GREAT AUSTRALIAN BIGHT RESEARCH PROGRAM

RESEARCH REPORT SERIES

Status, distribution and abundance of iconic species and apex predators in the Great Australian Bight

Final Report GABRP Project 4.1

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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 environmental, economic and social values of the region; providing an information source for all to use.

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1. EXECUTIVE SUMMARY

Theme 4 of the Great Australian Bight (GAB) Research Program, the *Ecology of Iconic Species and Apex Predators* contains three projects. Project 4.1 *Status, distribution, and abundance of iconic species and apex predators in the GAB*, explicitly addressed the paucity of baseline information on iconic and apex predator species' distributions, status and trends in abundance, which was identified as a key knowledge gap for the GAB region. Such information is critical to understanding the importance of the region in terms of the diversity, distribution and biomass of iconic and apex predator species, and to provide essential baseline information to assist in their management.

The project undertook a series of targeted, multidisciplinary surveys to assess the status, distribution and abundance of key iconic and apex predator species in the GAB region. These included aerial surveys to assess the occurrence and distribution of dolphins and other cetaceans using inshore habitats; offshore ship-based acoustic and visual surveys to assess the occurrence and distribution of baleen and toothed whales in offshore shelf, shelf-break and slope habitats; offshore pelagic long-line-based surveys incorporating satellite telemetry to characterise the spatial and temporal distribution and habitat use of pelagic sharks; and ground and aerial surveys on off-shore islands to assess the status and trends in abundance of pinniped and some seabird breeding populations.

Inshore cetacean aerial surveys identified five species of cetaceans, including southern right whale, humpback whale, minke whale, short-beaked common dolphin, and bottlenose dolphin. Short-beaked common dolphins were particularly abundant and estimated to number 20,000 – 22,000 individuals (0.67 – 0.73 dolphins/km^2) in coastal waters between Ceduna and Coffin Bay, indicating that shelf waters of the eastern GAB represent important habitat for this species.

There were 58 cetacean sightings recorded during three offshore aerial surveys in the eastern and central GAB. Eight cetacean species were identified, including pygmy blue whale, fin whale, sperm whale, pilot whale, killer whale, Risso's dolphin, short-beaked common dolphin, common or offshore bottlenose dolphins, and a probable beaked whale. Although blue whales were not sighted in the eastern GAB or south of Kangaroo Island, they were sighted along the Bonney Coast between Robe and Portland.

The offshore visual and acoustic survey encompassed an area of the eastern GAB that had not previously been systematically surveyed for cetaceans. Acoustic surveys detected 15 discrete acoustic events of odontocete (toothed whale) vocalisations. Sperm whales were acoustically detected on four occasions comprising a total of nine individuals in water depths between 500 and 2000 m. Visual surveys recorded three sperm whales, one group of 100-150 pilot whales, and a beaked whale. Maximum entropy modelling was used to predict suitable sperm whale habitat in the GAB region using presence only data.

The offshore pelagic shark survey used a combination of pelagic long-line and satellite telemetry methods, with seven long-line sets undertaken over a 15-day period between the du Couedic Canyon, south-west of Kangaroo Island, and the continental shelf-break area south of Head of Bight. Five pelagic and oceanic shark species were recorded, including blue sharks, shortfin makos, common thresher, bigeye thresher and school sharks. White sharks were encountered at the Neptune Islands. Fourteen satellite tags were deployed on four shark species: blue shark (7), shortfin mako (1), white shark (5) and a single bigeye thresher. Analyses of movement data indicated that although species traversed widely,

all had significant focal areas in the GAB, and there was evidence of species-specific preference for different habitats and depth ranges. The occurrence of the predominantly subtropical and tropical species, the bigeye thresher in the GAB, and its subsequent migration through the south-east Indian Ocean to tropical waters off Exmouth, Western Australia was a significant new scientific discovery.

The project compiled the most comprehensive synthesis of recent and historic surveys of pinniped pup abundance in the GAB region. The study highlighted that the GAB region is very important for Australia's pinniped biodiversity, containing an estimated 93% and 98% of its Australian sea lion and long-nosed fur seal populations. The study identified that while populations of both long-nosed and Australian fur seals have largely recovered following colonial sealing, populations of the threatened Australian sea lion are smaller than previously estimated and presently undergoing a rapid decline. Across the GAB region, the rate of decline was estimated to be 2.8% per year, equivalent to a 76% decline over three generations (~38 years), meeting the IUCN criteria for 'Endangered' (>50% and <80% decline over three generations). Of significant concern is the finding that almost 40% of individual breeding sites assessed in the GAB region meet the 'Critically endangered' IUCN criteria (>80% decline over three generations).

The project collected abundance data on three key seabird species at some of their offshore island breeding sites. The focal species included seabirds from three distinct foraging guilds: crested terns (resident surface plunge divers); little penguins (resident non-flying diving seabirds); and flesh-footed shearwater (highly migratory near surface forager). Crested tern breeding colonies were surveyed using aerial photography during the nesting period, the study providing the first abundance estimates for some breeding sites. Little penguins were surveyed at two important breeding sites off the western Eyre Peninsula (Olive and Pearson Island) using a combination of burrow transects, census plots and direct burrow counts. Comparison of results from earlier surveys suggests a potential decline of 80% and 66% at Olive and Pearson Islands, respectively since 2004. Flesh-footed shearwaters were surveyed using burrow transects and direct burrow counts at their only known breeding sites in the eastern GAB. The surveys estimated 928 and 5,785 breeding pairs at Lewis and Smith Islands, respectively, representing the first quantitative surveys for this species in South Australia.

This project presents the most comprehensive synthesis to date of the status, distribution and abundances of iconic and apex predator species in the GAB region. Its findings support previous assessments identifying the GAB region as potentially supporting the greatest diversity, density and biomass of marine predators in coastal Australian waters,. However, basic information for many of the key species in the region is still rudimentary, especially for cetaceans, seabirds and sharks. The scale, remoteness and logistic challenges in accessing the regions offshore islands, shelf, slope and oceanic habitats, has greatly limited the development of this basic knowledge. The paucity of key baseline data presents a major challenge for the management of the region, especially for species that are matters of national environmental significance (threatened, endangered or migratory species), where there are greater requirements to manage and mitigate potential risks from human activities and impacts. The project has identified knowledge gaps and research priorities, which if addressed, would significantly enhance management of these key species, their habitats on which they ultimately depend and on the broader GAB region itself.

2. INTRODUCTION

The Great Australian Bight (GAB) region is a geographically expansive coastal, continental shelf and oceanic bio-region located between Cape Pasley, Western Australia and Cape Otway, Victoria off southern Australia. Pelagic ecosystems in the region support important regional economies and fisheries, and can be defined as the Bonney Upwelling Region between Cape Otway and Cape Jaffa, the Lacepede Shelf between Cape Jaffa and Cape Gantheaume, Kangaroo Island, eastern Great Australian Bight between Cape du Couedic, Kangaroo Island and Cape Adieu, and central and western Great Australian Bight between Cape Adieu and Cape Pasley, near Esperance. A new focus on petroleum exploration in the GAB recently included the granting of several exploration leases, and a program of seismic surveys and planned drilling of exploration wells to assess these leases for commercial quantities of hydrocarbons. This formed the impetus for development of the Great Australian Bight Research Program, which incorporated a series of ecological surveys to assess the biodiversity, distribution and habitat use by threatened, endangered and protected marine predator species in this globally unique temperate marine ecosystem.

Complex interactions between physical and biological processes in the GAB support a marine ecosystem that is inhabited by populations of marine predators with high global conservation significance and economic value to local communities. Oceanographic and physical features that support pelagic productivity in these ecosystems include fronts that form between coastal water masses and the in-flowing tropical Leeuwin Current warm water masses originating on the shallow shelves (McClatchie *et al.* 2006), and seasonal up-welling and down-welling in the coastal, shelf, and shelf slope habitats (Middleton and Cirano 2002; Kämpf *et al.* 2004; Kämpf 2007; Middleton and Bye 2007; van Ruth *et al.* 2010). The importance of these features to pelagic and mesopelagic biodiversity, and their role in supporting fauna that comprise the deep scattering layer (DSL) in Australian shelf and oceanic waters is poorly understood, as are the drivers of spatial, seasonal and diurnal variation in productivity within these ecosystems. These factors were explored in other research themes of the Great Australian Bight Research Program. Benthic biodiversity in the du Couedic and the Bonney Canyons was examined by Currie *et al.* (2012) and Currie and Sorokin (2014). These authors determined that these features represented separate bio-regions where community structure varied with depth; highest diversities were observed at the canyon heads. In combination, these oceanographic and physical features are considered important in underpinning high densities of large iconic or apex predators (Goldsworthy *et al.* 2013).

Iconic species is a term applied to species of marine mega-fauna that have inherent societal importance as their existence is highly valued (e.g., southern bluefin tuna (*Thunnus maccoyii*), white shark (*Carcharodon carcharias*), dolphins and whales). The term apex predator describes species with few or no predators that occupy the highest trophic levels. These species play an important role in ecosystem function and have ecological significance independent of their iconic status. Although some research has been conducted on individual species within the greater GAB region, for many of the iconic species and apex predators, basic information on distribution, abundance and status is limited (Rogers *et al.* 2013).

All cetacean species (whales, dolphins and porpoises) are protected in Australian waters under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Marine Bioregional Plans have been developed to support strategic informed decision making in relation to Commonwealth marine areas and the application of the EPBC Act to protect marine biodiversity and promote the

sustainable use of the marine environment. These plans identify conservation values of the marine bioregion which include species and places protected under the EPBC Act and key ecological features. There is a network of Commonwealth Marine Reserves within these marine bioregions, and in the Great Australian Bight (GAB) these include the Bremer Commonwealth Marine Reserve in the west, the GAB Commonwealth Marine Reserve in the central GAB, and the Western and Southern Kangaroo Island Commonwealth Marine Reserves, and the Murray Commonwealth Marine Reserve in the East. These reserves are considered important foraging and or migration areas for a number of cetacean species, including blue (*Balaneoptera musculus*), humpback (*Megaptera novaeangliae*), sei (*Balaenoptera borealis*), fin (*Balaenoptera physlaus*), sperm (*Physeter macrocephalus*) and killer whales (*Orcinus orca*), and the GAB Commonwealth Marine Reserve encompasses important calving and nursing grounds for southern right whales (*Eubalaena australis*). In the GAB, localised areas of high productivity that may be important feeding habitat for whales have been identified in the Albany Canyon group, the Kangaroo Island canyons and adjacent shelf-break, and the Kangaroo Island Pool.

The South-west Marine Bioregional Plan encompasses Commonwealth waters of the western GAB to the eastern end of Kangaroo Island, South Australia (DSEWPaC 2012b). For this region, four species of cetacean are listed in the species report card, based on available information that supports the identification of biologically important behaviours such as calving, migration and foraging. The three species most relevant to the GAB area of the South-west Marine Region are the blue whale, most likely the pygmy blue whale (*Balaenoptera musculus brevicauda*), southern right whale and sperm whale (DSEWPaC 2012c). While there is currently no Marine Bioregional plan for the south-east region, a regional profile has been compiled which summarises key ecological features and regionally significant species (DoE 2015b). The south-east region encompasses Commonwealth waters of the GAB east of Kangaroo Island, and includes the Bonney Coast Upwelling, an area of seasonal upwelling associated with high primary productivity (e.g. Kämpf *et al.* 2004) that supports high densities of apex predators (Goldsworthy *et al.* 2013). However, there are limited to no data on the temporal and spatial distribution and abundance of most cetacean species in the central GAB and information is particularly lacking for odontocetes in slope and off-shelf waters. To date, 32 cetacean species have been recorded in the GAB region (Table 1; Groom and Coughran 2012; Groom *et al.* 2014; Gill *et al.* 2015; Segawa and Kemper 2015), however, for most of these species, information on occurrence in the GAB is limited to strandings or opportunistic sightings data.

The GAB region also contains most of Australia's breeding and haul-out sites for the Australian sea lion (*Neophoca cinerea*) and long-nosed fur seal (*Arctocephalus forsteri*), as well as establishing populations of the Australian fur seal (*Arctocephalus pusillus doriferus*) (Shaughnessy *et al.* 2010, 2011, 2015). The area supports a large number of seabird species including several shearwater species (*Puffinus* and *Ardenna* spp.), little penguins (*Eudyptula minor*), terns (*Sterna* spp.), several storm petrels, gannets and albatrosses (Copley 1996; Einoder and Goldsworthy 2005; Einoder *et al.* 2011). The region also supports large numbers of large pelagic teleost and shark species, including southern bluefin tuna, white sharks and shortfin mako (*Isurus oxyrinchus*) (Bruce *et al.* 2006; Bestley *et al.* 2008, 2009; Patterson *et al.* 2008; Rogers *et al.* 2015a; Rogers and Bailleul 2015). Although some research has been conducted on individual species within the GAB, for many the basic information on their status, abundance and distribution is limited (Rogers *et al.* 2013).

Table 1. List of cetacean species recorded to occur in the Great Australian Bight from stranding or sighting records. Sources are: a= Segawa and Kemper 2015, b = Groom and Coughran 2012, c= Coughran *et al.* 2014, d= Gill *et al.* 2015.

