southern Australian bottlenose dolphin (*Tursiops australis*) has recently been described as a new species endemic to coastal waters of southern Australia (Charlton et al. 2006, Möller et al. 2008, Charlton-Robb et al. 2011, Moura et al. 2013). This species shows fine-scale genetic structuring in central South Australia (SA), and bottlenose dolphins from the eastern GAB (St Francis Islands located east of Ceduna to Coffin Bay) are known to belong to a different genetic population to that found in the Spencer Gulf (Bilgmann et al. 2007b). Population genetic structure for this species needs to be further elucidated to clarify if there are more populations of this species in SA waters than the two already identified (Bilgmann et al. 2007b). Common dolphins also show marked genetic structuring in the region and a recent comprehensive study identified multiple management units (MUs) of this species in southern and southeastern Australian waters (Bilgmann et al. 2014). For example, a genetically distinct common dolphin population is regionally distributed in coastal and shelf waters of the GAB (Bilgmann et al. 2014). This population shows significant genetic differentiation to their neighbouring populations: common dolphins off Esperance, Western Australia (WA) to the west; and a population to the east ranging from approximately Eyre Peninsular in SA to Wilsons Promontory in Victoria (VIC) (Bilgmann et al. 2014).

Studies assessing the distribution and abundance of bottlenose and common dolphins have recently been conducted in central SA (Bilgmann et al. in prep, Parra et al. in prep). These studies did not include the eastern GAB, and little is known about the dolphins' occurrence, distribution and abundance between Ceduna and Coffin Bay. While southern Australian bottlenose dolphins are likely to be found in coastal regions and relatively close to shore (Bilgmann et al. 2007b), common dolphins are often found in coastal and shelf waters up to at least the 100-m depth contour (Bilgmann et al. 2008, Möller et al. 2012). Common dolphins in South Australia are thought to be associated with their main targeted prey (Bilgmann et al. 2008, Gibbs 2011, Möller et al. 2011), sardines (*Sardinops sagax*), which occur in relatively high numbers in the eastern GAB (Ward et al. 2009). Bottlenose and

common dolphins are found in the eastern GAB year round (Kemper and Gibbs 2001, Kemper et al. 2005, Bilgmann et al. 2008). Main threats likely to affect the local populations of common and bottlenose dolphins in the region include indirect catches in purse-seine, gillnet, and trap fisheries (Hamer et al. 2009, AFMA 2012), entanglements in debris (Shaughnessy et al. 2003), intentional killing (Kemper and Gibbs 2001), and pollution (Lavery et al. 2008, Lavery et al. 2009).

Despite the importance of the eastern GAB for southern right whales, bottlenose and common dolphins, an additional 24 cetacean species have been recorded in these waters either as live stranded animals or carcasses found beach washed (Kemper et al. 2005). These include humpback whales (*Megaptera novaeangliae*), Antarctic minke whales (*Balaenoptera bonaerensis*) and Dwarf minke whales (*Balaenoptera acutorostrata*, Long-finned pilot whales (*Globicephala melas*) and Short-finned pilot whales (*Globicephala macrorhynchus*), Strap-toothed whales (*Mesoplodon layardii*), Pygmy sperm whales (*Kogia breviceps*), Pygmy right whales (*Caperea marginata*), and others (see appendix 2 for a full list of species; list adopted from Kemper et al. 2005).

Objectives

The aim of this study was to investigate the occurrence and distribution of cetacean species in coastal and shelf waters between Ceduna and Coffin Bay in the eastern GAB, SA, using aerial surveys and distance sampling methodology. We present the results from one systematic line-transect survey covering a large area of the continental shelf in the eastern GAB, and two coastal transects surveying the area of 1 nautical mile off the coast and the 40m depth contour. We present sighting data, distributional maps and estimates of relative abundance for common dolphins, the most sighted cetacean species in the region.

METHODS

Survey Design

Line transect survey

Transects between Ceduna (32°14'S, 133°42'E) and Coffin Bay (34°43'S, 135°36'E) were aligned north to south, and spaced 15 km apart. Transects start and end points were at the coastline and at the 100m depth contour, extending to a maximum of 136 nautical miles (252 km) from the coast to the continental shelf. Each transect was flown once, alternating between north-south, and south-north flight directions. Flights took place between 23 July and 8 August 2013 - the peak season for southern right whale nursing and calving off southern Australia (Pirzl 2008). Surveys were conducted from a Partenavia, twin-engine, six-seat, high-wing aircraft commonly used for aerial surveys of cetaceans. All line-transects were flown at an altitude of 500 feet (152.4 m) and speed of 100 knots (185.2 km/h) in good sighting conditions of wind speed less than 15 knots (i.e. Beaufort sea state ≤ 3). The survey team consisted of four people: the pilot (front-left), the survey leader (front-right), and two observers (rear-right and rear-left) looking out to either side of the plane through flat windows, which allowed them to view down to a 70 degree angle. Communication between survey leader and observers took place via aviation headsets connected to a four way intercom, and recorded on a digital voice recorder. The observers called out declination angles to all sightings as they came abeam using inclinometers, and reported data on species group size and sighting conditions (i.e. Beaufort sea state, glare severity and angle, visibility, cloud cover and turbidity). The survey leader entered survey effort data, sighting conditions and data called by the observers, together with time stamp signals of positions from a GPS system. Data were entered and stored in a handheld computer using the software CYBERTRACKER and a sequence specifically designed for cetacean aerial surveys. Surveys were flown in 'passing mode' and survey effort was not suspended to circle back when a sighting was made, except when species identification and/or school size was uncertain. In such cases a circle back procedure was initiated and effort was suspended to circle the animals and confirm species identification. The survey was then resumed at the point on the transect line where survey effort was previously suspended.

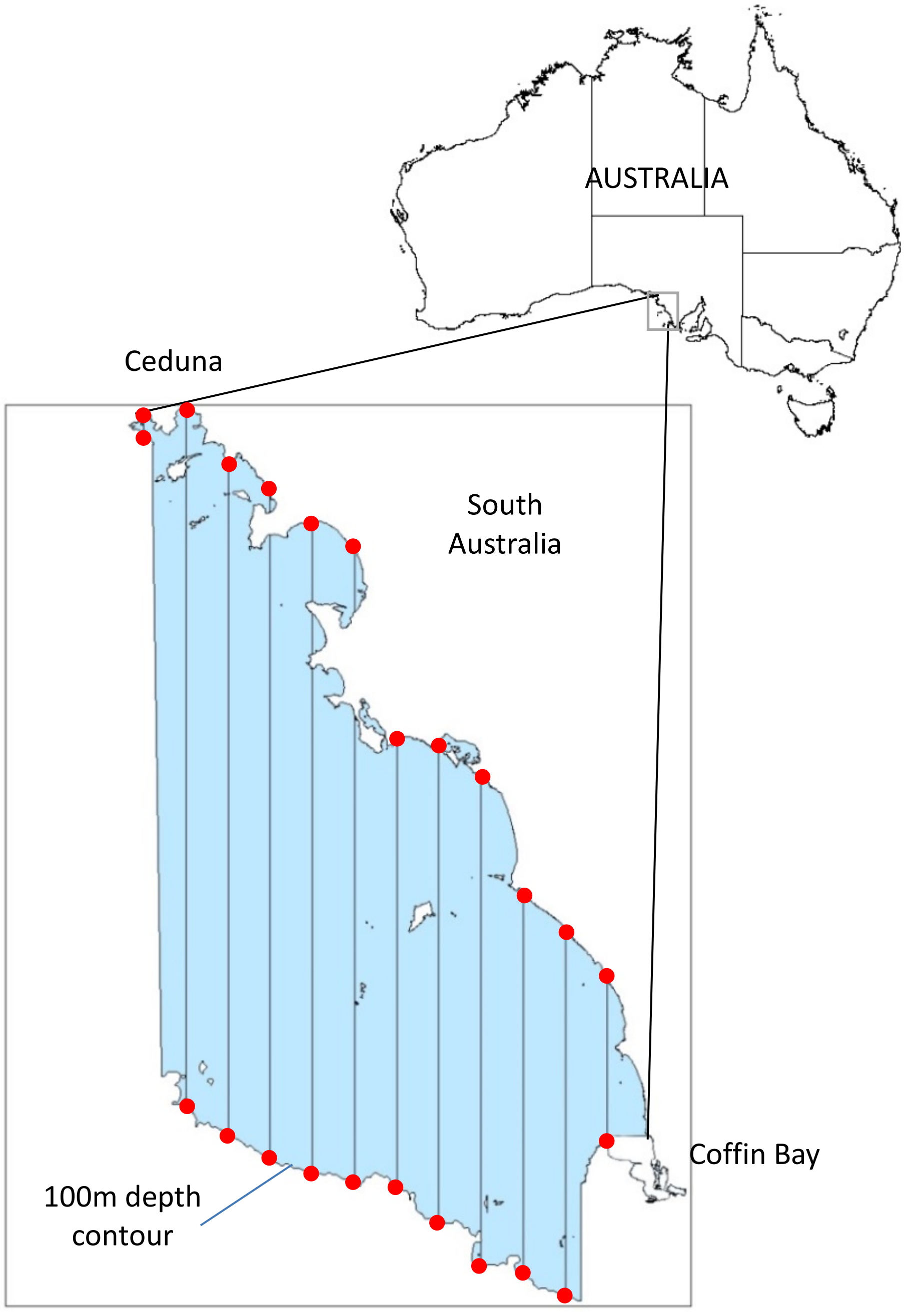

Figure 1. Map of the study area indicating aerial survey line transect layout. Start and end points of transects are marked with a red dot, and transects were numbered from 1-12, west to east. Effort on transect was paused when flying over headlands and/or islands.