Common name	Scientific name	Stranding	Sighting
Dwarf minke whale	*Balaenoptera acutorostrata*	a	d
Antarctic minke whale	*B. bonaerensis*	a	d
Sei Whale	*B.borealis*		d
Bryde’s whale	*B. edeni*	a	
Blue whale	*B. musculus*	a	
Pygmy blue whale	*B. musculus brevicauda*		d
Omura's whale	*B. omurai*	a	
Fin whale	*Balaenoptera physalus*	a	d
Arnoux’s beaked whale	*Berardius arnuxii*	a,c	
Pygmy right whale	*Caperea marginata*	a	d
Southern right whale	*Eubalaena australis*	a	d
Short-beaked common dolphin	*Delphinus delphis*	a	d
Pygmy killer whale	*Feresa attenuata*	a	d
Short-finned pilot whale	*Globicephala macrorhynchus*	a	
Long-finned pilot whale	*G. melas*	a	d
Risso’s dolphin	*Grampus griseus*	a	
Southern bottlenose whale	*Hyperoodon planifrons*	a	d
Pygmy sperm whale	*Kogia breviceps*	a	
Dwarf sperm whale	*K. sima*	a	
Humpback whale	*Megaptera novaeangliae*	a,b	d
Andrews’ beaked whale	*Mesoplodon bowdoini*	a	
Gray’s beaked whale	*M. grayi*	a,c	
Hector’s beaked whale	*M. hectori*	a,b,c	
Strap-toothed whale	*M. layardii*	a,b,c	
True's beaked whale	*M. mirus*	c	
Killer whale	*Orcinus orca*	a	d
Melon headed whale	*Peponocephala electra*	b	
Spectacled porpoise	*Phocoena dioptrica*	a	
Sperm whale	*Physeter macrocephalus*	a,b	d
False killer whale	*Pseudorca crassidens*	a	
Shepherd’s beaked whale	*Tasmacetus shepherdi*	a	d
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	a	
Common bottlenose dolphin	*T. truncatus*	a	
Cuvier’s beaked whale	*Ziphius cavirostris*	a,c	
Southern right whale dolphin	*Lissodeplhis peronii*	a	d

3. BACKGROUND AND NEED

Given the limited information on many iconic and apex predator species in the GAB, surveys of their distribution, abundance, and biodiversity in the region were needed. This knowledge is particularly important when assessing overlaps between marine industry activities, and threatened, protected and listed migratory species. For example, the southern right whale, blue whale, Australian sea lion and white shark are currently listed as endangered or threatened under the *EPBC Act (1999),* and actions towards a better understanding of their distribution and population dynamics are required under their respective Recovery Plans. Moreover, the development of effective management measures to manage risks of potential impacts to threatened and protected species relies strongly on robust baseline data. Information on the distribution and relative abundance of marine predators in the GAB will also be critical to informing future ecological risk assessment processes. Species were selected for this project based on a combination of factors, including their predicted ecological importance in the GAB region, the significance of GAB subpopulations to species persistence, and their conservation and management status (Rogers *et al.* 2013).

Theme 4 of the Great Australian Bight Research Program, *Ecology of Iconic Species and Apex Predators,* addresses scientific knowledge gaps by providing information on the distribution and abundance of iconic and apex predator species in the GAB (Rogers *et al.* 2013). Cetacean sighting data and satellite telemetry data collected during Project 4.1 will be included in subsequent multi-species analyses within Project 4.2 to identify shared habitats for apex predators in the GAB.

4. OBJECTIVES

Project 4.1 aims to provide background information on the relative distributions and abundances of key iconic and apex predator species in the GAB. It has four main tasks including:

i) assessing the occurrence and distribution of southern right whales and other cetaceans using inshore habitats of the GAB;
ii) assessing the occurrence and distribution of pygmy blue whales and other cetaceans using offshore habitats of the GAB;
iii) characterising the spatial and temporal distribution of pelagic sharks and large teleosts in the GAB; and
iv) obtaining abundance indices of key pinniped and seabird populations in the GAB.

Reporting of objectives is broken down into six key components/reporting sections:

Section 5. Inshore aerial cetacean surveys
Section 6. Offshore aerial cetacean surveys
Section 7. Offshore acoustic and visual cetacean surveys
Section 8. Offshore pelagic shark surveys
Section 9. Status and trends in abundance of pinnipeds
Section 10. Survey of selected seabird breeding colonies

Survey data on the offshore distribution of whales, and satellite tracking movement data of sharks, collected as part of this project will also be analysed and incorporated into the multispecies analyses of

Project 4.2, *Identifying Areas of Ecological Significance for iconic species and apex predators in the Great Australian Bight*. Pinniped abundance data will also be incorporated in analyses of Project 4.2, and all the abundance and distribution data collected from Project 4.1 will be incorporated into trophodynamic ecosystem models of the GAB being developed as part of Project 7.1 *Knowledge integration of socio-ecological systems of the Great Australian Bight*.

5. INSHORE AERIAL CETACEAN SURVEYS

Occurrence, distribution and abundance of cetaceans off the western Eyre Peninsula in the Great Australian Bight

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5.1 Executive Summary

- This study provides an assessment of the occurrence and distribution of cetaceans in shelf and coastal waters, based on aerial surveys undertaken off the western Eyre Peninsula, eastern Great Australian Bight (GAB), South Australia.
- Aerial line-transect surveys were used to estimate the relative abundance of short-beaked common dolphins (*Delphinus delphis*) and two along-shore surveys were also flown to assess occurrence of southern right whales (*Eubalaena australis*) in coastal waters.
- Five cetacean species were identified, including seven southern right whales, three humpback whales, one minke whale (*Balaenoptera* sp.), 71 schools of short-beaked common dolphins, and 14 schools of bottlenose dolphins (*Tursiops* spp.).
- Short-beaked common dolphins appear to be particularly abundant in the region, and the shelf waters of the eastern GAB likely represent an important habitat for this species.
- Relative abundance of short-beaked common dolphins was estimated to be 20,000–22,000 using distance sampling methods with densities of 0.67–0.73 dolphin/km^2.
- These results corroborate previous findings which suggested that inshore GAB waters are an important habitat for short-beaked common dolphins in Australia.
- Bottlenose dolphins (*Tursiops* spp.) were the second most commonly sighted cetacean and only sighted in coastal areas, <12 km from shore.
- The dissimilar distribution and ecology of the two dolphin species may result in them showing different levels of sensitivity to regional anthropogenic impacts.
- Data indicate that some southern right whales may use the eastern GAB for transiting from feeding grounds to coastal aggregation sites at the Head of Bight and/or Fowlers Bay.
- As the species continues to recover from whaling, it is possible that some of these areas will become more frequently used by this species.

5.2 Introduction

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 have been reported, 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 recognised as an important breeding ground (DSEWPaC 2012a).

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.

5.2.1 Background and Need

Southern right whales were subject to commercial whaling in the 19th and 20th centuries, resulting in substantial declines in abundance (DSEWPaC 2012a). Although protected in Australian waters in 1935, populations were further depleted by illegal Soviet whaling in the 1960s (Tormosov *et al.* 1998). 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 2012a). Following protection in 1935, their numbers started to increase but were subsequently reduced further as a consequence of illegal Soviet whaling in the 1960s, which delayed southern right whale recovery (Tormosov *et al.* 1998; DSEWPaC 2012a). Hunting of southern right whales is currently banned under the International Whaling Commision (IWC) moratorium on commercial whaling. Since then, the south-western Australia population has undergone some recovery, with annual aerial surveys between Cape Leeuwin (Western Australia; WA) and Ceduna (South Australia; 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 2012a). 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 2012a; Torres *et al.* 2013). The most recent published population estimate off southern Australia is approximately 3,500 individuals (Bannister 2011). Furthermore, southern right whale habitat occupancy is still substantially less than their historical occupancy (DSEWPaC 2012a). Threats to southern right whales include vessel collisions, anthropogenic noise (shipping, industrial and seismic surveys), commercial fishing entanglement and coastal development (DSEWPaC 2012a). They are also likely to be impacted by climate variability and change (DSEWPaC 2012a).

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). Neither studies have included 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 aggregating, calving and nursing). 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 Fowlers Bay (Bannister 2011; DSEWPaC 2012a). Other known calving grounds are located west of the Head of Bight in southern Western Australia (Bannister 2011; DSEWPaC 2012a). 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, 2008, 2014). Both *Tursiops truncatus* and *T. aduncus* are known to occur in the region, and a third *Tursiops* species, the southern Australian bottlenose dolphin (*T. 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 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 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). 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 WA to the west; and a population to the east ranging from approximately Eyre Peninsula 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.* unpub. data, Parra *et al.* unpub. data). 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, sardines (*Sardinops sagax*) (Bilgmann *et al.* 2008; Gibbs 2011; Möller *et al.* 2011), 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).

5.2.2 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, 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, one following the coastline at a distance of 1 nautical (nm) mile offshore and the other following the 40 m depth contour. We present sighting data, distributional maps and estimates of relative abundance for common dolphins, the cetacean species sighted most frequently in the region.

5.3 Methods

5.3.1 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. Transect start and end points were at the coastline and at the 100 m depth contour, respectively, extending to a maximum of 136 nm (252 km) from the coast to the edge of 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, which is 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 of all sightings as they came abeam using inclinometers, and reported data on species group sizes 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.

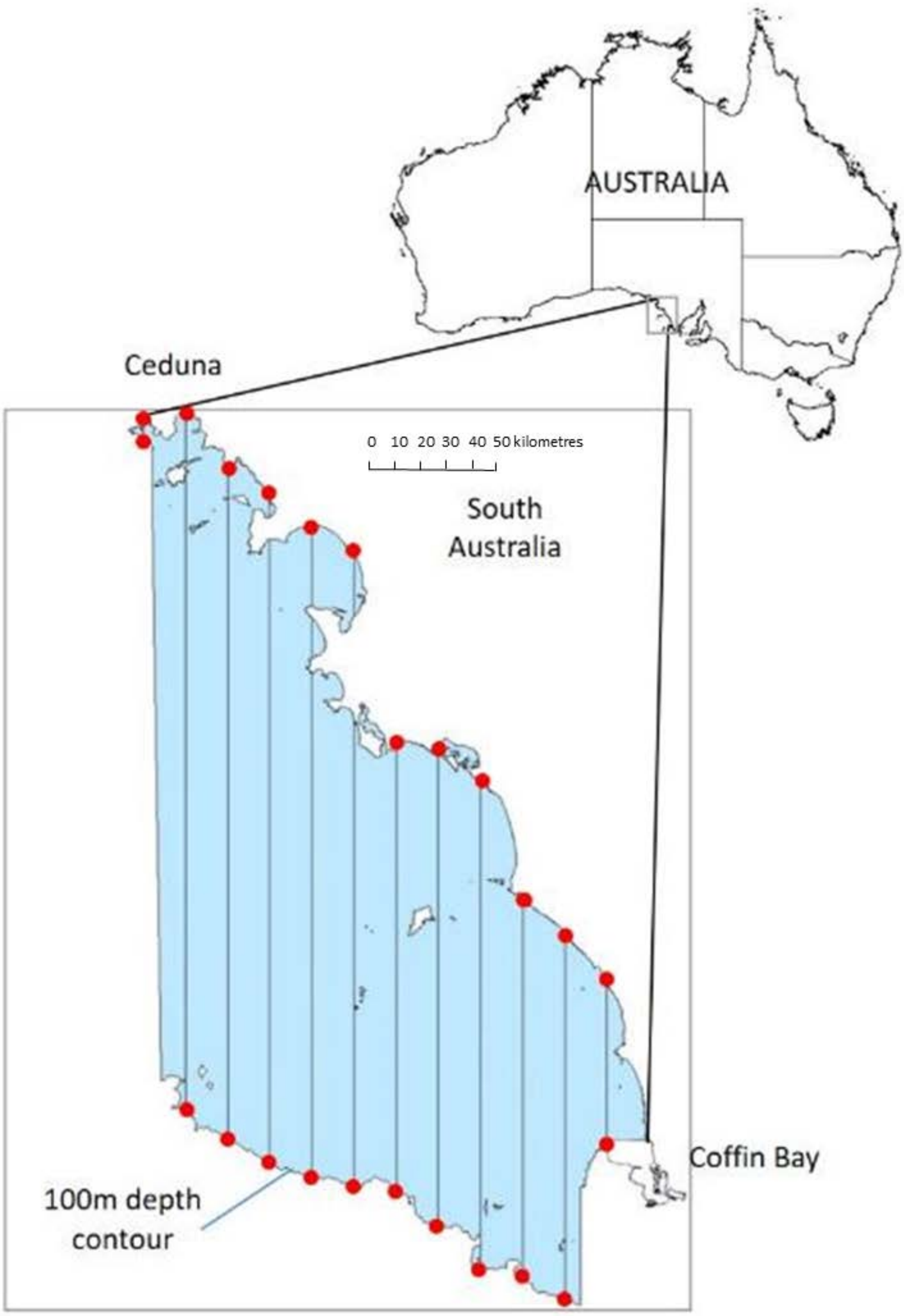

Figure 5.1. Map of the study area indicating aerial survey line transect layout. Start and end points of transects are marked with a red dot, and transects were numbered from 1-12, west to east. Effort on transect was paused when flying over headlands and/or islands.

Coastal survey

For the coastal survey two along-shore transects were designed. The first transect followed the coastline within 1 nm from shore to scan the area between the transect line and shore line, replicating the survey design of Bannister (2011). The along-shore transect aimed to assess southern right whale occurrence beyond the area previously surveyed 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 survey waters at medium depth, and at greater distance from shore, which may be utilised by southern right whales as they 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), which is 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).

5.3.1 Data analysis

Line-transect survey

Abundance was estimated only for those species with a 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 functions, 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 dolphin 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.* unpub. data).

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).

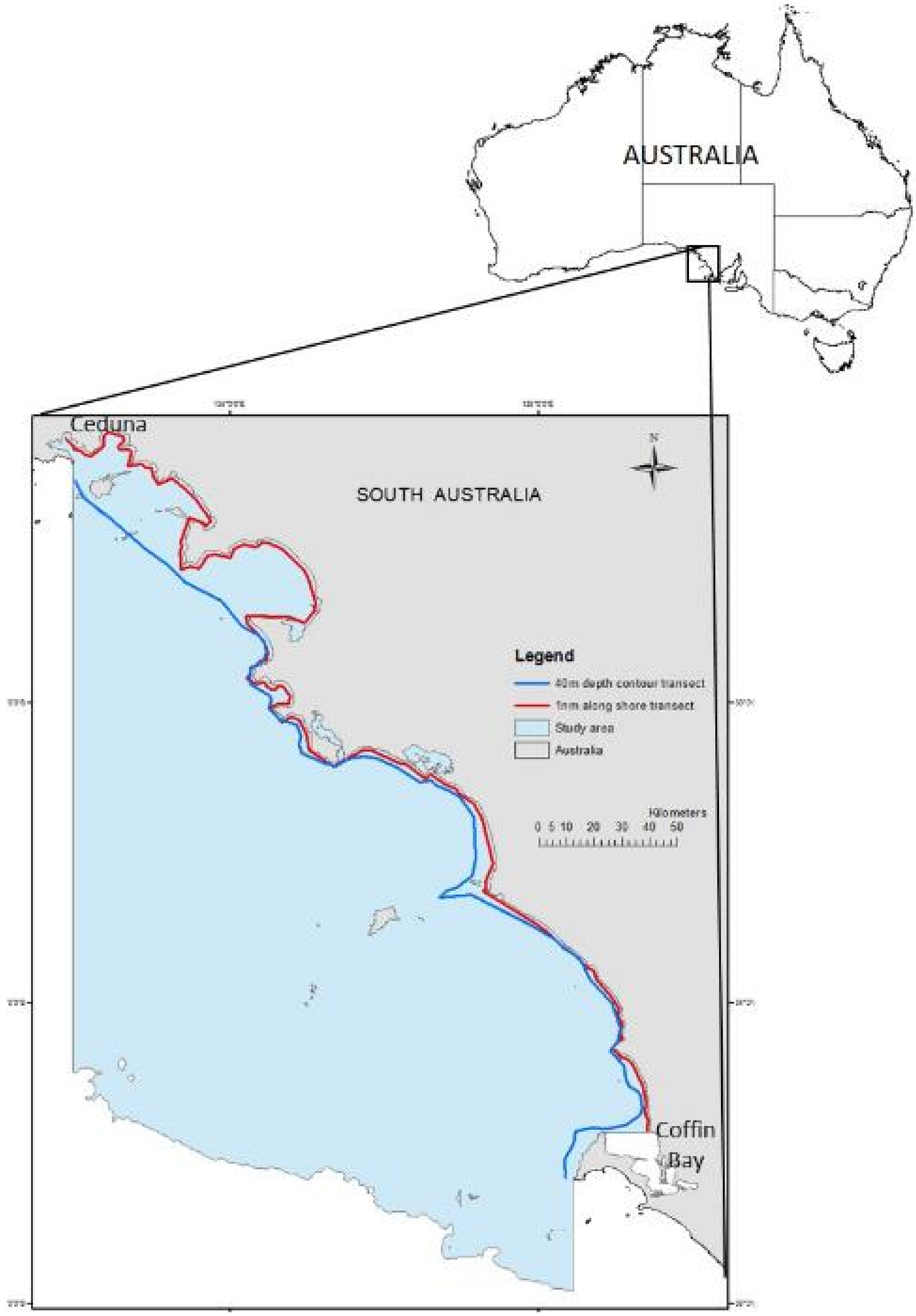

Figure 5.2. Map of the study area indicating the layout of the two coastal transects. The 1 nautical mile from shore transect is displayed in red and the 40 metre depth contour transect in blue.

5.4 Results

Line-transect survey

Twelve equally spaced transects with a total length of 2,236 km were flown covering an area of 29,822.4 km^2 between Ceduna (west) and Coffin Bay (east). The coastline and the 100 m depth contour were the northern and southern boundaries of the survey, respectively. Sightings 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 5.1. The table also shows the respective data for the coastal surveys. The most commonly sighted cetacean species was the short-beaked common dolphin, with a total of 59 schools sighted with species confirmed (Figure 5.3). 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 (Figure 5.4), southern right whale, humpback whale and minke whale (Figure 5, Table 1).

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 5.3 and 4; Appendix 5.1).

Table 5.1. Summary of sightings recorded during the line transect survey (12 equally spaced transects) and the coastal surveys (1 nm 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 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* spp.)	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

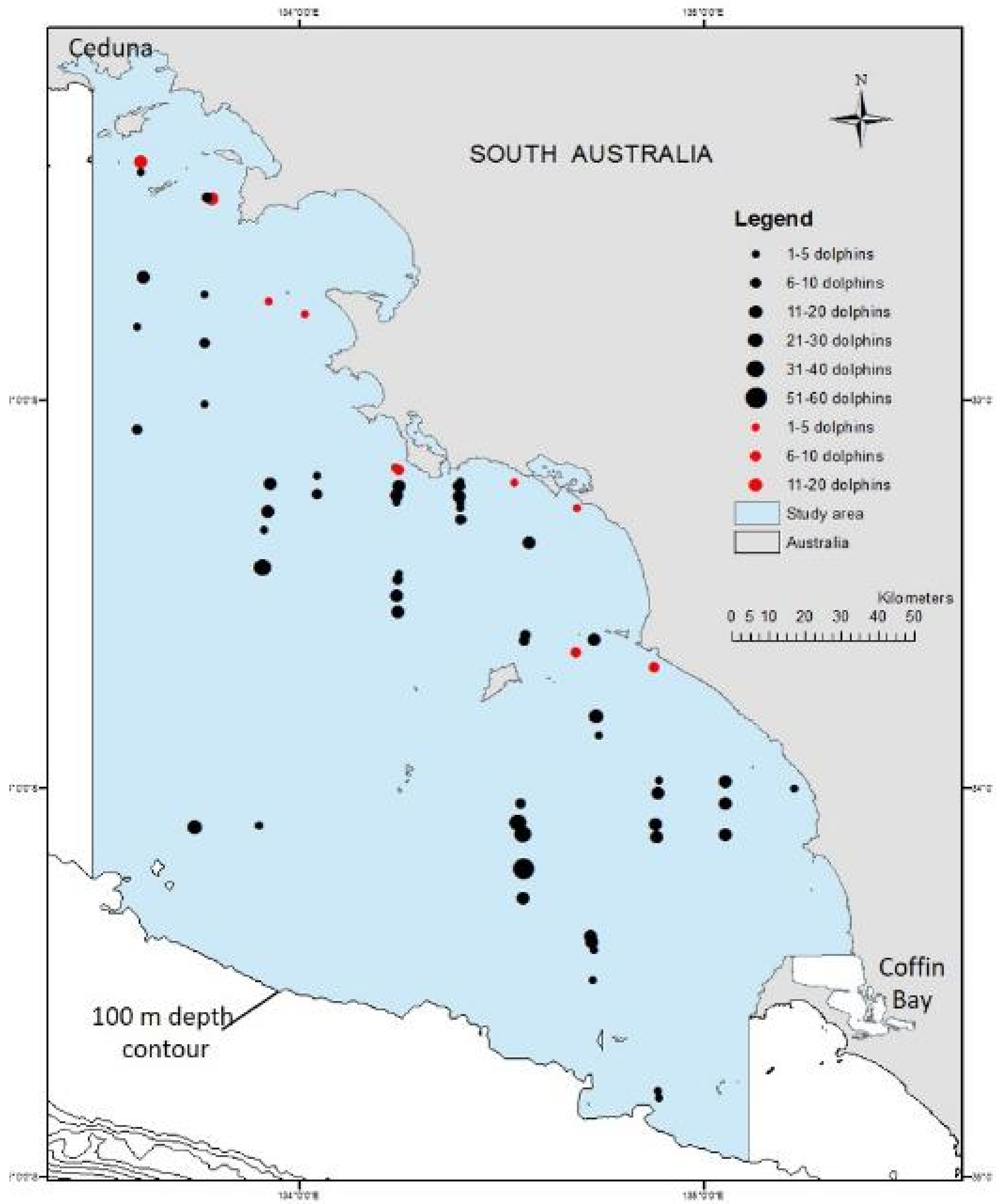

Figure 5.3. Study area and sightings of common dolphin schools between Ceduna and Coffin Bay, South Australia, during aerial surveys in July and August 2013. Sightings from line transects are displayed in black and those from coastal transects in red. Dot size increases proportionally with the number 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.

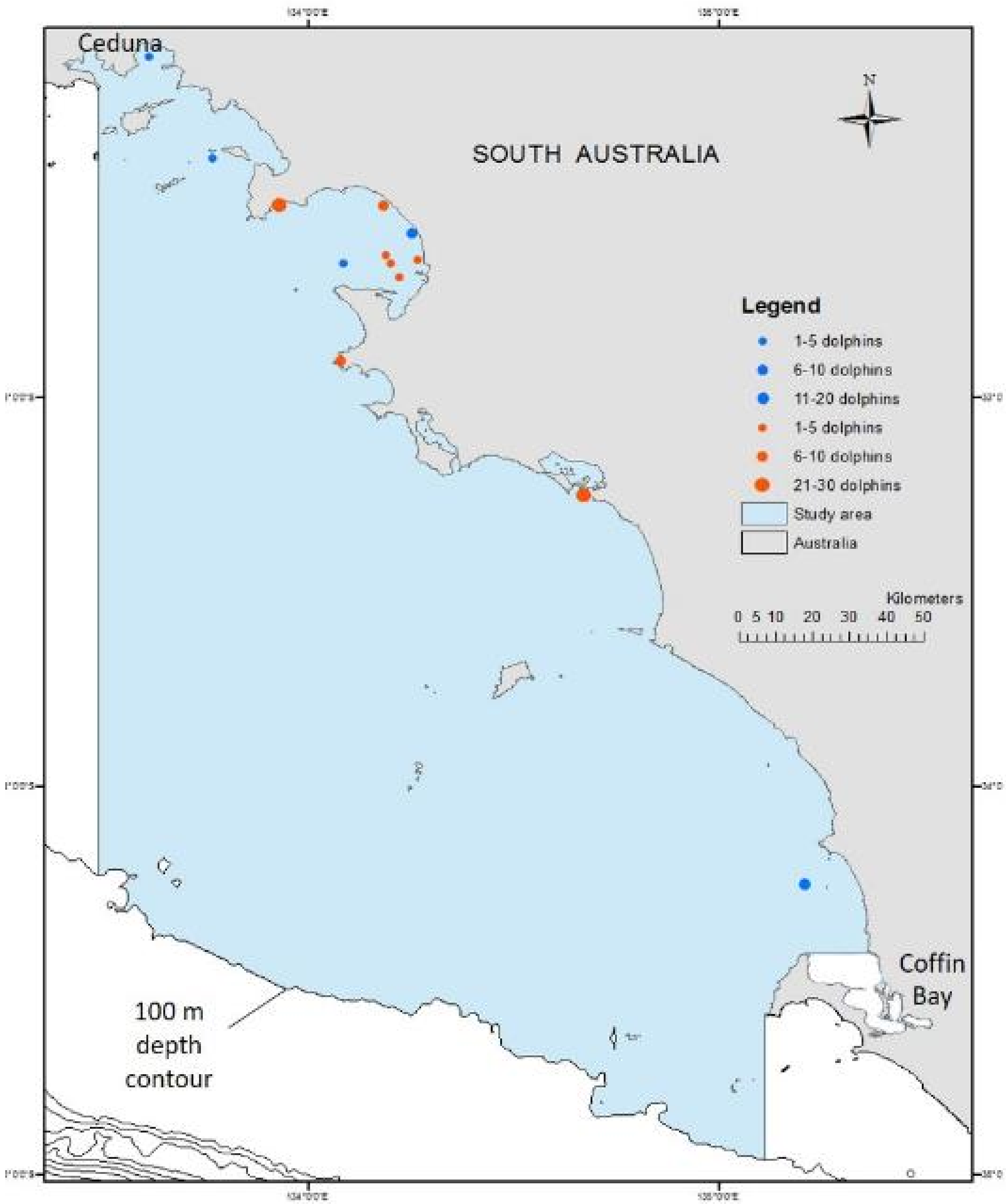

Figure 5.4. Study area and sightings of bottlenose dolphin schools between Ceduna and Coffin Bay, South Australia, during aerial surveys in July and August 2013. Sightings from line transects are displayed in blue and those from coastal transects in orange. Dot size increases proportionally with the 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.

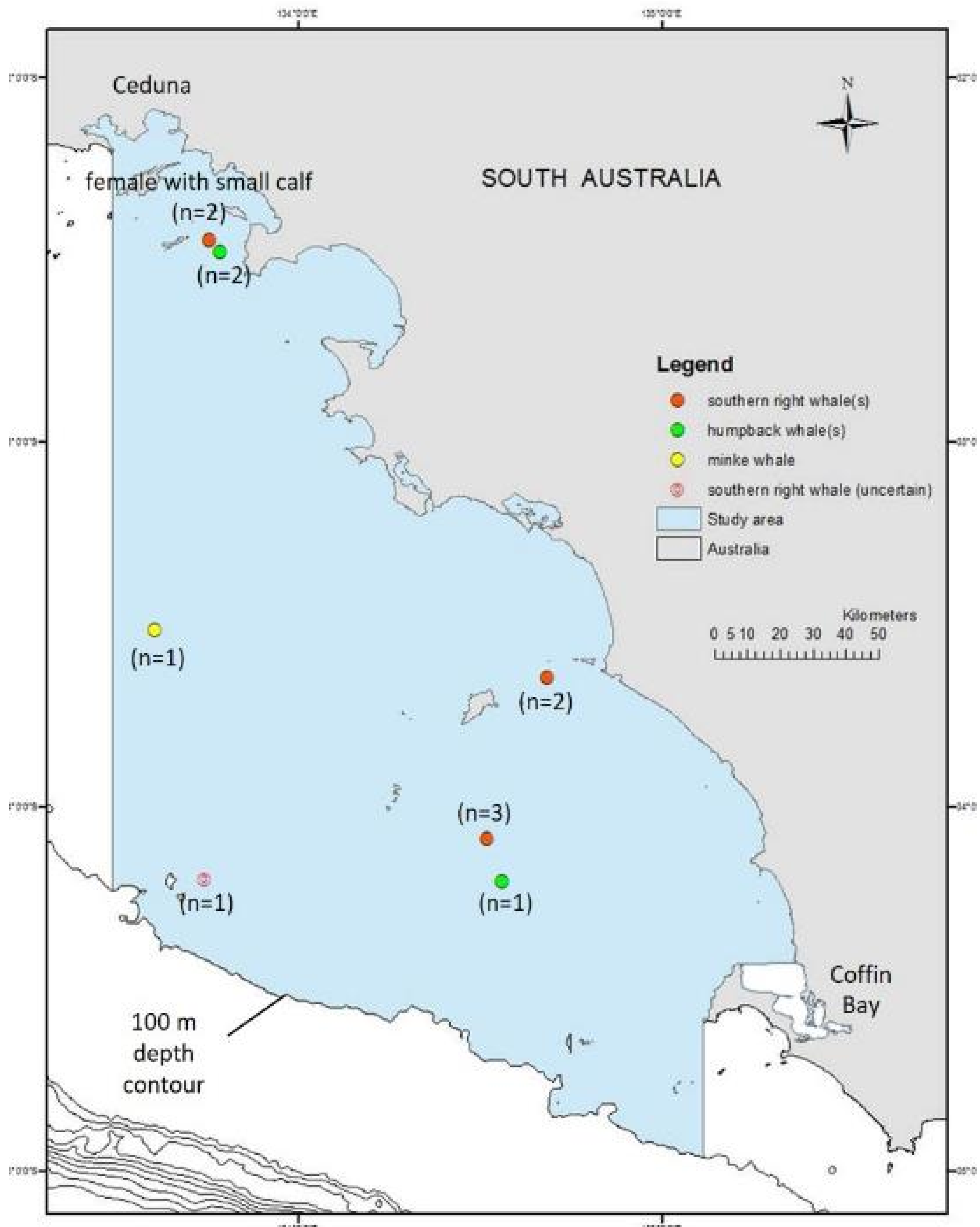

Figure 5.5. Study area and sightings of southern right whales (red), humpback whales (green), and one minke whale (yellow) between Ceduna and Coffin Bay, South Australia, during aerial surveys in July/August 2013. GPS locations of sightings from line transects were adjusted for perpendicular distance to the transect line.