Coastal survey

For the coastal survey two along shore transects were designed. The first transect followed the coastline within one nautical mile from shore to scan the area between the transect and the shore line, replicating the survey design of Bannister (2011). In the latter region, southern right whale cows about to give birth or with newborn calves are frequently found close to shore (Bannister 2011). The along shore transect aimed to assess southern right whale occurrence beyond the previously surveyed area by Bannister (2011), i.e. between Ceduna and Coffin Bay. The second transect followed the 40 m depth contour approximately parallel to the coast. The area around the 40 m bathymetry was chosen to cover waters at medium depth, and at greater distance from shore, which may be utilized by southern right whales to travel from offshore feeding grounds to calving grounds at the Head of Bight (31°30'S, 131°10'E) (Bannister 2011), and/or Fowlers Bay (31°59'S, 132°34'E), the latter a historically significant whaling location.

The coastal surveys were conducted with the same Partenavia aircraft and observer team as the line-transect survey (pilot, observer leader and two observers) and followed the same protocols. Transects were designed with the Garmin software HOMEPORT 2.2.3 (Garmin Ltd.) and the track was uploaded onto an aviation GPS. During flights the pilot followed the survey track, and line tracking was checked by the observer leader throughout the flight. Both transects were flown at 1,000 feet (304.8 m; twice the altitude of the line transect survey design) and 100 knots (185.2 km/h) to replicate the survey design of (Bannister 2011).

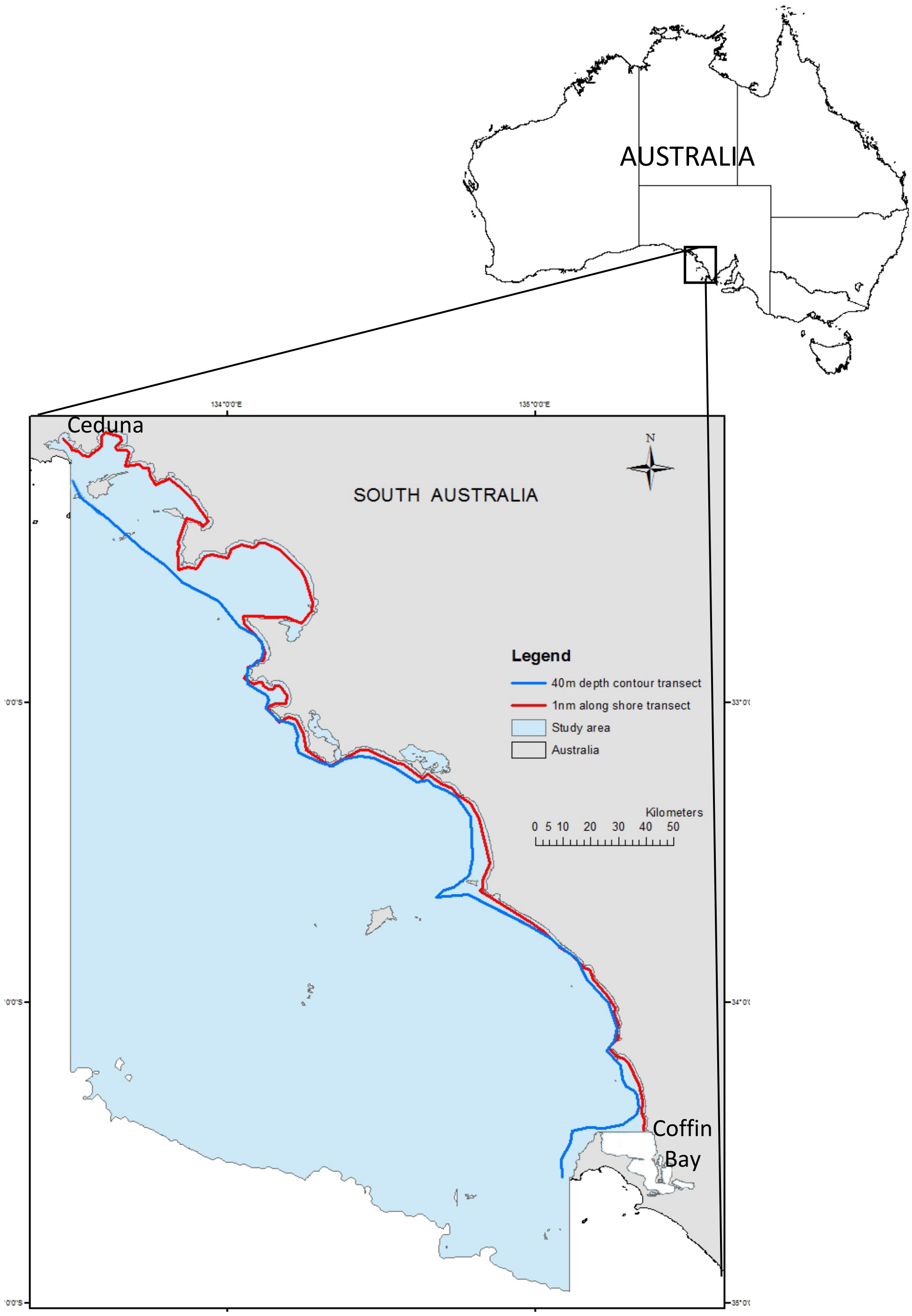

Figure 2. Map of the study area indicating the layout of the two coastal transects. The 1 nautical mile from short transect is displayed in red and the 40 meter depth contour transect in blue.

Data analysis

Line-transect survey

Abundance was estimated only for those species with sufficient number of sightings (see Buckland et al. 2004 for rationale). Analyses were conducted in DISTANCE 6 (release 2) using Conventional Distance Sampling (CDS) and Multiple Covariate Distance Sampling (MCDS) (Thomas et al. 2009). In the CDS engine, we used uniform, half normal and hazard rate detection functions, and in the MCDS engine, half normal and hazard rate, and combined these with different adjustment terms (cosine, hazard rate, simple polynomial, hermite polynomial). Best fit model(s) were selected based on the lowest Akaike Information Criterion (AIC) (Buckland et al. 2001, Burnham and Anderson 2002). Summary statistics and abundance estimates of models from both analyses were compared.

While CDS is suitable for simple data analyses, MCDS allows for modeling the detection probability as a function of variables other than distance that may contribute to heterogeneity in detection probabilities (Borchers et al. 1998). When detection on the track line is not certain, this is important because methods can be biased if detection probabilities vary among schools (Borchers et al. 1998). MCDS analysis allows for inclusion of explanatory variables (here covariates: Beaufort sea state, cloud cover, visibility impacted by glare, and school size) that may influence abundance estimation. We also estimated density of individuals in the study area to compare estimates with those derived from previous studies of the same species in central SA (Spencer Gulf and shelf waters south of the Gulf to the 100 m depth contour, Investigator Strait and Gulf St Vincent) (Parra et al. in prep).

Coastal surveys

Southern right whale counts from coastal surveys were also compared to counts of southern right whales between Cape Leeuwin in Western Australia and Ceduna in South Australia recorded between 1993 and 2010 as part of a long-term research program on southern right whales (Bannister 2011).

RESULTS

Line-transect survey

Twelve equally spaced transects with a total length of 2,236 km were flown between 23 July and 8 August 2013, which is around the peak season for southern right whale calving and nursing off southern Australia (Pirzl 2008). In total, an area of 29,822.4 km^2 was covered between Ceduna (west) and Coffin Bay (east) in SA. The coastline and the 100 m depth contour were the northern and southern boundaries of the survey, respectively. Sighting data were collected for a total of five cetacean species detected while on effort (i.e. while on transect). A summary of number of schools/pods, and individuals sighted for each species during the line transect survey are shown in Table 1. The table also shows the respective data for the coastal surveys. The most commonly sighted cetacean species was the short-beaked common dolphin (*Delphinus delphis*), with a total of 59 schools sighted with species confirmed (Figure 3). The common dolphin was the only species that resulted in sufficient sightings for abundance estimates in DISTANCE. Other cetacean species sighted during line transect surveys were the bottlenose dolphin (*Tursiops* sp.) (Figure 4), southern right whale (*Eubalaena australis*), humpback whale (*Megaptera novaeangliae*), and minke whale (*Balaenoptera* sp.) (Figure 5, Table 1). All bottlenose dolphins sighted in this study were likely to be the southern Australian bottlenose dolphin (*Turisops australis*) based on their small body size, light coloration, relatively small school sizes of ≤30 individuals and close distance from shore (Bilgmann et al. 2007b, Charlton-Robb et al. 2011).

Sightings detected during the line transect survey were adjusted for perpendicular distance from the transect line by applying geometric functions in Excel, which incorporated declination angle, bearing and the GPS location on the transect line when the sighing was abeam (Lerczak and Hobbs 1998) (Figure 3 and 4; Appendix 1).

Table 1. Summary of sightings recorded during the line transect survey (12 equally spaced transects) and the coastal surveys (1 nautical mile from shore and 40 m depth contour transects). Total number of schools/pods and total number of individuals sighted are given for each species. Numbers in parentheses are sightings with uncertain species identification. Three bottlenose dolphin sightings, detected close to shore while off transect, were also added to the coastal survey counts.