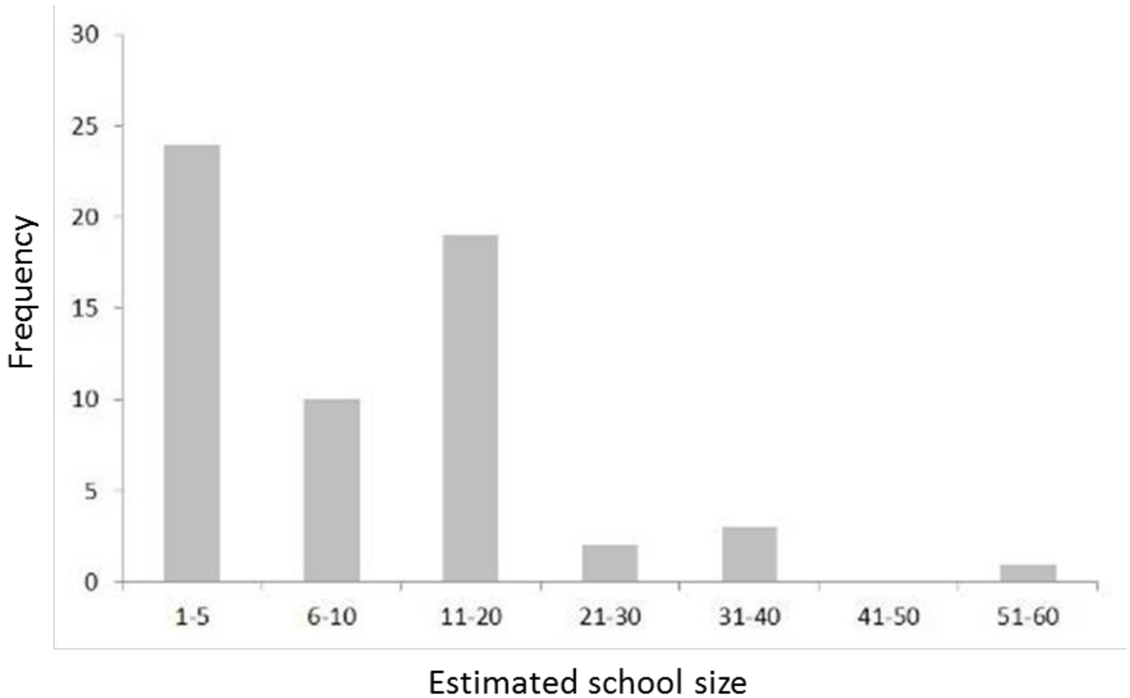

Figure 5.6. Frequency of common dolphin school sizes spotted during the line transect survey (on effort sightings). Dolphin schools were pooled into school size bins of 1-5; 6-10; 11-20; 21-30; 31-40; 41-50; and 51-60 dolphins.

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 5.3 and 5.4) are displayed in Figure 5.6.

The *Tursiops* species sighted could not be confirmed, but may have been either the Indo-Pacific bottlenose dolphin (*T. aduncus*) or the Australian bottlenose dolphin (*T. australis*). Offshore bottlenose dolphins (*Tursiops truncatus*) were not seen during the surveys. Previous genetic studies have confirmed the presence of the southern Australian bottlenose dolphin 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 resulting 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 been shown to perform well in similar studies (Thomas *et al.* 2009). The summary statistics of detection function models are shown in Appendix 5.2.

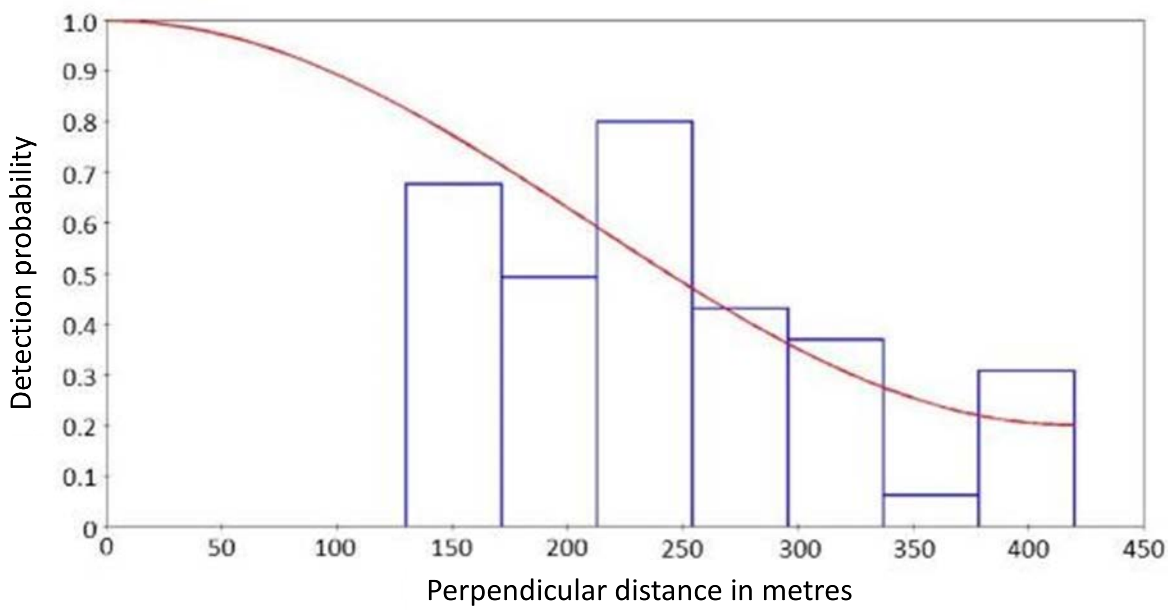

Figure 5.7. Detection function plot for common dolphin sightings from line-transect surveys between Ceduna and Coffin Bay, using Conventional Distance Sampling method, uniform key function with cosine adjustment model (Buckland *et al.* 2001).

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 5.7. 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 was N = 21,366 (95% CI= 12,221 - 37,356) (Appendix 5.2).

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 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., when the AIC would decrease): 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 5.2. 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 5.2). 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 5.2). The fitted detection function is given in Figure 5.8. 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 5.2).

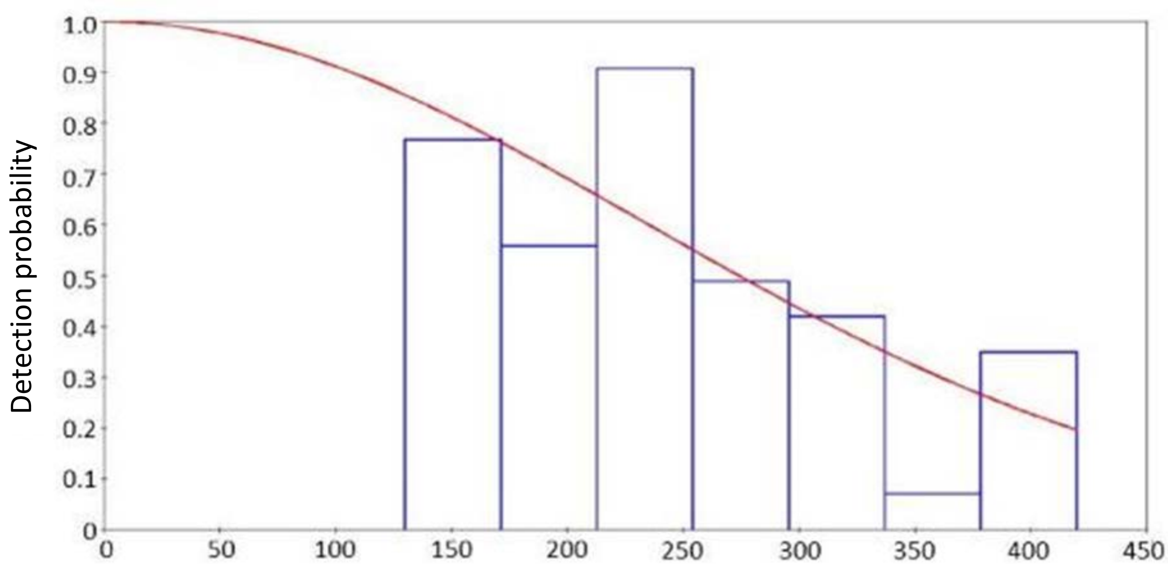

Figure 5.8. Detection function plot for common dolphin sightings from line-transect surveys between Ceduna and Coffin Bay (Multiple Covariate Distance Sampling method, halfnormal key function with cosine adjustment model without inclusion of covariates; Buckland et al. 2001).

Coastal surveys

The 1 nm 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 nm from shore transect, 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 m depth contour transect, we detected humpback whales and common dolphins (see Appendix 5.1). 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 5.5).

5.5 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 m isobath. It provides the first abundance estimates for common dolphins in the region. The results provide 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, 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 2012a).

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.* unpub. data).

The importance of eastern GAB shelf waters for cetaceans, and in particular for the southern right whale, is currently unknown (DSEWPaC 2012a). 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 recovery of southern right whales (Bannister 2011). Areas east of Ceduna were not included in this program.

Coastal and shelf waters between Ceduna and Coffin Bay are potentially of increasing importance for southern right whales for two reasons. First, where suitable habitat is available, areas may increase in importance for nursing and calving (DSEWPaC 2012a). 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 2012a). Second, migration of southern right whales across shelf waters of this region is likely to occur when whales move seasonally 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. While the long-term recovery objective is to minimise 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 minimising anthropogenic threats (DSEWPaC 2012a). The Australian *Conservation Management Plan for the Southern Right Whale 2011-2021* (DSEWPaC 2012a) 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 if 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 use the area. The detection of species during aerial surveys 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 15 km used here. Ideal line spacing was estimated to be around half that 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 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.

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). There, numbers of southern right whales ranged between a minimum of 167 recorded in 1993 to a maximum of 782 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. 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 are the South Australian Sardine Fishery (SASF), a purse-seine fishery targeting sardines (Hamer *et al.* 2008), and the gillnet fishery of the Southern and Eastern Scalefish and Shark Fishery (SESSF) targeting gummy sharks (AFMA 2011). Hundreds of dolphins have died in the purse-seine fishery over the past two decades, and an observer program has been developed to reduce 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 interactions between common dolphins and the gillnet fishery (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.

5.6 Conclusions

We found that at least five cetacean species in coastal and offshore waters off the western Eyre Peninsula during the austral winter: short-beaked common dolphins, southern Australian bottlenose dolphins, southern right whales, humpback whales and a minke whale. Short-beaked common dolphins appear to be particularly abundant in the region, and the shelf waters of the eastern GAB likely represent an important habitat for this species. The southern Australian bottlenose dolphin was the second most commonly sighted cetacean species and was restricted to areas <12 km from shore. Sightings of endangered southern right whales were low compared to previous studies west of Ceduna, suggesting that the surveyed region did not represent a core area of use for this species during our study period. Our data, however, indicate that some southern right whales may use the eastern GAB for transiting from feeding grounds to coastal aggregation sites at the Head of the Bight and/or Fowlers Bay. As the species continues to recover from whaling, it is possible that it will use some of these areas more frequently.

5.7 Acknowledgements

We are thankful for the administrative support provided by Flinders Partners Pty Ltd, South Australian Research and Development Institute and the Commonwealth Scientific and Industrial Research Organisation. We are thankful for the logistical support provided by Observair and its Chief Pilot, Brad Welch. We also thank Shae Small and Juliette Coudert for field assistance. The research was conducted

under Flinders University and Southern Adelaide Health Service Animal Welfare Committee approval (#E326) and DEWNR, SA research permit (#E25889-3).

5.8 Appendices

Appendix 5.1 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 5.2 Summary statistics of the Conventional Distance Sampling (CDS) and Multiple Covariate Distance Sampling (MCDS) analyses in DISTANCE. 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; N = Abundance Estimate; CV = Coefficient of Variance; df = degrees of freedom.

CDS

Key Function_Adjustment Term_Truncation	Delta AIC	AIC	ESW/EDR	D	95% Confidence Interval		%CV	N	%CV	df	95% Confidence Interval	
CDS_Hn_Cos_LT130_RT420	1.63	572.26	147.36	0.67	0.37	1.23	0.31	20214	31.05	93.66	11067	36921
CDS_Un_Cos_LT130_RT420	0	570.62	129.93	0.73	0.42	1.26	0.28	21884	28.29	83.23	12602	38003
CDS_Hn_HP_LT130_RT420	1.63	572.26	147.36	0.67	0.37	1.23	0.31	20214	31.15	93.66	11067	36921
CDS_Hr_SP_LT130_RT420	2.81	573.43	182.28	0.64	0.33	1.26	0.35	19383	34.57	93.12	9945	37775

MCDS

Key Function_Adjustment Term_Truncation	Delta AIC	AIC	ESW/EDR	D	95% Confidence Interval		%CV	N	%CV	df	95% Confidence Interval	
MCDS_Hn_Cos_LT130_RT420	1.63	572.26	147.36	0.67	0.37	1.23	0.31	20214	31.15	93.66	11067	36921
MCDS_Hn_SP_LT130_RT420	1.63	572.26	147.36	0.67	0.37	1.23	0.31	20214	31.15	93.66	11067	36921
MCDS_Hn_HP_LT130_RT420	1.63	572.26	147.36	0.67	0.37	1.23	0.31	20214	31.15	93.66	11067	36921
MCDS_Hr_Cos_LT130_RT420	2.81	573.43	182.28	0.64	0.33	1.26	0.35	19383	34.57	93.12	9945	37775
MCDS_Hr_SP_LT130_RT420	2.81	573.43	182.28	0.64	0.33	1.26	0.35	19383	34.57	93.12	9945	37775
MCDS_Hr_HP_LT130_RT420	2.81	573.43	182.28	0.64	0.33	1.26	0.35	19383	34.57	93.12	9945	37775

6. OFFSHORE AERIAL CETACEAN SURVEYS

Offshore cetacean aerial surveys in the Great Australian Bight

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6.1 Executive Summary

- Three aerial surveys for cetaceans were carried out between December 2015 and April 2016 in the eastern and central Great Australian Bight (GAB).
- Surveys were completed in mid-December, late January and mid-April. The first two surveys were flown over two days and the third was flown over three days.
- A total of 9,678 km was flown, of which 4,269 km was on effort (i.e. on designated survey transects in the GAB). This represented an area surveyed of 103,488 km^2 in total, including 46,970 km^2 on effort.
- Most survey effort was focused on the outer shelf from south-west of Kangaroo Island (KI) to south of the Head of Bight. On the third day of the April survey, two areas west of Eyre Peninsula were also surveyed, including an area of surface upwelling and likely cetacean habitat.
- A total of 58 cetacean sightings was recorded, including 27 on effort (from designated transects), and 31 off effort (i.e. sighted in transit or after leaving transects).
- Eight species were identified, including: blue whales (*Balaenoptera musculus brevicauda*); a fin whale (*Balaenoptera physalus*); sperm whales (*Physeter macrocephalus*); pilot whales (*Globicephala melas*); killer whales (*Orcinus orca*); Risso's dolphins (*Grampus griseus*); short-beaked common dolphins (*Delphinus delphis*); and common or offshore bottlenose dolphins (*Tursiops* sp.).
- There were many sightings of unidentified dolphins ('dolphin sp.'), and a sighting of probable beaked whales of unknown species.
- Species diversity and abundance, particularly on the outer shelf in the central-eastern GAB were low during the first two surveys in December and late January, but were several times higher during the April survey.
- Blue whales were not sighted in the eastern GAB or south of KI during any surveys, but were sighted along the Bonney Coast between Robe and Portland. Sperm (or 'likely sperm') whale waswas the only species sighted in the eastern GAB during all three surveys. Dolphin sp. represented the most commonly sighted taxon, while pilot whales occurred in the highest density.
- Species never or very rarely sighted during previous Blue Whale Study (BWS) surveys in the GAB region included a fin whale, killer whales and Risso's dolphins.
- Species' distribution generally concurred with predicted habitat from prior surveys. Sperm whales, pilot whales, killer whales, Risso's dolphins, likely beaked whales and a fin whale were found on the upper slope, not far outside the shelf-break (160–200 m depth contours). Sperm whales tended to be in deeper, steeper terrain, while pilot whales, killer whales, Risso's dolphins, and likely beaked whales were in shallower, less steep terrain. The fin

whale was just offshore of the shelf-break. Dolphin sightings were widely distributed in shelf and upper slope waters, from close inshore to just offshore of the shelf break.

- The 2015–16 upwelling season was relatively strong compared to previous seasons, with sustained upwelling evident from late December to mid-February, and again through much of March.
- Surface chl-*a* concentrations in the eastern GAB peaked during March and April, and this correlated with the observed timing of enhanced cetacean diversity and abundance during the April survey.

6.2 Introduction

The eastern Great Australian Bight (GAB) is a relatively productive region due to interactions between seasonal upwelling associated with the Flinders Current, and warm intrusions from the Leeuwin Current (Middleton and Cirano 2002; Kämpf *et al.* 2004; McClatchie *et al.* 2006). The eastern GAB is the western extremity of an extensive upwelling system extending eastwards to the west coast of Tasmania, now sometimes referred to as the Great Southern Australian Upwelling System (Kämpf *et al.* 2004; Kämpf 2015). Large clupeid fisheries and a diversity of marine fauna are dependent on primary productivity, which drives a food web dominated by schooling fish and squid, with apex predators including otariid seals and seabirds (Goldsworthy *et al.* 2013).

The eastern GAB also supports a diversity of cetacean predators, yet until recently knowledge about the species present, their distribution and ecology was rudimentary. Probably the best-known species have been the short-beaked common dolphin (*Delphinus delphis*), due to its association with the sardine (*Sardinops sagax*) fishery in the eastern GAB (Bilgmann *et al.* 2008, Hamer *et al.* 2008), and the southern right whale (*Eubalaena australis*) which fasts while breeding along South Australia's coastline during winter and spring (Burnell and Bryden 1997), beyond the productive area of the eastern GAB. A diversity of other mysticete and odontocete species has also been sighted in this region (Gill *et al.* 2015).

Pygmy blue whales (*Balaenoptera musculus brevicauda*) also aggregate in the eastern GAB in high densities in some years to forage on the neritic euphausiid (*Nyctiphanes australis*) (Gill *et al.* 2011), which occurs throughout the shelf waters of this upwelling system (Blackburn 1980). At times, the eastern GAB has appeared to be a more important blue whale foraging ground than the adjacent Bonney Upwelling, a term often applied to shelf waters from Cape Otway, Victoria, to west of Robe in South Australia (Butler *et al.* 2000).

The cetaceans in the eastern GAB have rarely been surveyed. Aerial surveys are the most effective method for surveying such large areas. Since late 2003, the Blue Whale Study (BWS) has conducted aerial surveys for blue whales in shelf and upper slope waters to the south and west of Kangaroo Island. During these surveys, cetacean occurance was characterised by high variability. Blue whales were abundant in December 2003 and 2005, but in low densities or not sighted during other months and years (Gill *et al.* 2011; BWS unpublished data). Similar variability was also apparent for other species, mostly odontocetes (Gill *et al.* 2015).

The purpose of this report is to summarise the sightings information from three aerial surveys for cetaceans on the outer shelf and upper slope in the central and eastern GAB during the summer-autumn upwelling season in 2015–16., including:
a) relative abundance estimates for whales calculated from either encounter rates, or distance sampling;

b) cetacean distribution and density, including as far as possible, intra- and inter-seasonal comparisons;
c) relationships between cetacean occurrence and environmental variables.

6.1 Methods

6.1.1 Aerial survey

The approach to the survey design was to carry out aerial surveys, each of 3 days in duration, using the approach below, when weather permitted:

- Day 1: survey known or likely areas used by cetaceans in the eastern GAB, on the shelf and slope southwest and west of Kangaroo Island. This area has been surveyed by BWS multiple times in other years, including monthly in the 2011/12 season, and large numbers of blue whales have been sighted there in some years.
- Day 2: survey an extension area into the central GAB. If no whales were seen in the survey area on Day 1, fly parallel just outside and just inside the shelf break (on outward/return legs), for maximum distance coverage; this repeats 2011/12 survey pattern. If whales were seen in the survey area on Day 1, pickup and continue the saw tooth pattern westward from the Day 1 end point. If no whales are seen after a reasonable distance, change to shelf break-parallel track to complete survey.
- Day 3: if the weather window persists for a third day, and if whales were sighted in the extension survey on Day 2, and if the survey were to continue further westward and could likely shed light on westward distribution, then continue the extension westwards as far as logistically practical either by parallel or sawtooth transects (alternative 1); or (alternative 2) survey an additional area of potential cetacean habitat identified from near-real-time remote sensed data of SST and chl-a, and/or from prior knowledge of the region's biological oceanography and/or bathymetry and/or knowledge of previous or recent cetacean activity, preferentially using a saw-tooth pattern and including a randomly selected control area en route. One such possible area is the upwelling plume off the west coast of Eyre Peninsula. Survey activities on this day would be informed by information from the previous two days, and by logistic constraints (weather, distance to area of interest, aircraft endurance, pilot duty hours).

The primary survey area spanned from south of Cape du Couedic, Kangaroo Island (136° 40' E) westward to south of Head of Bight (131° 30' E) (Figure 6.1). A secondary survey area was off the west coast of Eyre Peninsula in a region that often displays a surface upwelling plume. The surveys were designed to detect blue whales, but the area covered also encompasses known habitat of sperm whale, beaked whale, pilot whale, and dolphins.

Surveys were planned for the dates below and spanned the upwelling season:

- 15 December 2015
- 30 January 2016
- 15 March 2016

Aerial survey methods are detailed in Gill *et al.* (2011). A high-wing twin-engine Aero Commander 500 aircraft suitable for offshore survey work was used. A team of three observers (two searching, one recording) scanned the survey area and recorded positions of cetaceans and associated attributes (e.g. group size, behaviour) and environmental conditions (e.g. sea state, glare, upwelling fronts). Sightings of other marine fauna were also recorded. Surveys were conducted in 'passing' mode at an altitude of 457 m, in which the aircraft remained on course along transects, and for each sighting a GPS position on the trackline and a vertical angle (by clinometer) were recorded as the sighting passed abeam (at 90° to the aircraft's track). Vertical angles corresponded to distances off track, so actual positions of sightings could be post-calculated. If diversions from survey transects were required to confirm species identification or group size, the aircraft left transects in 'closing mode' and circled the sighting until the desired data were obtained, before resuming the transect. The methods were designed to assess the occurrence and relative abundance (including density) of blue whales and other cetaceans inhabiting outer shelf and upper slope environments.

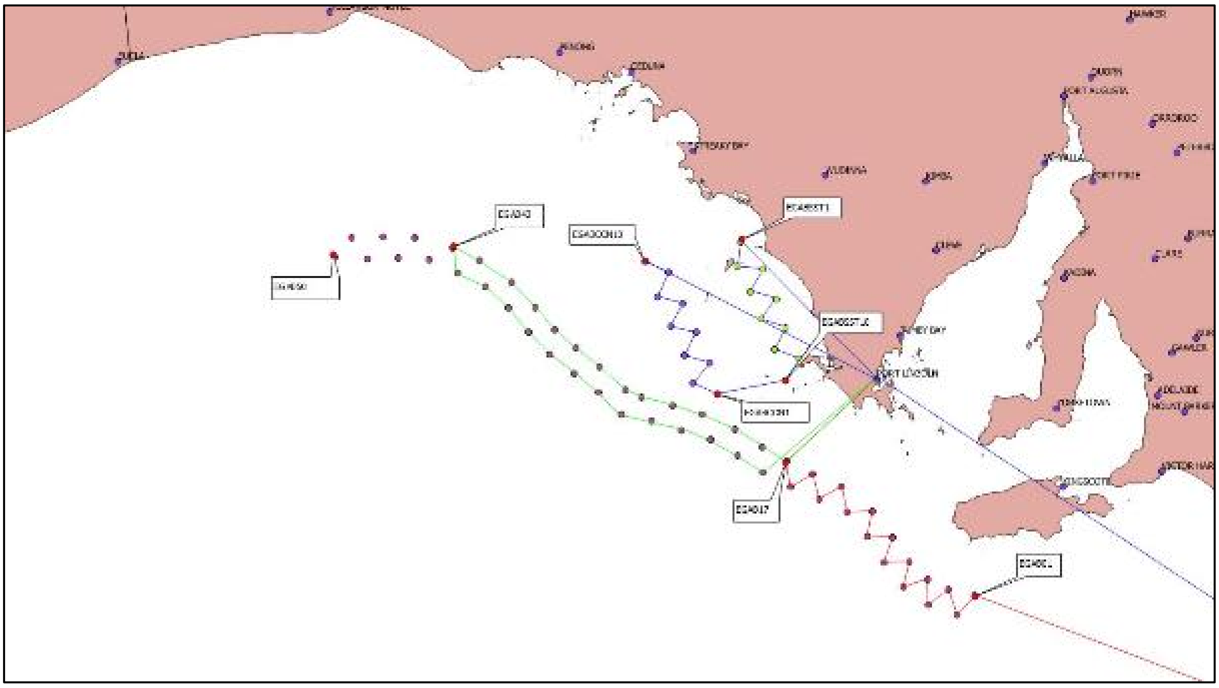

Figure 6.1. Aerial survey tracks used for the GAB cetacean surveys. The surveys continued west to waypoint EGAB50.

6.1.2 Measures of abundance

For each species, using distance sampling to estimate abundance requires at least 60 sightings (Buckland *et al.* 2005). Since the total number of sightings for all species was 58, distance sampling was not a valid method. Measures used were encounter rate (ER), defined as animals sighted per 1000 km of trackline on effort (e.g. see Gill *et al.* 2011), and density (number of animals sighted per area surveyed on effort, assuming a strip width coverage of 11 km, which is the effective range of visibility at 457 m altitude). In other words, the density is the ER divided by 11, or animals per 1000 km^2.