Cetacean species sighted	Number of schools/pods sighted			Total number of individuals (direct count or best estimate)
	Line-transect survey	Coastal surveys	Total number of sightings	
Common dolphin (*Delphinus delphis*)	59 (+5)	12 (+1)	71 (+6)	722 (+15)
Bottlenose dolphin (*Tursiops australis*)	6 (+1)	8 (+2)	14 (+3)	107 (+10)
Southern right whale (*Eubalaena australis*)	2 (+1)	1	3 (+1)	7 (+1)
Humpback whale (*Megaptera novaeangliae*)	1	1	2	3
Minke whale (*Balaenoptera* sp.)	1	0	1	1

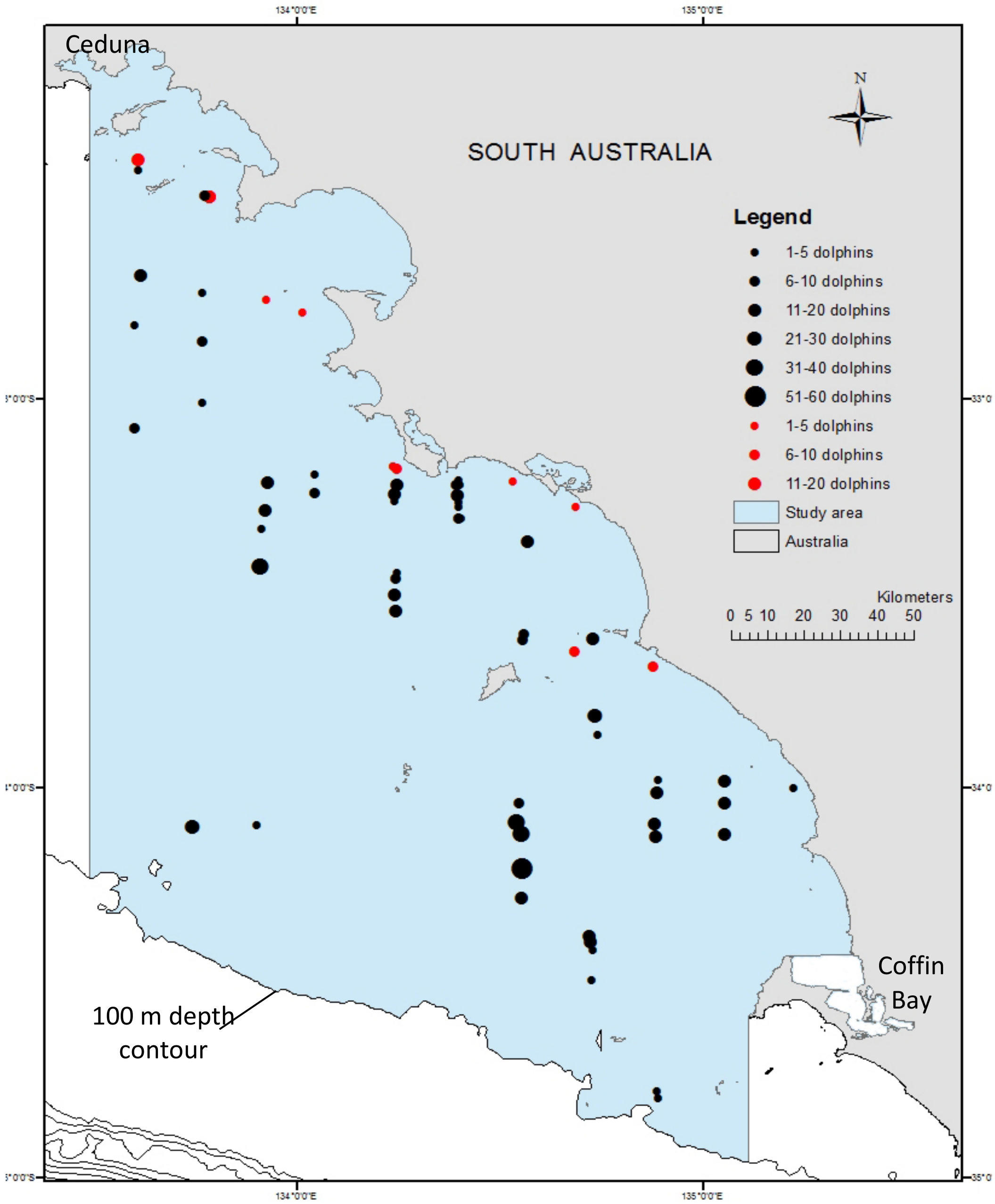

Figure 3. Study area and sightings of common dolphin schools between Ceduna and Coffin Bay, South Australia, during aerial surveys in July/August 2013. Sightings from line transects are displayed in black and from coastal transects in red. Dot size increases proportionally with the number of individuals in schools, pooled into school size bins (1-5; 6-10; 11-20; 21-30; 31-40; 41-50; and 51-60 dolphins). GPS locations of sightings from line transects were adjusted for perpendicular distance to the transect line.

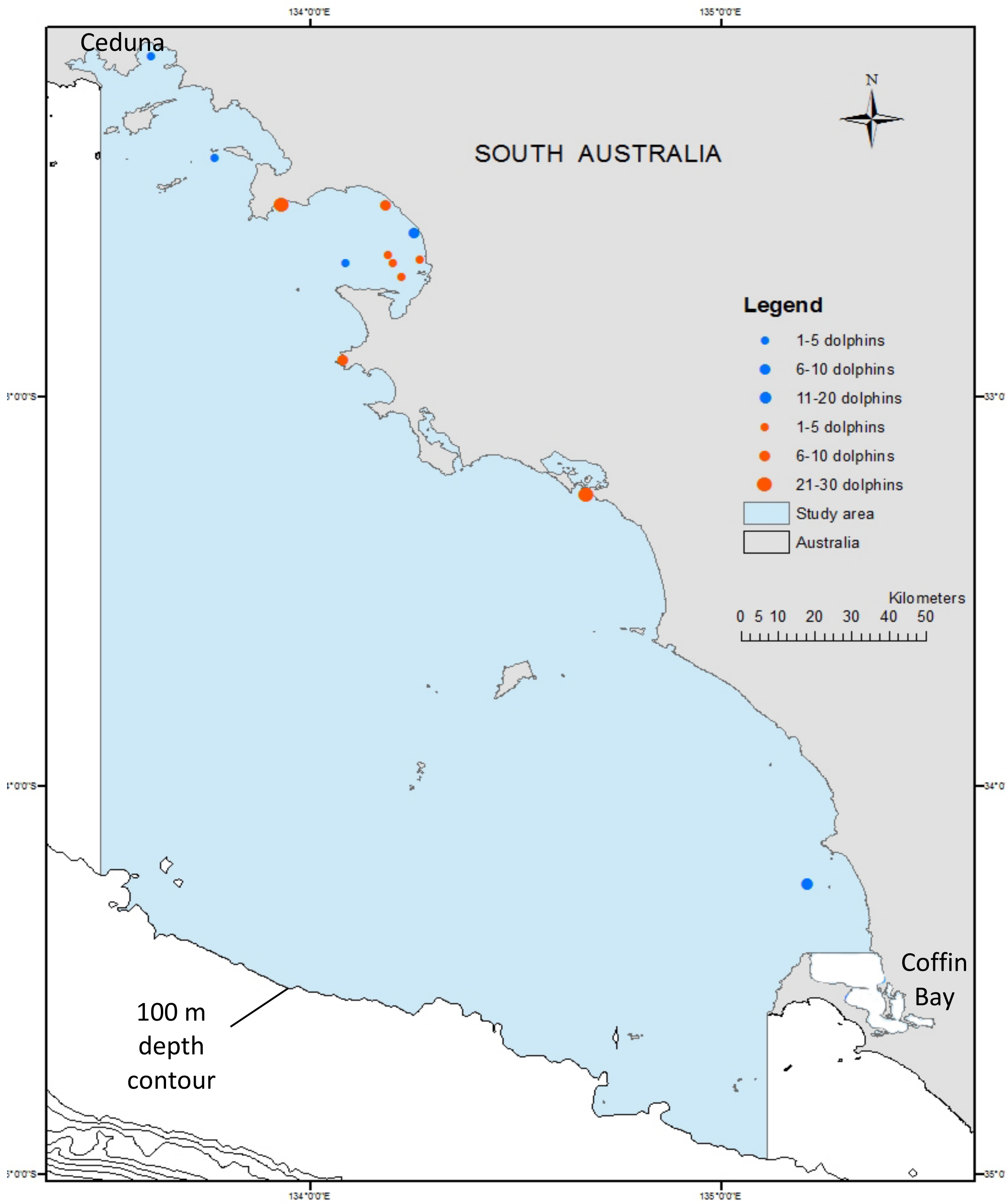

Figure 4. Study area and sightings of bottlenose dolphin schools between Ceduna and Coffin Bay, South Australia, during aerial surveys in July/August 2013. Sightings from line transects are displayed in blue and from coastal transects in orange. Dot size increases proportionally with the number of individuals in schools, pooled into school size bins (1-5; 6-10; 11-20; 21-30 dolphins). GPS locations of sightings from line transects were adjusted for perpendicular distance to the transect line.