6.1.3 Environmental variables

A preliminary investigation of the influence of environmental variables was restricted to two variables: an upwelling intensity index (UII), and surface chlorophyll-*a* concentration. UII was derived from daily (1500 h) wind stress data from Cape Nelson weather station, Victoria, using the methods of Van Ruth (2010). Despite its distance from the eastern GAB, upwelling synchrony occurs across

the broader upwelling system at the scale of pressure systems and wind fields experienced in this study (Kämpf *et al.* 2004). Hence, the Cape Nelson data can be regarded as representative of the upwelling system as a whole. Five-day means were used to smooth the data. Mean monthly composite MODIS AQUA chl-*a* data for the 2015–16 upwelling season were downloaded from the NOAA ERDDAP site[1]. The sampling area was bounded by 34°–36°S, 133°–137°E, and includes most of the 'Kangaroo Island pool' and the upwelling plume west of Eyre Peninsula, where enhanced concentrations of chl-*a* may be expected after upwelling (Ward *et al.* 2006).

Depth (m) and slope (m/km) were derived for all sighting locations from the General Bathymetric Chart of the Oceans (GEBCO) 1-Minute World Bathymetry Grid using Vertical MapperTM v3.0 extension in MapInfoTM v.10 (resolution approximately 1 nm^2 at the study area latitude).

6.2 Results

6.2.1 Summary of surveys

All surveys started and ended at Portland, Victoria. Details of surveys are summarised in Table 6.1. A total of 4,269 km on effort trackline allowed on effort survey coverage of 46,970 km^2, based on an 11 km strip width.

The second day in all three surveys was flown in transects that were parallel to and either side of the shelf break, extending west to waypoint EGAB50. The third day on survey EGAB3 (20 April) was flown on the sawtooth transects (EGABSST) west of Eyre Peninsula, and the sawtooth control transects further offshore (EGABCON). Seven of the nine days that were planned for aerial surveys were completed. The first two surveys were reduced to two days each due to unforeseeable bad weather. During surveys EGAB1 (mid-December) and EGAB2 (late January-early February), after good survey conditions prevailed on the first two days of each survey, the weather deteriorated on the final day and the aerial survey could not be undertaken.

6.2.1 Summary of cetacean sightings

A total of 58 cetacean sightings were recorded. Sightings are shown in Figure 6.2 and summarised in Tables 6.2 and 6.3, and Appendix 6.1. There were 27 'on effort' sightings recorded while on survey transects, and 31 sightings 'off effort', either in transit to and from survey areas, or when closing with on effort sightings. Off effort sightings include all blue whale sightings recorded in transit between Portland, Victoria, and Robe, SA.

[1] Sourced from http://coastwatch.pfeg.noaa.gov/erddap/wms/erdMHchlamday/index.html

Table 6.1. Summary of aerial surveys for cetaceans in the eastern Great Australian Bight between December 2015 and April 2016.

Survey #	Dates	Total km	Total km^2 surveyed	On effort km	On effort km^2 surveyed	Days on effort completed
15-12-1 (EGAB1)	09-11 Dec 2015	2,960	29,590	1,272	13,992	2 of 3
16-1-1 (EGAB2)	31 Jan-02 Feb 2016	3,007	33,077	1,278	14,058	2 of 3
16-4-1 (EGAB3)	18-20 April 2016	3,711	40,821	1,720	18,920	3 of 3
TOTAL		9,678	103,488	4,269	46,970	7 of 9

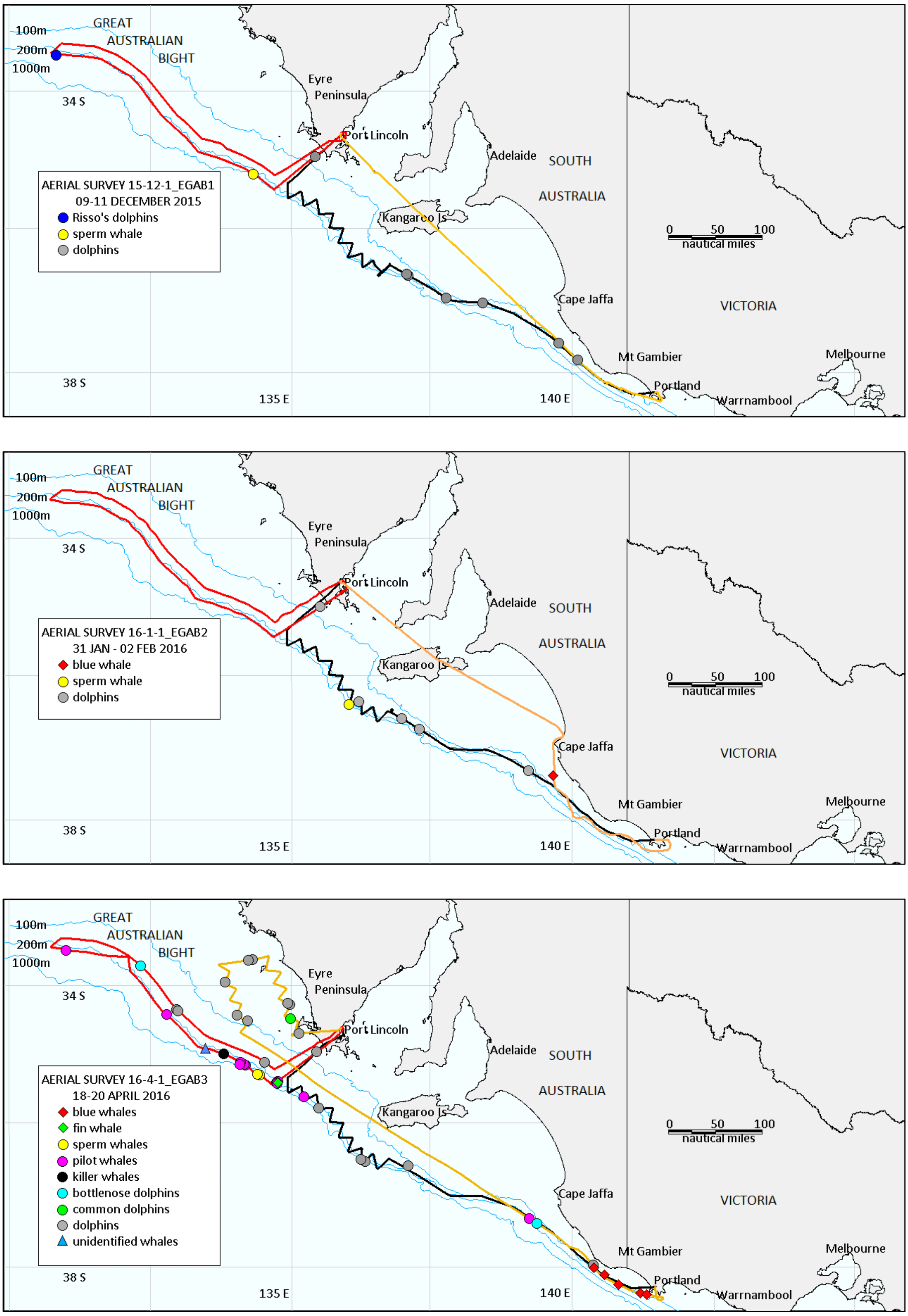

Figure 6.2. Maps for the three multi-day aerial surveys in the eastern GAB undertaken between December 2015 and April 2016. In each survey, the first day's track is shown in black; the second day's in red; and the third in orange.

Table 6.2. Summary of all sightings (on and off effort) for each aerial survey in the eastern GAB and for all surveys combined.

Survey dates	# sight-ings	# species	Sight-ings/ species	Species		No.	Mean group size	Mean depth m	Mean slope m/km
09-11 Dec 2015	9	3	1	Sperm whale		1	1	756	4.5
			1	Risso's dolphins		60	60	458	1.3
			7	Dolphins sp.		265	37	114	0.9
31 Jan-02 Feb 2016	9	3	1	Blue whale		1	1	59	0.1
			1	Like[2] sperm whale		1	1	1371	10.9
			7	Dolphins sp.		343	49	131	0.6
18-20 April 2016	40	9	5	Blue whales		5	1	90	0.3
			1	Fin whale		1	1	225	4.3
			2	Sperm whales		3	1.5	1281	4.1
			11	Pilot whales		646	58	515	2.9
			1	Killer whales		10	10	494	2.5
			2	Bottlenose dolphins		525	263	123	0.3
			1	Common dolphins		3	3	76	0.2
			16	Dolphins sp.		239	15	172	1.9
			1	Unidentified whales		3	3	461	3.0
All surveys combined	58	9	6	Blue whales		6	1	85	0.2
			1	Fin whale		1	1	225	4.3
			4	Sperm & like sperm		5	1.3	1172	5.9
			11	Pilot whales		646	58	515	3.0
			1	Killer whales		10	10	494	2.5
			1	Risso's dolphins		60	60	458	1.3
			2	Bottlenose dolphins		525	263	123	0.3
			1	Common dolphins		3	3	76	0.2
			30	Dolphins sp.		847	28.2	149	1.4
			1	Unidentified whales		3	3	461	3.0

Table 6.3. Summary of on effort cetacean sightings for each aerial survey and for all surveys combined, 2015-16. Distance and area surveyed are shown on Table 6.2. ER = encounter rate.

Survey dates	Species	N sights	N animals	Mean group size	ER (animals/ 1000km)	Density (animals/ 1000km^2)
09-11 Dec 2015	Sperm whale	1	1	1	0.8	0.07
	Risso's dolphins	1	60	60	47.2	4.30
31 Jan-02 Feb 2016	Like sperm whale	1	1	1	0.8	0.07
	Dolphins sp.	1	5	5	3.9	0.36
18-20 Apr 2016	Sperm whales	2	3	1.5	1.7	0.16
	Pilot whales	7	206	72	119.8	10.89
	Killer whales	1	10	10	5.8	0.53
	Bottlenose dolphins	1	25	25	14.5	1.32
	Common dolphins	1	3	3	1.7	0.16
	Dolphins sp.	11	224	20.4	130.2	11.84
	Unidentified whales	1	3	3	1.7	0.16
All surveys combined	Sperm & like sperm whales	4	5	1.3	1.2	0.11
	Pilot whales	7	266	38	62.3	5.66
	Risso's dolphins	1	60	60	14.1	1.28
	Killer whales	1	10	10	2.3	0.21
	Bottlenose dolphins	1	25	25	5.9	0.53
	Common dolphins	1	3	3	0.7	0.06
	Dolphins sp.	12	229	18.8	53.6	4.88
	Unidentified whales	1	3	3	0.7	0.06

[2] The term 'like sperm (or other) whale' is used in cetacean research to denote an animal that has not been identified but resembles a sperm whale.

6.3 Discussion

6.3.1 Pygmy blue whales *Balaenoptera musculus brevicauda*

Although the importance of the shelf-break zone south and west of Kangaroo Island to foraging blue whales is well established (Gill *et al.* 2011), blue whales were not sighted in the eastern GAB on these surveys. This is consistent with previous seasons' surveys in the region (Table 6.4) in which blue whales were abundant only during December 2003 and December 2005.

Variability in blue whale presence was supported by anecdotal, unconfirmed reports from other sources. About 25 blue whales and surface swarms of krill were reported by a fisher around the Murray and Sprigg Canyons during late November-early December 2015. We did not find those whales on 9 December. In December 2015, a group of blue whales was reported in an unidentified location by tuna spotting pilots working in the eastern GAB, while a further sighting was reported west of Kangaroo Island in late December. In mid-December 2014, tuna spotting pilots reported a group of 25–30 blue whales within a small area west of Kangaroo Island.

6.3.2 Fin whale *Balaenoptera physalus*

The sighting on 19 April 2016 was the westernmost fin whale sighting recorded by BWS, and the first by BWS in the eastern GAB (Figure 6.3). There is a record of a fin whale stranding near Port Lincoln in 1999[3]. Fin whales are generalist feeders, preying on schooling krill, fish and squid (Jefferson *et al.* 2008). The sighting on 19 April was near groups of pilot whales, suggesting the presence of schooling prey.

Figure 6.3. The fin whale sighted on the aerial survey on 19 April 2016, showing the white lower right jaw unique to this species. The distinctive dorsal chevron is also visible between the pectoral fins.

6.3.3 Sperm whales *Physeter macrocephalus*

Sperm whales may be abundant in the GAB. BWS has sighted them during aerial surveys in the eastern GAB and Kangaroo Island region over the years, and they were the only species observed during all three 2015-16 surveys. BWS has observed them in November, December and April of

[3] http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=37

previous years, but they have been absent from a number of surveys as well (see Table 6.4). However, deep, long diving odontocete cetaceans such as sperm (and beaked) whales may be under-represented in aerial survey data as they are unavailable for sighting during feeding dives which may last 40 minutes or more (Whitehead 2003). Sperm whales were often detected acoustically but not sighted during a vessel-based cetacean acoustic survey west of KI during autumn 2013 (Marine Conservation Research International 2013). All sightings by BWS in the eastern GAB over the years appeared to have been of bachelor schools of young adults, or of similar-sized males or mature males (Figure 6.4), either solitary or in pairs. There has not been any evidence of nursery schools consisting of adult females and young (Whitehead 2003). Mean group size during the 2015-16 surveys was 1.3, somewhat smaller than the mean size of 1.9 from 34 sightings reported by Gill *et al.* (2015) between Bass Strait and the eastern GAB.

Figure 6.4. Adult male sperm whale sighted on 19 April 2016, showing the forward-angled blow and large blunt head.

A 'like sperm whale' was sighted on 1 January 2016, which dived as the aircraft approached. The position was just offshore of the shelf break, the large size and colouration of the whale, and the clear sight of a forward-angled blow strongly indicated that this was a sperm whale.