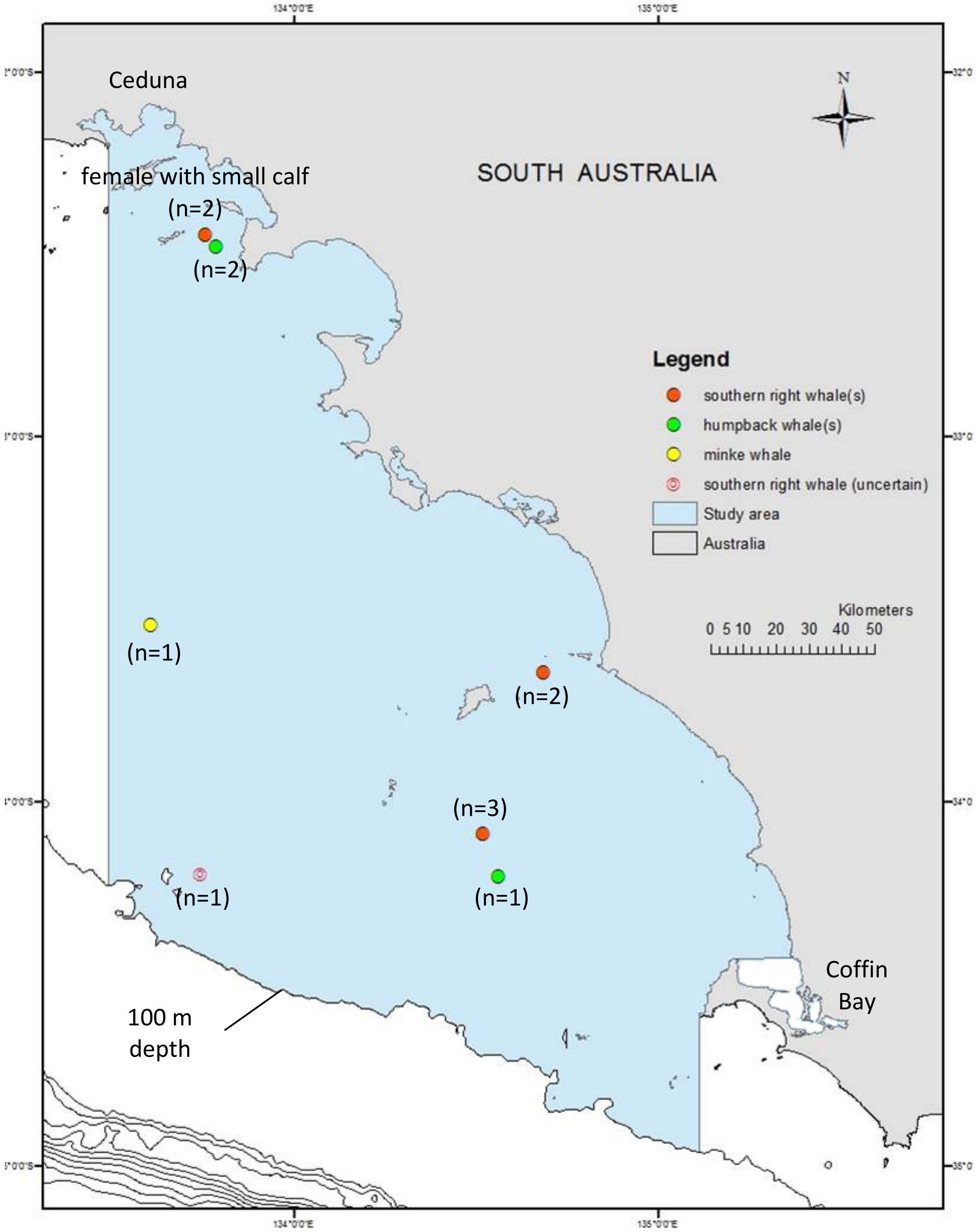

Figure 5. Study area and sightings of southern right whales (red), humpback whales (green), and one minke whale (yellow) between Ceduna and Coffin Bay, South Australia, during aerial surveys in July/August 2013. GPS locations of sightings from line transects were adjusted for perpendicular distance to the transect line.

Estimates of relative abundance where calculated for common dolphins only. The other cetacean species did not have sufficient number of sightings to create sensible estimates (Buckland et al. 2004). Common dolphin school sizes recorded during the line transect survey (using the same school size bins as in Figures 3 and 4) are displayed in Figure 6.

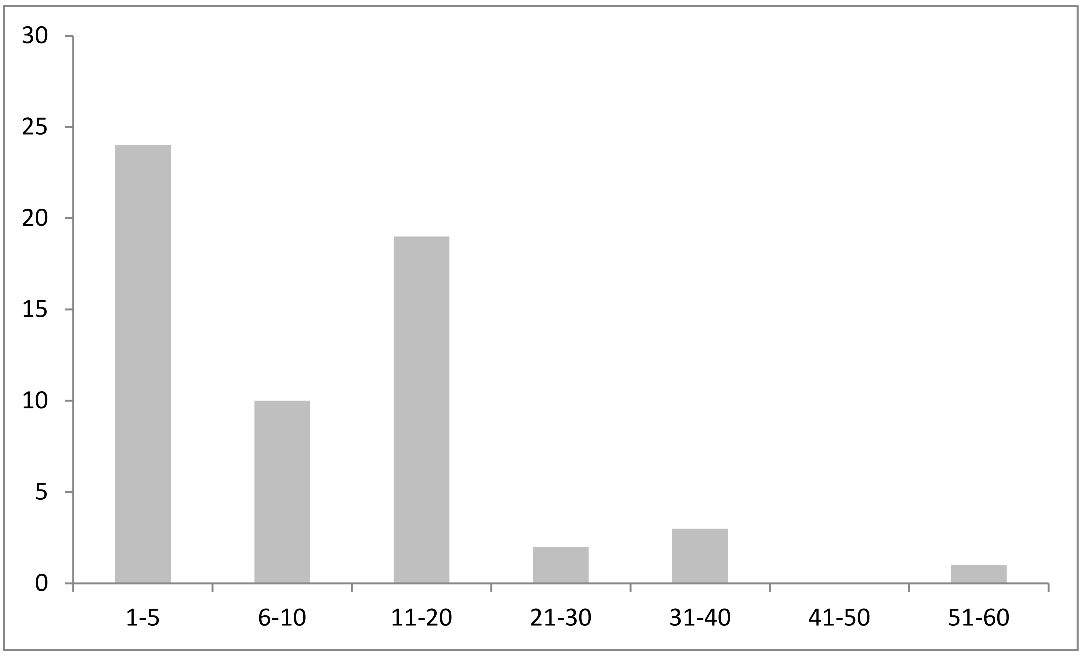

Figure 6. Frequency of common dolphin school sizes spotted during the line transect survey (on effort sightings). Dolphin schools were pooled into school size bins of 1-5; 6-10; 11-20; 21-30; 31-40; 41-50; and 51-60 dolphins.

As mentioned above, all sighted bottlenose dolphins were identified as the southern Australian bottlenose dolphin (*Tursiops australis*). Offshore bottlenose dolphins (*Tursiops truncatus*), although known to migrate through the area, were not seen during the surveys. It is also known from previous genetic studies that southern Australian bottlenose dolphins occur in the region between Ceduna and Coffin Bay (Bilgmann et al. 2007b, Möller et al. 2008, Charlton-Robb et al. 2011).

Estimates of relative abundance

For estimates of relative abundance of common dolphins we used both CDS and MCDS analyses. We undertook preliminary analysis in DISTANCE to decide for best truncation distances by assessing differences in the produced detection functions. The data was left-

truncated at a perpendicular distance of 130 m to account for an obstructed view down to the transect line, and right-truncated at a distance of 420 m to remove outliers, and to improve model fit. Truncation of data is commonly used in distance sampling analyses (see Buckland et al. 2001, Thomas et al. 2009). For the CDS analysis, we used four standard detection function models: half normal key with cosine adjustments, uniform key with cosine adjustments, half-normal key with hermite polynomial adjustments, and hazard rate key with simple polynomial adjustments. These combinations of key functions and adjustment terms have shown to perform well in similar studies (Thomas et al. 2009). The summary statistics of detection function models are shown in Appendix 3.

For the CDS analysis, comparisons of AIC from all permutations of the detection functions and potential adjustment terms resulted in the uniform key function with the cosine adjustment term showing the lowest AIC. Goodness-of-fit was also performed for each model assessing quantile-quantile (q-q) plots, Kolmogorov-Smirnov test, and Cramer von Mises statistics for exact data (Buckland et al. 2001, Thomas et al. 2009). Based on the lowest AIC, the uniform key with cosine adjustment model was selected as the model with 'best fit' to the data. The fitted detection function is given in Figure 7. The estimated strip width for the uniform key function with cosine adjustment term was 129.93 m, the estimated common dolphin density was 0.72 dolphin/km^2 (CV = 0.28) and the estimated number of individuals N = 21,366 (95% CI= 12,221 - 37,356) (Appendix 3).

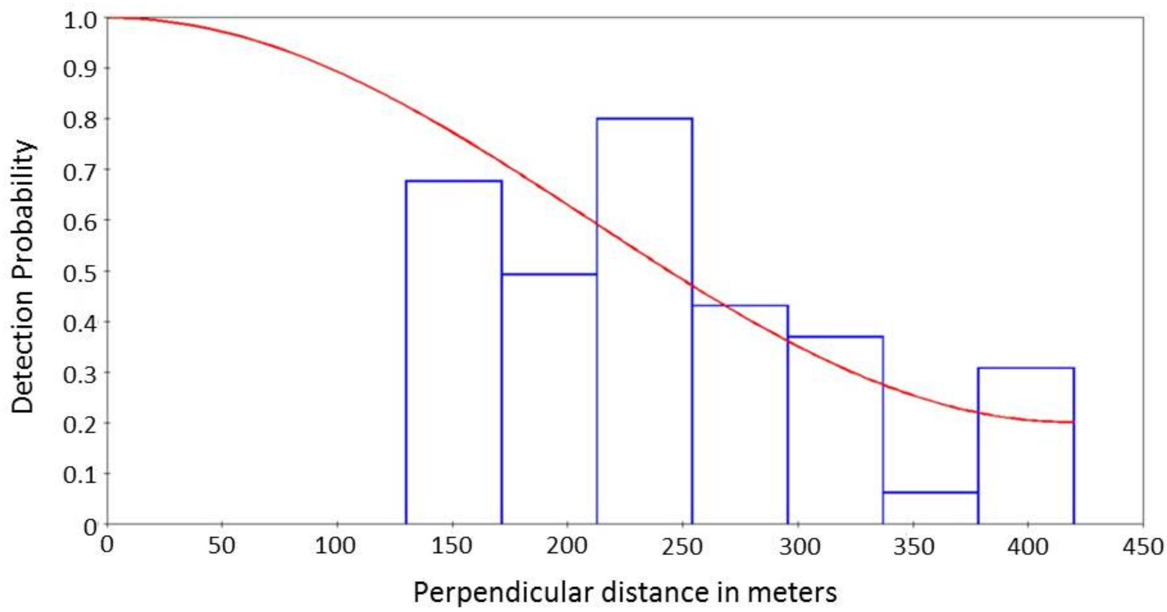

Figure 7. Detection function plot for common dolphin sightings from line-transect surveys between Ceduna and Coffin Bay (Conventional Distance Sampling method, uniform key function with cosine adjustment model; Buckland et al. 2001).