6.3.4 Long-finned pilot whales *Globicephala melas*

The pilot whales sighted in this region (Figure 6.5) were undoubtedly long-finned pilot whales *Globicephala melas;* although short-finned pilot whales have been recorded in the GAB from stranding records (Segawa and Kemper 2015). Overall, they were the most commonly sighted species during the 2015–16 surveys, and found in higher density than any other species, despite their apparent absence during EGAB1 and EGAB2 (Table 6.3). During previous years' surveys they have been sighted in the eastern GAB during December, February and March (Table 6.4). Nothing is known of their seasonal movements, if any, within this region, or their affinities with populations observed off Victoria, Tasmania or Western Australia (Ross 2006). In the 2015-16 surveys, mean group size was 58, compared with 46 from 40 sightings reported by Gill *et al.* (2015). All groups photographed showed a range of size classes including calves (Figure 6.5). Mean sightings depth was 515 m, compared with 634 m reported by Gill *et al.* (2015), confirming that pilot whales tend to occupy the upper slope in depths favoured by sperm whales. Long-finned pilot whales are primarily

squid feeders, but in the Northern Hemisphere they are also known to consume fish (Jefferson *et al.* 2008); the same may be true in southern Australian waters.

Figure 6.5. Mixed-size-class group of pilot whales sighted on the aerial survey on 20 April 2016. Four calves are in this group.

6.3.5 Killer whales *Orcinus orca*

Killer whales are little known along Australia's southern coast, with only six sightings recorded over 12 years during BWS aerial surveys (Gill *et al.* 2015). The group of 10 sighted on 19 April 2016 was larger than the mean (3.5), and equalled the largest group reported by Gill *et al.* (2015). A calf was present in this group (Figure 6.6), the first sighted during BWS aerial surveys. Killer whales prey on baleen and toothed whales, dolphins, seals, sharks, fish and cephalopods in Australian waters (Morrice 2004).

Figure 6.6. Adult female killer whale and young calf sighted on the aerial survey on 19 April 2016.

6.3.6 Risso's dolphins *Grampus griseus*

During aerial survey EGAB1 a group of Risso's dolphins recorded (Figure 6.7). BWS has only sighted one other group of Risso's during many years of surveys between the GAB and western Bass Strait. The earlier sighting (February 2012) was only 50 km east of the recent sighting, remarkably close given the scale of aerial survey coverage over the years.

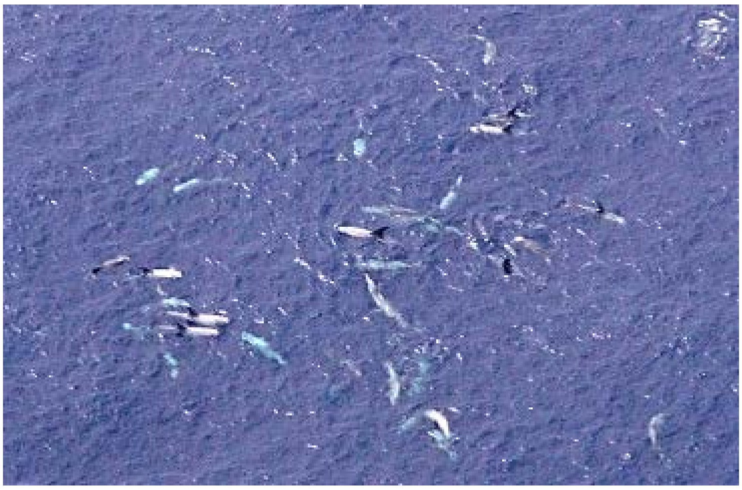

Figure 6.7. A group of Risso's dolphins sighted on the aerial survey on 10 December 2015, showing the pale coloration and large dorsal fins typical of adults.

While Ross (2006) states that Risso's dolphins have been recorded from all States and Territories of Australia, except the Northern Territory, Jefferson *et al.* (2013) state that they have been recorded only off Australia's east coast. Little is known of their ecology and nothing of their movements (Ross 2006). Further surveys are required to assess the significance of the GAB to this species. Group size in the 2012 sighting was 40 and depth was 339 m, compared with the group size of 60 and depth of 458 m during EGAB1. A range of size classes was evident in both sightings, and in both sightings their behaviour was described as 'milling' (apparent random direction of movement) and 'socialising' (frequent interactions between individuals). Such behaviour may be common during daylight. In the Northern Hemisphere, Risso's dolphins feed mostly at night, exclusively on squid (Baird 2002).

6.3.7 Other dolphin species

Unidentified dolphins (dolphin sp.) were the most commonly recorded cetacean during the surveys, with 31 sightings (mean group size 29, mean depth 149 m). Group size was half that (58) reported by Gill *et al.* (2015) from 384 sightings at a mean depth of 134 m.

Figure 6.8. Socially active bottlenose dolphins sighted on the aerial survey on 20 April 2016. The surfacing posture and pigmentation of the animal at lower left enabled identification of it as *Tursiops* sp., probably *T. truncatus.*

The majority of dolphins sighted were most likely short-beaked common dolphins *Delphinus delphis* (e.g. Bilgmann *et al.* 2008; Hamer *et al.* 2008), a species that is poorly understood in terms of population demography and movements. Bottlenose dolphins were also sighted on the 2015-16 surveys. They are represented by more than one species in this region (Segawa and Kemper 2015). Given the offshore locations of both bottlenose dolphin sightings, they are likely to have been common, or offshore bottlenose dolphins *Tursiops truncatus.*

6.3.8 Unidentified whales

Three unidentified whales sighted briefly on the aerial survey of 19 April 2016 were likely to have been beaked whales. They were ~5-6 m long and appeared light grey. Possible candidate species which have been recorded from either sighting and / or stranding records from southern Australia are: Cuvier's beaked whale *Ziphius cavirostris*; Gray's beaked whale *Mesoplodon grayi*; True's beaked whale *Mesoplodon mirus*; and the strap-toothed beaked whale *Mesoplodon layardii* (Groom and Coughran 2012; Coughran *et al*. 2014; Gill *et al.* 2015; Segawa and Kemper 2015). These deep-diving, squid eating whales live in remote offshore waters, are cryptic in habit and rarely observed.

Shepherd's beaked whales *Tasmacetus shepherdi*, sighted twice to the west of Kangaroo Island in recent years (Marine Conservation Research International 2013, Gill *et al.* 2015), were ruled out as their very distinctive pigmentation was not apparent during the brief sighting of these three whales.

6.3.9 Past aerial surveys of the eastern GAB by BWS

BWS first conducted aerial surveys in the eastern GAB in December 2003. Surveys before those of 2015-16 covered the shelf break south, as well as west of Kangaroo Island. The months and years within which BWS conducted surveys in this region, and species observed during these surveys, are given in Table 6.4. Figure 6.9 (copied from Gill *et al.* 2015) summarises regional aerial survey effort between 2003 and 2012, using a 25x25 km grid. The target species for these surveys was the pygmy blue whale, and other species were recorded whenever encountered.

High variability in cetacean abundance was found in the eastern GAB during past seasons (Table 6.4). Patchy temporal effort makes it difficult to draw significant conclusions from these data.

Blue whales were numerous in December 2003 and December 2005, and at these times the eastern GAB and Kangaroo Island region appeared to be the primary regional foraging ground for this species, as very few were found simultaneously in the adjacent Bonney Upwelling region (Gill *et al.* 2011). In December 2003, large krill surface swarms were seen in areas where blue whales were abundant and surface feeding was frequently observed. December 2003 also showed the highest species diversity including both mysticete and odontocete cetaceans (5 species). The only other months during which blue whales were sighted were November and December 2011, and they were in very low numbers. During the remaining six surveys, no blue whales were sighted.

Pilot whales were the most frequently encountered species during these prior surveys (4 times), followed by dolphins (3) and sperm whales (3). Dolphins were numerically the most abundant 'species' encountered overall, followed by pilot whales. February 2012 was an exceptional month as Risso's dolphins and Shepherd's beaked whales were encountered, both previously unsighted during BWS surveys. At the time this was one of fewer than 10 sightings of free-swimming Shepherd's beaked whales worldwide. During December 2004, March 2005 and March 2006 there were no sightings of any cetaceans.

Table 6.4. Summary of surveys and sightings of cetaceans on blue whale aerial surveys in the eastern GAB and Kangaroo Island region undertaken by BWS. ER = encounter rate (number of encounters per km of survey).

Month and year	N blue whales	Km flown	Blue whale ER*	Other species	Other spp. ER	Other spp. density
2-13 December 2003 (6 surveys)	135	3792	35.6	Minke whale (1) Sperm whales (7) Pilot whales (30) Dolphins (1504)	0.3 1.8 7.9 396.6	0.03 0.16 0.72 36.1
18 April 2004	0	1200	0	Sperm whales (2) Dolphins (74)	1.7 61.7	0.15 5.6
13 December 2004	0	747	0		0	0
29 March 2005	0	246	0		0	0
19 December 2005	33	490	67.3	Pilot whales (65) Dolphins (367)	132.7 748.9	12.1 68.1
29 March 2006	0	872	0	0		
27-28 November 2011	1	1570	0.6	Sperm whales (4)	2.5	0.23
20 December 2011	3	1176	2.6	0		
3-4 February 2012	0	1905	0	Risso's dolphins (40) Pilot whales (30)	21.0 15.7	1.9 1.4
26-27 February 2012	0	1620	0	Shepherd's beaked whales (6)	3.7	0.34
28-29 March 2012	0	1947	0	Pilot whales (565)	290.2	26.4

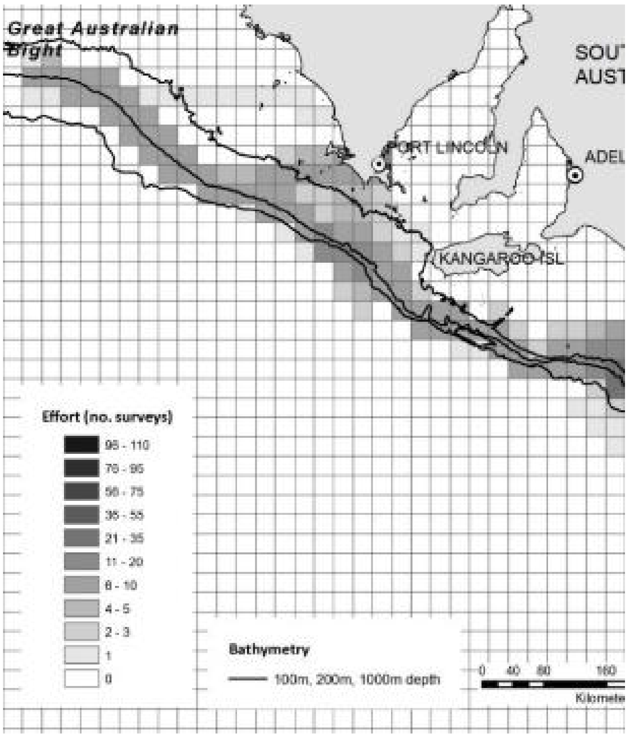

Figure 6.9. Distribution of aerial survey effort in the GAB/KI region by BWS from December 2003 to March 2012. This is a cropped version of Figure 1 of Gill *et al.* (2015).

6.3.10 Cetacean habitat in the eastern GAB

The EGAB presents a diversity of cetacean habitats from the broad gently sloping shelf to the steeper upper slope, and the complex bathymetry of its canyon systems. Enriched water from shelf-break upwelling south of Kangaroo Island accumulates along the shelf edge and is advected into the 'Kangaroo Island Pool', feeding a secondary upwelling, inshore to the west of Eyre Peninsula, making this one of the most productive marine regions around Australia (McClatchie *et al.* 2006; Ward *et al.* 2006).

These surveys have confirmed that the outer shelf and upper slope region of the GAB are likely foraging habitat for a diversity of cetacean species. Gill *et al.* (2011, 2015) have previously found a diversity of species in this region including pygmy blue whales, a minke whale, sperm whales, pilot whales, Risso's dolphins, Shepherd's beaked whales and 'dolphin species'. The 2015-16 surveys have added fin whales and killer whales to the list of species recorded by BWS in the EGAB, although both had been sighted previously in the Bonney Upwelling. Both species are rarely sighted off southern Australia. We were able to identify both common dolphins and bottlenose dolphins during the current surveys, also previously known to occur in the region.

During aerial survey EGAB3, numerous dolphins, as well as the only krill surface swarms sighted during the EGAB surveys, were sighted in the previously unsurveyed (at least by BWS) upwelling zone west of Eyre Peninsula, underlining its potential as a cetacean aggregation area. Further surveys should be considered for this area during future upwelling seasons.

Distribution of species in the 2015-2016 aerial surveys generally conformed to what is known of their ecology, and results of past surveys in the region. Sperm whales were found in deeper, steeper terrain on the upper slope than other species. Pilot whales, killer whales, Risso's dolphins and 'like' beaked whales were also on the upper slope, but in shallower depths and gentler slopes than sperm whales. These findings were consistent with those of Gill *et al.* (2015). Risso's dolphins occur from tropical to temperate regions, but our GAB sightings are consistent with a preference elsewhere for shelf and slope waters in temperate regions (Jefferson *et al.* 2013).

6.3.11 Possible environmental influences on survey results

The results shown in Tables 6.2 and 6.3 indicate striking temporal differences in species diversity and abundance between surveys. The December and January-February (EGAB1 and EGAB2) surveys were alike in their low species diversity and low numbers of sightings overall. In contrast, the April survey (EGAB3) showed both higher species diversity and abundance, and a wider distribution of sightings.

This upwelling system demonstrates clear seasonality in upwelling intensity and primary productivity (Ward *et al.* 2006; Nieblas *et al.* 2009; Gill *et al.* 2011). Peak upwelling intensity tends to occur in February and peak primary production in February-March, although considerable variability has been noted between seasons (i.e., years) in both timing and intensity (Nieblas *et al.* 2009; Gill *et al.* 2011). This is highly likely to influence variability in cetacean sightings between seasons (e.g. compare 2003–04 and 2004–05, Table 6.4).