In the MCDS analysis we used combinations of half normal and hazard rate key functions with different combinations of cosine, hermite polynomial, and simple polynomial adjustment terms. The uniform key function is not available in the MCDS analysis, and it is substituted by half normal and hazard rate key functions only (Thomas et al. 2010). We used the same right and left truncation of the data as for the CDS analysis. In contrast to the CDS analysis, the MCDS analysis allows for additional covariates to be included in the detection function model in addition to the observed distance. These covariates are entered through the scale parameter of the key function (via a log link function), which means that the covariates are assumed to influence the 'scale' of the detection function but not its 'shape' (Buckland et al. 2001, Thomas et al. 2009). The following covariates were added one by one, and tested if they improved model fit (i.e. if the AIC decreased): Beaufort sea state, cloud cover, glare and school size (cluster size). Each covariate added to any possible combination of key function and adjustment term led to convergence failure. Adding more than one covariate at a time also led to convergence failure, and was therefore disregarded. Any step undertaken to facilitate convergence (for example, setting the number of adjustment terms

manually to zero) did not improve convergence. As recommended in such cases, we only considered null models (no covariates) for model selection, and disregarded the models with convergence failure (Buckland et al. 2001). Summary statistics for each null model and univariate model (each covariate added on its own) are displayed in Appendix 3. Results from the CDS and the MCDS analyses using the same combination of key function and adjustment term resulted in the same estimates. Similar to the CDS criteria for model selection, we selected the best fit model based on lowest AIC among the null models (all converged). Since the uniform key function (selected for CDS) is not available in the MCDS engine, the results from the best fit model of CDS and MCDS, including the abundance estimates, differed slightly. However, the same results were produced when the same models were used (see summary statistics in Appendix 3). The half normal key function fitted the data best in the MCDS analysis (lowest AIC), regardless of the adjustment term used, and all three possible combinations of adjustment terms with the half normal key function led to the same values (Appendix 3). The fitted detection function is given in Figure 8. The estimated strip width for the half normal function with any of the adjustment terms was 146.36 m, and the estimated common dolphin density was 0.66 dolphin/km^2 (CV = 0.31). Number of individuals was estimated at N = 19,735 (95% CI= 10,747 - 36,241). Models with hazard rate key functions produced outputs that differed only slightly from those of the half normal key functions (Appendix 3).

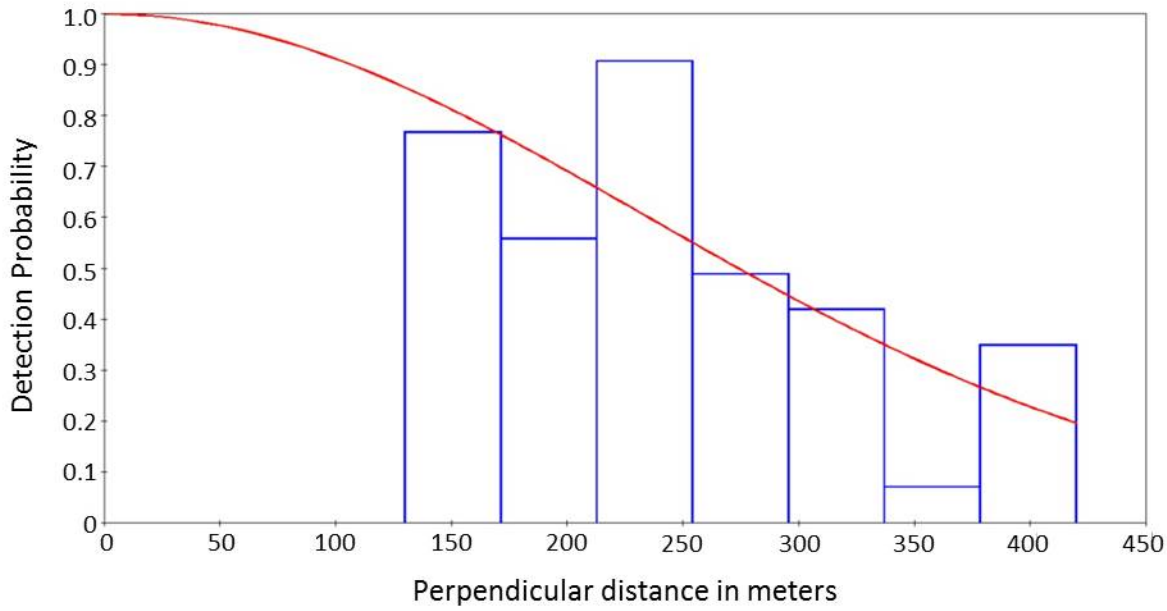

Figure 8. Detection function plot for common dolphin sightings from line-transect surveys between Ceduna and Coffin Bay (Multiple Covariate Distance Sampling method, halfnormal key function with cosine adjustment model without inclusion of covariates; Buckland et al. 2001).

Coastal surveys

The 1 nautical mile along shore transect of 498 km length was flown in a southeast to northwest flight direction on 24 July 2013. The 40 m depth contour transect of 393 km length was flown in the opposite direction, from northwest to southeast, on 7 August 2013. During the 1 nautical mile from shore transect, which followed the design of (Bannister 2011), the only cetacean species detected were bottlenose and common dolphins. No southern right whales were sighted during this transect. While on effort for the 40 meter depth contour transect we detected humpback whales and common dolphins (see Appendix 1). Bottlenose dolphins and southern right whales were not sighted on this transect, although the latter species was sighted near the 40 m depth contour south of Ceduna during the line transect survey (Figure 5).

DISCUSSION

This study provides the first systematic coastal and shelf survey, and assessment of the occurrence of southern right whales and other cetaceans between Ceduna and Coffin Bay, eastern Great Australia Bight, out to the 100 meter isobath. It also provides the first abundance estimates for common dolphins in the region. The results provide a valuable contribution for a better understanding of the occurrence, distribution and abundance of cetaceans in these waters, a geographic region of major importance oceanographically (Middleton and Bye 2007) and commercially (Ward et al. 2009, Ward et al. 2012). This information can also be used for evaluating the recovery of the endangered southern right whale - a species that currently still shows habitat occupancy and numbers well below pre-whaling times (DSEWPaC 2012).

Altogether, five cetacean species were detected, with a total of seven southern right whales, three humpback whales, one minke whale, and 71 and 14 schools of common and bottlenose dolphins, respectively. The relative abundance calculated from 59 unique sightings of common dolphin schools during the line transect survey resulted in estimates of N = 21,366 (D CV = 0.28; 95% CI = 12,221 - 37,356) and density of D = 0.72 dolphin/km^2 when using CDS, and N = 19,735 (D CV = 0.31; 95% CI= 10,747 - 36,241) and D = 0.66 dolphin/km^2 when using MCDS, in an area of 29,822.4 km^{2}between Ceduna and Coffin Bay. Similar densities for common dolphins were estimated from summer and winter aerial surveys in central SA (Spencer Gulf, Gulf St. Vincent and Investigator Strait), using the same aerial survey methodology (Parra et al. in prep).

The importance of eastern GAB shelf waters for cetaceans, and in particular for the endangered southern right whale, is currently unknown (DSEWPaC 2012). Previous to this study, little research effort had focused on the occurrence, distribution and abundance of cetaceans between Ceduna and Coffin Bay. Mainly coastal regions west of Ceduna as far as Cape Leeuwin in WA had been surveyed on a yearly basis since 1993 as part of a long-term research program to monitor southern right whale recovery (Bannister 2011). Areas east of Ceduna were not included in this program.

Southern right whale populations declined significantly as a consequence of 19th century whaling, and in the 1920s estimated numbers in the southern hemisphere were as low as 300 individuals (total estimate for waters of Australia, Argentina and South Africa) (DSEWPaC 2012). Following protection in 1935, their numbers started to increase but were subsequently reduced further as a consequence of illegal Soviet whaling in the 1960s, delaying southern right whale recovery (Tormosov et al. 1998, DSEWPaC 2012). Hunting of southern right whales is currently banned under the IWC moratorium on commercial whaling, and southern right whales in southwestern Australia (Cape Leeuwin to Ceduna) appear to be increasing at a maximum biological rate of approximately 7% per annum (Bannister 2011, DSEWPaC 2012).

Coastal and shelf waters between Ceduna and Coffin Bay are potentially of increasing importance for southern right whales for two reasons. First, although southern right whales were rarely seen in coastal waters between Ceduna and Coffin Bay after their numbers were considerably reduced due to whaling, the region may be of increasing importance as the population recovers from this activity. Where suitable habitat is available, areas may increase in importance for nursing and calving (DSEWPaC 2012). No 'emerging areas of importance' have yet been identified between Ceduna and Coffin Bay. However, this section of the coast is part of the current core coastal range of southern right whales and presents suitable habitat (DSEWPaC 2012). Second, migration of southern right whales across shelf waters of this region are likely to occur when whales seasonally move from feeding grounds south of Australia (in the Sub-Tropical Front) to their main calving and nursing grounds close to shore at the Head of Bight and/or to other aggregation sites, such as Fowlers Bay (Bannister 2011).

Our study provides evidence that southern right whales occur in shelf waters east of Ceduna, presumably crossing these waters seasonally as they travel to and from aggregation sites closer to shore. This study has therefore provided additional information on the occurrence, distribution and habitat use of southern right whales in non-coastal habitat areas of the eastern GAB, an interim objective (Target 3.3) of the *Conservation Management Plan for the Southern Right Whale 2011-2021* (DSEWPaC 2012). While the long-term recovery objective is to minimize anthropogenic threats to allow the conservation status of

the southern right whale to improve so that it can be removed from the threatened species list under the EPBC Act, interim objectives focus on targets that can be achieved in shorter time frames. This includes increasing relevant knowledge about the species, monitoring species recovery, and minimizing anthropogenic threats (DSEWPaC 2012). The Australian *Conservation Management Plan for the Southern Right Whale 2011-2021* (DSEWPaC 2012) identified the main threats of southern right whales as entanglements, vessel collisions, whaling should it become legal again for any country, climate variability and change, noise interference, habitat modification, and overharvesting of prey. In particular, vessel collisions are of concern because southern right whales appear to be the primary whale species involved in vessel collisions in the southern hemisphere (Van Waerebeek et al. 2007). Furthermore, pollution such as potential oil spills may have a considerable impact on endangered southern right whales, in particular when females nursing young calves are impacted. Near Ceduna we detected a female southern right whale with a small calf and the pair was moving north-west. The detection of humpback whales and one minke whale during this study shows that the region between Ceduna and Coffin Bay is also used by other whale species. Since aerial surveys are 'snap shots' of temporal and spatial distribution of animals, other whale species that were not seen during this study may also utilize the area. The detection of species during aerial surveys therefore only represents a minimum number of sightings for the region.

The line transect survey design of this study has several limitations that are likely to have influenced cetacean detection ability in the study area, and accuracy of the abundance estimates for common dolphins. First, logistic and time constraints did not allow for a higher number of line transects to be flown over the survey area with closer line spacing than the spacing of 15 km between transect lines used here. Ideal line spacing was estimated to be around half the distance (i.e. around 7-8 km). Second, surveys were flown using a single observer platform (one observer on each side of the plane) rather than a double observer platform (two independent observers on each side of the plane). Double observer platforms increase the detection ability and allow for correction of abundance estimates for perception bias (i.e. the bias that occurs when an observer misses a sighting due to human error). Third, the common dolphin abundance estimates could not be corrected for

availability bias. This bias occurs when dolphin sightings are missed because the dolphins are diving and are too far below the water surface to be visible from the air. Thus our abundance estimates are likely to be biased downwards because of availability of bias. Helicopter surveys can, for example, be used to conduct focal follows of dolphin schools in the study area to assess the approximate proportion of time dolphins are invisible to aerial observers, allowing for correction of the data for availability bias. However, helicopter surveys are expensive and could not be conducted for this study.

During the coastal survey (1 nm from shore and 40 m depth contour transects), we only detected humpback whales, common dolphins and bottlenose dolphins. Southern right whales were not seen close to shore, which is in contrast to the relatively large number of whales at aggregation sites along the coast west of Ceduna (Bannister 2011). West of Ceduna, numbers of southern right whales ranged between a minimum of 167 recorded in 1993 to a maximum of 782 recorded in 2009 (Bannister 2011).

East of Ceduna, the most sighted cetacean species for both the line transect and coastal surveys, was the common dolphin. Common dolphins which are locally distributed in these waters of the eastern GAB belong to a population that is genetically differentiated from common dolphins off Esperance, WA to the west, and those of Spencer Gulf region to the east (Bilgmann et al. 2014). The second most commonly sighted dolphin species was the southern Australian bottlenose dolphin (*Tursiops australis*). This species is likely endemic to southern Australian waters (Charlton-Robb et al. 2011, Moura et al. 2013) and exhibits fine-scale genetic structuring off South Australia (Bilgmann et al. 2007b). Both common and bottlenose dolphins, due to their local distribution and fine-scale genetic structuring, are potentially sensitive to regional anthropogenic impacts. The main threats for dolphins in southern Australia are human induced, including operational fishery interactions, entanglements in debris, intentional killings, coastal development and pollution (Gales et al. 2003). Common dolphins, in particular, are subject to operational interactions with fisheries. Two fisheries that are known to have operational interactions with common dolphins include: 1) the South Australian Sardine Fishery (SASF), a purse-seine fishery targeting sardines (Hamer et al. 2008); and 2) the gillnet fishery of the Southern and Eastern Scalefish and Shark Fishery (SESSF) targeting gummy sharks (AFMA 2011). While hundreds of dolphins

have died in the purse-seine fishery over the past two decades, with an observer program developed aimed at reducing these mortalities (Hamer et al. 2008), the gillnet fishery has only recently been identified as leading to dolphin mortalities (mainly common dolphin, see AFMA 2012). Mortality rates of dolphins from entanglement in gillnets are high (approximately 95%), and the Australian Fisheries Management Authority (AMFA) is currently seeking solutions to minimize common dolphin gillnet fishery interactions (AFMA 2013). The cumulative impact of the two fisheries on the dolphin populations, together with other anthropogenic impacts such pollution and/or habitat destruction, are currently unknown.

In conclusion, the aerial surveys conducted indicated that at least five cetacean species inhabit coastal and offshore waters between Ceduna and Coffin Bay during winter: short-beaked common dolphins (*Delphinus delphis*), southern Australian bottlenose dolphins (*Tursiops australis*), southern right whales (*Eubalaena australis*), humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera* sp.) Common dolphins appear to be particularly abundant in the region. The low number of sightings of southern right whales in both offshore and inshore areas suggests that this stretch of coastline may not currently be a core area of use for this species, however, our results suggest that some animals use the region for transiting from feeding grounds to aggregation sites at the Head of the Bight and/or Fowlers Bay. The sighting of a single mother/calf pair may indicate that southern right whales occasionally utilize shelf waters between Ceduna and Coffin Bay for calving and nursing. The region may increase in importance as the population continues to recover from whaling.

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APPENDIX

Appendix 1 Summary of sightings during line transect and coastal surveys between Ceduna and Coffin Bay. Sightings on effort for line transects are displayed on a white background, sightings of coastal surveys (1nm from shore and 40 m depth contour transects) on a light grey, and off transect sightings on a dark grey background.

Transect	Sightings Number	Date	Time	Species ID	Species Certainty	No of ind (best estimate)	Latitude	Longitude	Flight Direction	Altitude (feet)	Sightings Effort	Observer Position	Bearing	Declination Angle	Perp Dist Nmiles
1		30/07/2013	16:46:20	No sighting					North-South	500					
2	1	30/07/2013	15:21:44	Minke Whale	Positive	1	-33.5152	133.6053	South-North	500	On	Right	90	35	0.39
2	2	30/07/2013	15:42:05	Common Dolphin	Positive	8	-33.0740	133.6057	South-North	500	On	Right	90	40	0.32
2	3	30/07/2013	15:50:50	Common Dolphin	Positive	4	-32.8078	133.6117	South-North	500	On	Right	90	20	0.74
2	4	30/07/2013	16:05:47	Common Dolphin	Positive	12	-32.6805	133.6183	South-North	500	On	Right	90	42	0.30
2	5	30/07/2013	16:17:00	Common Dolphin	Positive	2	-32.4089	133.6181	South-North	500	On	Right	90	26	0.55
2	6	30/07/2013	16:19:01	Dolphin	Positive	11	-32.3513	133.6080	South-North	500	On	Left	270	40	0.32
2	7	30/07/2013	16:28:51	Bottlenose Dolphin	Uncertain	10	-32.2033	133.6198	South-North	500	On	Right	90	24	0.61
2	8	30/07/2013	16:39:45	Bottlenose Dolphin	Positive	1	-32.1213	133.6103	South-North	500	On	Left	270	45	0.27
3	9	30/07/2013	12:57:27	Bottlenose Dolphin	Positive	1	-32.3828	133.7614	South-North	500	On	Left	270	30	0.47
3	10	30/07/2013	12:59:35	Southern Right Whale	Positive	2	-32.4453	133.7545	South-North	500	On	Left	270	20	0.74
3	11	30/07/2013	13:12:41	Common Dolphin	Positive	7	-32.4754	133.7681	South-North	500	On	Left	270	45	0.27

3	12	30/07/2013	13:25:13	Common Dolphin	Positive	5	-32.7260	133.7647	South-North	500	On	Left	270	50	0.23
3	13	30/07/2013	13:29:18	Common Dolphin	Positive	8	-32.8500	133.7617	South-North	500	On	Left	270	40	0.32
3	14	30/07/2013	13:34:48	Common Dolphin	Positive	3	-33.0075	133.7699	South-North	500	On	Right	90	45	0.27
3	15	30/07/2013	14:18:55	Common Dolphin	Positive	30	-34.1004	133.7399	South-North	500	On	Left	270	40	0.32
3	16	30/07/2013	14:28:12	Southern Right Whale	Uncertain	1	-34.1999	133.7435	South-North	500	On	Left	270	50	0.23
3	17	30/07/2013	14:28:12	Dolphin	Positive	1	-34.1999	133.7435	South-North	500	On	Left	270	50	0.23
4	18	30/07/2013	10:18:01	Common Dolphin	Positive	3	-34.0927	133.8948	South-North	500	On	Left	270	35	0.39
4	19	30/07/2013	10:47:36	Common Dolphin	Positive	32	-33.4306	133.9073	South-North	500	On	Left	270	50	0.23
4	20	30/07/2013	10:58:55	Common Dolphin	Positive	4	-33.3315	133.9088	South-North	500	On	Left	270	40	0.32
4	21	30/07/2013	11:00:30	Common Dolphin	Positive	13	-33.2855	133.9272	South-North	500	On	Right	90	32	0.43
4	22	30/07/2013	11:06:30	Common Dolphin	Positive	13	-33.2135	133.9238	South-North	500	On	Left	270	45	0.27
5	23	30/07/2013	8:28:43	Bottlenose Dolphin	Positive	2	-32.6518	134.0810	North-South	500	On	Right	270	40	0.32
5	24	30/07/2013	8:47:51	Common Dolphin	Positive	4	-33.1917	134.0390	North-South	500	On	Right	270	45	0.27
5	25	30/07/2013	8:55:31	Common Dolphin	Positive	10	-33.2405	134.0480	North-South	500	On	Left	90	33	0.42
5	26	30/07/2013	9:13:32	Common Dolphin	Uncertain	1	-33.5561	133.9983	North-South	500	On	Right	270	40	0.32
5	27	30/07/2013	9:28:58	Common Dolphin	Uncertain	2	-33.9876	133.9612	North-South	500	On	Left	90	45	0.27
5	28	30/07/2013	9:30:04	Common Dolphin	Uncertain	7	-34.0195	133.9601	North-South	500	On	Left	90	40	0.32
5	29	30/07/2013	9:47:52	Common Dolphin	Uncertain	3	-34.4469	134.0433	North-South	500	On	Right	270	48	0.24
6	30	06/08/2013	12:38:49	Bottlenose Dolphin	Positive	3	-32.5763	134.2601	North-South	500	On	Left	90	40	0.32
6	31	06/08/2013	12:39:38	Bottlenose Dolphin	Positive	6	-32.5763	134.2474	North-South	500	On	Right	270	40	0.32

6	32	06/08/2013	13:01:40	Common Dolphin	Positive	12	-33.2195	134.2497	North-South	500	On	Left	90	50	0.23
6	33	06/08/2013	13:16:51	Common Dolphin	Positive	12	-33.2418	134.2501	North-South	500	On	Left	90	20	0.74
6	34	06/08/2013	13:17:32	Common Dolphin	Positive	3	-33.2608	134.2446	North-South	500	On	Left	90	45	0.27
6	35	06/08/2013	13:24:06	Common Dolphin	Positive	5	-33.4456	134.2490	North-South	500	On	Left	90	42	0.30
6	36	06/08/2013	13:24:35	Common Dolphin	Positive	6	-33.4591	134.2365	North-South	500	On	Right	270	35	0.39
6	37	06/08/2013	13:26:06	Common Dolphin	Positive	13	-33.5018	134.2337	North-South	500	On	Right	270	27	0.53
6	38	06/08/2013	13:32:52	Common Dolphin	Positive	12	-33.5442	134.2494	North-South	500	On	Left	90	35	0.39
6	39	06/08/2013	13:39:49	Common Dolphin	Positive	2	-33.5442	134.2372	North-South	500	On	Right	270	50	0.23
7	40	06/08/2013	15:04:45	Common Dolphin	Positive	4	-33.3046	134.3935	South-North	500	On	Left	270	35	0.39
7	41	06/08/2013	15:04:45	Common Dolphin	Positive	3	-33.3046	134.3935	South-North	500	On	Left	270	35	0.39
7	42	06/08/2013	15:04:45	Common Dolphin	Positive	6	-33.3046	134.3935	South-North	500	On	Left	270	35	0.39
7	43	06/08/2013	15:09:03	Common Dolphin	Positive	3	-33.3046	134.4113	South-North	500	On	Right	90	28	0.51
7	44	06/08/2013	15:09:08	Common Dolphin	Positive	3	-33.2755	134.4028	South-North	500	On	Right	90	32	0.43
7	45	06/08/2013	15:09:30	Common Dolphin	Positive	3	-33.2649	134.4026	South-North	500	On	Right	90	32	0.43
7	46	06/08/2013	15:10:08	Common Dolphin	Positive	14	-33.2464	134.3904	South-North	500	On	Left	270	48	0.24
7	47	06/08/2013	15:11:02	Common Dolphin	Positive	4	-33.2201	134.4100	South-North	500	On	Right	90	20	0.74
7	48	06/08/2013	15:11:28	Common Dolphin	Positive	4	-33.2076	134.4028	South-North	500	On	Right	90	36	0.37
7	49	06/08/2013	15:11:28	Common Dolphin	Positive	6	-33.2201	134.3851	South-North	500	On	Left	270	28	0.51
8	50	23/07/2013	11:12:42	Common Dolphin	Positive	12	-34.2807	134.5457	South-North	500	On	Left	270	31	0.45
8	51	23/07/2013	11:19:57	Common Dolphin	Positive	55	-34.2061	134.5598	South-North	500	On	Right	90	27	0.53

8	52	23/07/2013	11:19:57	Humpback Whale	Positive	1	-34.2061	134.5598	South-North	500	On	Right	90	27	0.53
8	53	23/07/2013	11:33:45	Common Dolphin	Positive	35	-34.1182	134.5499	South-North	500	On	Left	270	56	0.18
8	54	23/07/2013	11:38:14	Southern Right Whale	Positive	3	-34.0881	134.5185	South-North	500	On	Left	270	10	1.53
8	55	23/07/2013	11:38:14	Common Dolphin	Positive	35	-34.0881	134.5185	South-North	500	On	Left	270	10	1.53
8	56	23/07/2013	11:49:18	Common Dolphin	Positive	10	-34.0363	134.5398	South-North	500	On	Left	270	30	0.47
8	57	23/07/2013	12:06:05	Common Dolphin	Positive	10	-33.6172	134.5496	South-North	500	On	Left	270	40	0.32
8	58	23/07/2013	12:11:26	Common Dolphin	Positive	10	-33.6020	134.5529	South-North	500	On	Left	270	34	0.40
8	59	23/07/2013	12:19:45	Common Dolphin	Positive	12	-33.3663	134.5896	South-North	500	On	Right	90	10	1.53
9	60	23/07/2013	12:51:32	Common Dolphin	Positive	20	-33.6142	134.7233	North-South	500	On	Right	270	35	0.39
9	61	23/07/2013	13:02:23	Common Dolphin	Positive	22	-33.8148	134.7435	North-South	500	On	Left	90	20	0.74
9	62	23/07/2013	13:08:22	Common Dolphin	Positive	2	-33.8626	134.7478	North-South	500	On	Left	90	26	0.55
9	63	23/07/2013	13:27:48	Common Dolphin	Positive	15	-34.3810	134.7097	North-South	500	On	Right	270	20	0.74
9	64	23/07/2013	13:32:21	Common Dolphin	Positive	15	-34.3937	134.7142	North-South	500	On	Right	270	27	0.53
9	65	23/07/2013	13:33:02	Common Dolphin	Positive	4	-34.4139	134.7333	North-South	500	On	Left	90	30	0.47
9	66	23/07/2013	13:35:41	Common Dolphin	Positive	3	-34.4916	134.7291	North-South	500	On	Left	90	43	0.29
10	67	23/07/2013	15:29:54	Common Dolphin	Positive	1	-34.7976	134.8838	North-South	500	On	Right	270	47	0.25
10	68	23/07/2013	15:30:32	Common Dolphin	Positive	2	-34.7794	134.8793	North-South	500	On	Right	270	28	0.51
10	69	23/07/2013	15:53:01	Common Dolphin	Positive	18	-34.1228	134.8734	North-South	500	On	Right	270	24	0.61
10	70	23/07/2013	15:58:37	Common Dolphin	Positive	12	-34.0897	134.8722	North-South	500	On	Right	270	30	0.47
10	71	23/07/2013	16:01:12	Common Dolphin	Positive	16	-34.0110	134.8799	North-South	500	On	Right	270	30	0.47

10	72	23/07/2013	16:07:05	Common Dolphin	Positive	2	-33.9783	134.8924	North-South	500	On	Left	90	49	0.23
11	73	23/07/2013	16:32:29	Common Dolphin	Positive	16	-33.9812	135.0612	North-South	500	On	Left	90	25	0.58
11	74	23/07/2013	16:39:20	Common Dolphin	Positive	18	-34.0369	135.0555	North-South	500	On	Left	90	40	0.32
11	75	23/07/2013	16:44:13	Common Dolphin	Positive	20	-34.1176	135.0565	North-South	500	On	Left	90	40	0.32
11	76	23/07/2013	17:11:50	Common Dolphin	Uncertain	0	-34.7519	135.0631	North-South	500	On	Left	90	29	0.49
12	77	23/07/2013	8:48:47	Bottlenose Dolphin	Positive	20	-34.2526	135.2019	South-North	500	On	Left	270	35	0.39
12	78	23/07/2013	9:05:27	Common Dolphin	Positive	5	-33.9986	135.2488	South-North	500	On	Right	90	8	1.92
1nm shore	79	24/07/2013	14:29:12	Common Dolphin	Uncertain	2	-33.8998	135.1790	SE-NW	1000	On	Left		50	
1nm shore	80	24/07/2013	14:42:23	Dolphin	Positive	4	-33.8503	135.1295	SE-NW	1000	On	Left		40	
1nm shore	81	24/07/2013	14:52:52	Dolphin	Positive	8	-33.6531	134.8664	SE-NW	1000	On	Left		35	
1nm shore	82	24/07/2013	15:16:43	Bottlenose Dolphin	Positive	26	-33.2523	134.6719	SE-NW	1000	On	Left		35	
1nm shore	83	24/07/2013	15:59:31	Bottlenose Dolphin	Positive	10	-32.9030	134.0789	SE-NW	1000	On	Right		37	
1nm shore	84	24/07/2013	16:24:45	Bottlenose Dolphin	Positive	2	-32.6445	134.2670	SE-NW	1000	On	Right		32	
1nm shore	85	24/07/2013	16:30:38	Bottlenose Dolphin	Positive	6	-32.5043	134.1834	SE-NW	1000	On	Left		41	
1nm shore	86	24/07/2013	16:43:48	Bottlenose Dolphin	Positive	25	-32.5050	133.9314	SE-NW	1000	On	Right		35	
40m depth	87	07/08/2013	13:31:05	Bottlenose Dolphin	Uncertain	-	-32.1111	133.5995	NW-SE	1000	Off	Left		35	
40m depth	88	07/08/2013	13:35:00	Bottlenose Dolphin	Uncertain	-	-32.1736	133.5019	NW-SE	1000	Off	Right		40	
40m depth	89	07/08/2013	13:47:16	Common Dolphin	Positive	16	-32.3822	133.6077	NW-SE	1000	On	Right		38	
40m depth	90	07/08/2013	14:01:16	Common Dolphin	Positive	15	-32.4770	133.7847	NW-SE	1000	On	Right		28	
40m depth	91	07/08/2013	14:01:16	Humpback Whale	Positive	2	-32.4770	133.7847	NW-SE	1000	On	Right			

40m depth	92	07/08/2013	14:01:16	Common Dolphin	Positive	13	-32.4770	133.7847	NW-SE	1000	On	Right	
40m depth	93	07/08/2013	14:24:48	Common Dolphin	Positive	2	-32.7439	133.9254	NW-SE	1000	On	Right	30
40m depth	94	07/08/2013	14:33:40	Common Dolphin	Positive	3	-32.7751	134.0131	NW-SE	1000	On	Right	38
40m depth	95	07/08/2013	15:01:02	Common Dolphin	Positive	3	-33.1703	134.2363	NW-SE	1000	On	Right	47
40m depth	96	07/08/2013	15:01:27	Common Dolphin	Positive	6	-33.1785	134.2459	NW-SE	1000	On	Right	50
40m depth	97	07/08/2013	15:01:02	Common Dolphin	Positive	4	-33.1703	134.2363	NW-SE	1000	On	Left	55
40m depth	98	07/08/2013	15:10:38	Common Dolphin	Positive	1	-33.2114	134.5319	NW-SE	1000	On	Right	49
40m depth	99	07/08/2013	15:21:18	Common Dolphin	Positive	4	-33.2769	134.6856	NW-SE	1000	On	Right	44
40m depth	100	07/08/2013	15:38:04	Common Dolphin	Positive	6	-33.6464	134.6825	NW-SE	1000	On	Left	36
40m depth	101	07/08/2013	15:38:04	Southern Right Whale	Positive	2	-33.6464	134.6825	NW-SE	1000	On		
40m depth	102	07/08/2013	15:57:11	Common Dolphin	Positive	6	-33.6855	134.8780	NW-SE	1000	On	Right	30
off trans	103	30/07/2013	8:11:49	Bottlenose Dolphin	Positive	2	-32.6885	134.2225			Off	Left	55
off trans	104	30/07/2013	8:12:50	Bottlenose Dolphin	Positive	2	-32.6527	134.2035			Off	Right	50
off trans	105	30/07/2013	8:13:28	Bottlenose Dolphin	Positive	1	-32.6323	134.1900			Off	Left	53

Appendix 2 List of species that potentially occur in the surveyed region - shelf and coastal waters between Ceduna and Coffin Bay in the Eastern Great Australian Bight, South Australia. The list of species is based on cetacean captures, strandings and mortalities in South Australia between 1881 and 2000; adopted from Kemper et al. (2005). Species that are underlined were detected during this study. For the minke whale sighting, it could not be determined if the animal was an Antarctic or dwarf minke whale.

COMMON NAME	SCIENTIFIC NAME
Dolphins and porpoises	
Spectacled porpoise	*Phocoena dioptrica*
<u>Bottlenose dolphin</u>	<u>*Tursiops* spp</u>.
<u>Short-beaked common dolphin</u>	<u>*Delphinus delphis*</u>
Small whales	
Strap-toothed whale	*Mesoplodon layardii*
Long-finned pilot whale	*Globicephala melas*
Pygmy sperm whale	*Kogia breviceps*
Pygmy right whale	*Caperea marginata*
<u>Antarctic minke whale</u>	<u>*Balaenoptera bonaerensis*</u>
Short-finned pilot whale	*Globicephala macrorhynchus*
Gray's beaked whale	*Mesoplodon grayi*
Southern bottlenose whale	*Hyperoodon planifrons*
Risso's dolphin	*Grampus griseus*
Dwarf sperm whale	*Kogia sima*
Killer whale	*Orcinus orca*
False killer whale	*Pseudorca crassidens*
Andrews' beaked whale	*Mesoplodon bowdoini*
Cuvier's beaked whale	*Ziphius cavirostris*
Arnoux's beaked whale	*Berardius arnuxii*
Hector's beaked whale	*Mesoplodon hectori*

Shepherd’s beaked whale	*Tasmacetus shepherdi*
Dwarf minke whale	*Balaenoptera acutorostrata*
Large whales	
Sperm whale	*Physeter macrocephalus*
Bryde’s whale	*Balaenoptera edeni*
Blue whale	*Balaenoptera musculus*
Southern right whale	*Eubalaena australis*
Humpback whale	*Megaptera novaeangliae*
Fin whale	*Balaenoptera physalus*

Appendix 3 Summary statistics of the Conventional Distance Sampling (CDS) and Multiple Covariate Distance Sampling (MCDS) analyses in DISTANCE. Successful analyses without log message warnings are highlighted in grey, and of those the model(s) with lowest AIC (best fit models) are marked with a black frame. AIC=Aikaike Information Criterion; ESW= Effective Strip Width; EDR=Effective Detection Radius; D=Density; LCL=Lower Confidence Level; UCL=Upper Confidence Level; N=Abundance Estimate; CV=Coefficient of Variance; df=degrees of freedom.

CDS

Key Function_Adjustement Tem_Truncation	Delta AIC	AIC	ESW/EDR	D	95% Confidence Interval		%CV	N	%CV	df	95% Confidence Interval		Log Messages
CDS_Hn_Cos_LT130_RT420	566.26	572.26	147.36	0.66	0.36	1.22	0.31	19735	31.15	64.56	10747	36241	CM
CDS_Un_Cos_LT130_RT420	564.62	570.62	129.93	0.72	0.41	1.25	0.28	21366	28.40	52.65	12221	37356	√
CDS_Hn_HP_LT130_RT420	566.26	572.26	147.36	0.66	0.36	1.22	0.31	19735	31.15	64.56	10747	36241	VHC
CDS_Hr_SP_LT130_RT420	567.43	573.43	182.28	0.63	0.32	1.24	0.35	18924	34.66	72.17	9670	37035	CM

MCDS

Key Function_Adjustement Tem_Truncation	Delta AIC	AIC	ESW/EDR	D	95% Confidence Interval		%CV	N	%CV	df	95% Confidence Interval		Log Messages
MCDS_Hn_Cos_LT130_RT420	566.26	572.26	147.36	0.66	0.36	1.22	0.31	19735	31.15	64.56	10747	36241	√
MCDS_Hn_SP_LT130_RT420	566.26	572.26	147.36	0.66	0.36	1.22	0.31	19735	31.15	64.56	10747	36241	√
MCDS_Hn_HP_LT130_RT420	566.26	572.26	147.36	0.66	0.36	1.22	0.31	19735	31.15	64.56	10747	36241	√
MCDS_Hr_Cos_LT130_RT420	567.43	573.43	182.28	0.63	0.32	1.24	0.35	18924	34.66	72.17	9670	37035	√

MCDS_Hr_SP_LT130_RT420	567.43	573.43	182.28	0.63	0.32	1.24	0.35	18924	34.66	72.17	9670	37035	√
MCDS_Hr_HP_LT130_RT420	567.43	573.43	182.28	0.63	0.32	1.24	0.35	18924	34.66	72.17	9670	37035	√
MCDS_Hn_Cos_LT130_RT420_CovariateBF	2.00	8.00	25.18	4.80	0.03	674.06	20.51	--	--	--	--	--	CF
MCDS_Hn_Cos_LT130_RT420_CovariateCloudCover	8.00	14.00	130.97	0.61	0.26	1.43	0.45	18078	45.06	66.14	7662	42650	CF
MCDS_Hn_Cos_LT130_RT420_CovariateGlare	0.00	6.00	162.83	0.61	0.37	1.02	0.26	18217	25.83	39.31	10897	30454	CF
MCDS_Hn_Cos_LT130_RT420_CovariateClusterSize	566.49	572.49	139.94	0.74	0.00	0.00	0.00	22032	--	--	--	--	B, VHC, CF
MCDS_Hn_SP_LT130_RT420_CovariateBF	2.00	8.00	25.18	4.80	0.03	674.06	20.51	--	--	--	--	--	CF
MCDS_Hn_SP_LT130_RT420_CovariateCloudCover	8.00	14.00	130.97	0.61	0.26	1.43	0.45	18078	45.06	66.14	7662	42650	CF
MCDS_Hn_SP_LT130_RT420_CovariateGlare	0.00	6.00	162.83	0.61	0.37	1.02	0.26	18217	25.83	39.31	10897	30454	CF
MCDS_Hn_SP_LT130_RT420_CovariateClusterSize	566.49	572.49	139.94	0.74	0.00	0.00	0.00	22032	--	--	--	--	B, VHC, CF
MCDS_Hn_HP_LT130_RT420_CovariateBF	2.00	8.00	25.18	4.80	0.03	674.06	20.51	--	--	--	--	--	CF
MCDS_Hn_HP_LT130_RT420_CovariateCloudCover	8.00	14.00	130.97	0.61	0.26	1.43	0.45	18078	45.06	66.14	7662	42650	CF
MCDS_Hn_HP_LT130_RT420_CovariateGlare	0.00	6.00	162.83	0.61	0.37	1.02	0.26	18217	25.83	39.31	10897	30454	CF
MCDS_Hn_HP_LT130_RT420_CovariateClusterSize	566.49	572.49	139.94	0.74	0.00	0.00	0.00	22032	--	--	--	--	B, VHC, CF
MCDS_Hr_Cos_LT130_RT420_CovariateBF	4.00	10.00	92.08	1.40	0.02	117.89	11.29	41664	--	--	--	--	CF
MCDS_Hr_Cos_LT130_RT420_CovariateCloudCover	10.00	16.00	178.24	0.58	0.33	1.03	0.29	17337	29.39	54.86	9738	30865	CF
MCDS_Hr_Cos_LT130_RT420_CovariateGlare	2.00	8.00	190.32	0.62	0.33	1.16	0.32	18515	32.02	65.51	9921	34551	CF
MCDS_Hr_Cos_LT130_RT420_CovariateClusterSize	569.21	575.21	189.76	0.66	0.00	0.00	0.00	19730	--	--	--	--	B, CF

MCDS_Hr_SP_LT130_RT420_CovariateBF	4.00	10.00	92.08	1.40	0.02	117.89	11.29	41664	--	--	--	--	CF
MCDS_Hr_SP_LT130_RT420_CovariateCloudCover	10.00	16.00	178.24	0.58	0.33	1.03	0.29	17337	29.39	54.86	9738	30865	CF
MCDS_Hr_SP_LT130_RT420_CovariateGlare	2.00	8.00	190.32	0.62	0.33	1.16	0.32	18515	32.02	65.51	9921	34551	CF
MCDS_Hr_SP_LT130_RT420_CovariateClusterSize	569.21	575.21	189.76	0.66	0.00	0.00	0.00	19730	--	--	--	--	B, CF
MCDS_Hr_HP_LT130_RT420_CovariateBF	4.00	10.00	92.08	1.40	0.02	117.89	11.29	41664	--	--	--	--	CF
MCDS_Hr_HP_LT130_RT420_CovariateCloudCover	10.00	16.00	178.24	0.58	0.33	1.03	0.29	17337	29.39	54.86	9738	30865	CF
MCDS_Hr_HP_LT130_RT420_CovariateGlare	2.00	8.00	190.32	0.62	0.33	1.16	0.32	18515	32.02	65.51	9921	34551	CF
MCDS_Hr_HP_LT130_RT420_CovariateClusterSize	569.21	575.21	189.76	0.66	0.00	0.00	0.00	19730	--	--	--	--	B, VHC, CF

Log Messages:

√ = Successful analysis (no log message warnings)

CM = Parameters are being constrained to obtain monotonicity

VHC = Some parameters are very highly correlated

CF = Convergence Failure

B = Abundance estimate via Bootstrap

bp

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