Figure 6.9 shows 5-day mean upwelling intensity index (UII) for the 2015–16 upwelling season. Values for this season are compared with a combined mean from the 13 previous seasons. After a strong downwelling event in late November-early December 2015, there were two strong upwelling events in December, with the EGAB1 survey taking place during the first of these events. This was followed by a period of sustained upwelling from the end of December until mid-February, with EGAB2 taking place during this period. After a brief period of negative wind stress, strong upwelling resumed between 10–30 March. Survey EGAB3 took place in the subsequent period of downwelling.

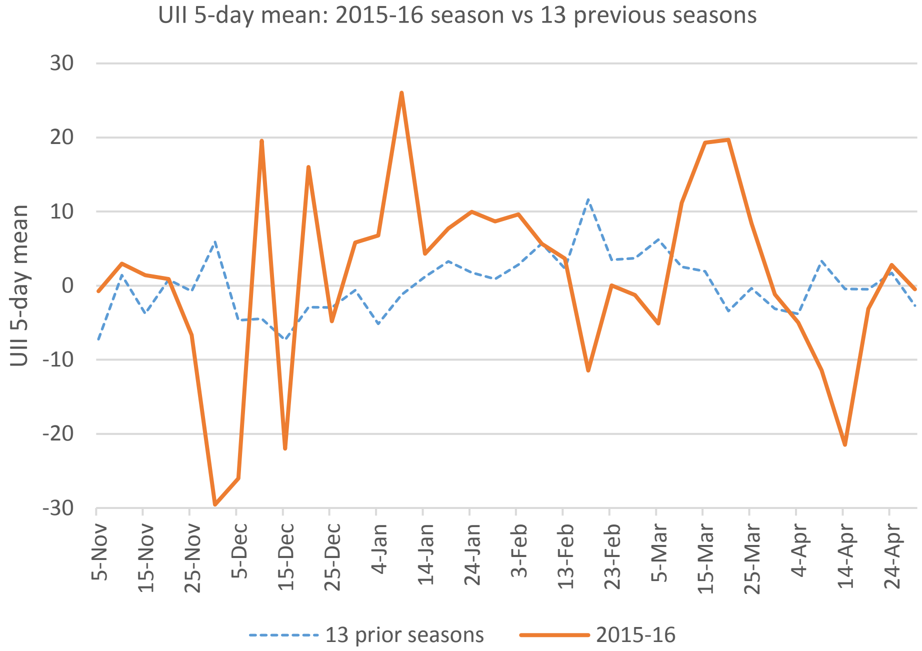

Figure 6.9. Five-day mean upwelling intensity index (UII) derived from 1500 h daily wind data from Cape Nelson, Victoria (using methods of Van Ruth *et al.* 2010). The 2015-16 season is compared with the mean from the 13 previous seasons. Positive values = upwelling-favourable wind stress; negative values = downwelling-favourable wind stress.

Comparison with the 13 previous seasons showed that 2015-16 was a relatively strong upwelling season, despite a very weak start in November, with upwelling events spread across much of the season. Presumably this sustained upwelling resulted in significant nutrient input into the EGAB. The low numbers of cetaceans observed during EGAB1 and EGAB2 are consistent with low levels of primary production typically observed early in upwelling seasons (e.g. Nieblas *et al.* 2009; Gill *et al.* 2011). The increased diversity and abundance recorded during EGAB3 are consistent with the hypothesis that primary and secondary production, and cetacean abundance in upwelling systems, usually approach their maxima several months after the onset of an upwelling season (e.g. Croll *et al.* 2005).

Evidence for enhanced productivity late in the upwelling season was provided by the MODIS AQUA chl-*a* data. Figure 6.10 shows mean monthly composite data for the sampling area. Mean chl-*a* levels were relatively low from November 2015 to February 2016, which appeared low given sustained upwelling early in the month (Figure 6.9).

Mean chl-*a* levels peaked during the sustained upwelling of March (highest individual value = 19.1 mg. m^{-3}), then remained relatively high during April (highest individual value = 9.0 mg. m^{-3}). Enhanced levels of primary production evident during March and April were likely available to higher trophic levels, ultimately including the cetaceans observed during the surveys.

These results are exploratory only. Sightings and environmental data presented in this report could be integrated with other published data (e.g. Gill *et al.* 2011, 2015) to further model the distribution and occurrence of cetaceans in the GAB.

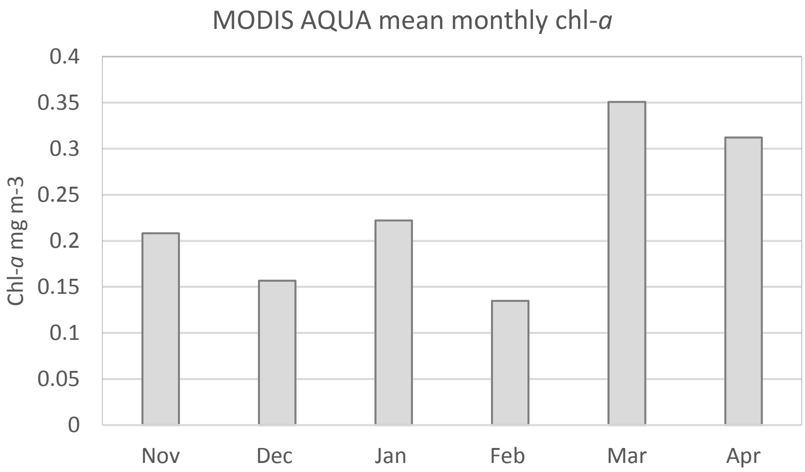

Figure 6.10. Mean monthly composite MODIS AQUA chl-*a* data for the 2015-16 upwelling season.

6.4 Acknowledgements

Thanks to observers, Dr Andrew Levings, Vincent Antony and Dr Maria Garcia for their hard work in the air. Thanks also to pilot Andrew Merwood and the operations staff at GAMair for fitting in with our unpredictable schedule.

6.5 Appendices

Appendix 6.1. All cetacean sightings in aerial surveys of the eastern GAB, December 2015 to April 2016

Date	Local time	Species	No.	Apparent behaviour	Latitude	Longitude	Depth m	Slope m/km	Notes
09-Dec-15	10:44	dolphins	5	not recorded	-37.865	140.092	86	0.2	
09-Dec-15	10:55	dolphins	10	feeding	-37.625	139.757	80	0.2	
09-Dec-15	11:32	dolphins	20	not recorded	-37.050	138.403	103	0.7	near many krill swarms
09-Dec-15	11:48	dolphins	50	not recorded	-36.981	137.746	160	3.2	moving fast in tight groups
09-Dec-15	12:07	dolphins	30	not recorded	-36.659	137.077	126	0.1	moving fast in tight groups
09-Dec-15	12:08	dolphins	50	not recorded	-36.644	137.041	154	1.8	moving fast in tight groups; many albatrosses
10-Dec-15	9:20	dolphins	100	fast travel east	-34.936	135.415	88	0.1	
10-Dec-15	9:50	sperm whale	1	defecated	-35.199	134.317	756	4.5	large male likely foraging & re-oxygenating
10-Dec-15	11:39	Risso's dolphins	60	milling, socialising	-33.450	130.804	458	1.3	obvious social inter-actions, calves in group
31-Jan-16	9:49	dolphins	200	not recorded	-37.348	139.215	196	2.1	big scattered school
31-Jan-16	10:32	dolphins	40	not recorded	-36.756	137.276	122	1.1	
31-Jan-16	10:39	dolphins	50	fast travel	-36.601	136.960	126	0.1	
31-Jan-16	11:09	dolphins	5	not recorded	-36.355	136.200	142	0.2	
31-Jan-16	11:13	like sperm	1	dived	-36.401	135.999	1371	10.9	large whale with forward-angled blow
01-Feb-16	9:50	dolphins	10	milling	-34.983	135.511	92	0.2	
02-Feb-16	13:11	blue whale	1	feeding	-37.410	139.655	59	0.1	adult whale; lunge fed near front; no krill visible
02-Feb-16	13:39	dolphins	8	travel	-38.154	140.409	123	0.1	
02-Feb-16	13:46	dolphins	30	milling	-38.247	140.703	118	0.5	
18-Apr-16	10:01	dolphins	50	feeding	-36.599	137.068	110	0.1	
18-Apr-16	10:08	blue whale	1	diving	-38.284	140.811	97	0.5	no krill sighted this area
18-Apr-16	10:19	blue whale	1	feeding	-38.153	140.570	62	0.1	surface lunge feeding on small scattered krill
18-Apr-16	12:09	dolphins	10	milling	-36.537	136.302	628	10.6	likely common dolphins; gannets & albies this area
18-Apr-16	12:10	dolphins	3	surfaced	-36.514	136.238	652	13.5	like commons
18-Apr-16	12:50	dolphins	3	surfaced	-35.766	135.479	303	4.1	like commons
18-Apr-16	13:03	pilot whales	300	fast travel	-35.607	135.216	240	3.8	very active group moving fast to west; some calves
19-Apr-16	10:22	dolphins	2	surfaced	-34.953	135.443	91	0.0	
19-Apr-16	10:39	pilot whales	40	slow travel	-35.383	134.754	167	1.0	
19-Apr-16	10:42	fin whale	1	slow travel offshore	-35.399	134.750	225	4.3	blew 3-4 times, dived 3 min then resurfaced. No krill. Near groups of pilots
19-Apr-16	10:45	pilot whales	30	milling	-35.399	134.731	334	5.6	socially active, at least 4 calves present
19-Apr-16	10:49	pilot whales	20	active	-35.414	134.743	430	6.7	near fin whale and other pilot groups
19-Apr-16	10:58	sperm whales	2	blowing	-35.285	134.433	1265	3.8	two large whales near each other
19-Apr-16	11:00	sperm whale	1	blowing; dived	-35.277	134.387	942	2.9	blew several times then fluke up dive
19-Apr-16	11:07	pilot whales	50	milling	-35.145	134.174	844	3.4	milling
19-Apr-16	11:09	pilot whales	40	milling	-35.130	134.158	783	3.0	milling
19-Apr-16	11:11	pilot whales	40	milling	-35.104	134.093	966	2.0	milling
19-Apr-16	11:13	pilot whales	40	slow travel	-35.136	134.073	494	2.5	not recorded
19-Apr-16	11:22	killer whales	10	fast travel	-34.982	133.786	461	3.0	no adult males seen; at least one mother-calf pair

19-Apr-16	11:36	unidentified whales	3	dived	-34.901	133.461	428	2.0	larger than pilots - grey – like beaked whales?
19-Apr-16	12:02	pilot whales	6	fast travel	-34.405	132.772	364	1.1	
19-Apr-16	13:01	pilot whales	30	travel	-33.454	130.983	129	0.1	at least one calf present
Date	Time	Species	Number	Apparent behaviour	Latitude	Longitude	1296	4.4	Notes
19-Apr-16	13:46	bottlenose dolphins	25	tight group	-33.682	132.308	129	0.1	pale grey with dorsal cape
19-Apr-16	14:05	dolphins	30	tight group	-34.331	132.956	127	0.1	
19-Apr-16	14:06	dolphins	100	scattered	-34.348	132.979	132	0.3	
19-Apr-16	14:41	dolphins	1	not recorded	-35.107	134.514	41	0.5	
20-Apr-16	10:22	dolphins	2	surfaced	-34.680	135.133	76	0.2	
20-Apr-16	10:34	common dolphins	3	fast travel	-34.460	134.985	82	0.0	hourglass pattern of *Delphinus* on breaching animal
20-Apr-16	10:45	dolphins	3	not recorded	-34.251	134.963	78	0.0	
20-Apr-16	10:45	dolphins	50	not recorded	-34.233	134.930	75	0.1	
20-Apr-16	11:22	dolphins	2	not recorded	-33.588	134.299	71	0.1	
20-Apr-16	11:24	dolphins	6	not recorded	-33.597	134.225	84	0.1	
20-Apr-16	11:44	dolphins	15	not recorded	-33.923	133.814	93	0.0	
20-Apr-16	12:02	dolphins	4	not recorded	-34.407	134.026	96	0.0	
20-Apr-16	12:06	dolphins	5	not recorded	-34.491	134.221	172	0.9	
20-Apr-16	14:03	pilot whales	50	slow travel	-37.359	139.232	117	0.5	tightly grouped; several calves
20-Apr-16	14:07	bottlenose dolphins	500	very active; socialising	-37.420	139.362	65	0.3	milling, breaching and otherwise very active; many calves present
20-Apr-16	14:29	dolphins	3	not recorded	-38.015	140.365	79	0.3	
20-Apr-16	14:30	blue whale	1	feeding likely	-38.052	140.377	124	0.3	dived near krill swarms
20-Apr-16	14:51	blue whale	1	feeding likely	-38.402	141.204	86	0.2	surfaced near small krill swarms
20-Apr-16	14:55	blue whale	1	feeding likely	-38.423	141.312	86	0.2	surfaced near small krill swarms

7. OFFSHORE CETACEAN SURVEYS

Passive acoustic and visual survey of cetaceans in the Great Australian Bight

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7.1 Executive summary

- The objective of the vessel-based passive acoustic and visual survey for cetaceans was to investigate the diversity and distribution of cetacean species on the shelf break and slope area of the eastern Great Australian Bight (GAB).
- A visual and passive acoustic survey for cetaceans was conducted aboard the *RV Ngerin* over the shelf-break and slope region of a previously unsurveyed area of the eastern GAB.
- The survey followed a systematic line transect design and ~2,108 km of on-transect survey effort was completed between 22 April and 01 May 2015.
- In total, 56 hours of visual observations and 141 hours of passive acoustic monitoring was conducted. The original survey design could not be completed due to adverse weather conditions.
- Odontocete (toothed whale) vocalisations were detected during 15 discrete acoustic events, 73% of which occurred during periods when no visual effort was undertaken. Eleven events contained non-sperm whale odontocete vocalisations, one of which was visually confirmed to be a group of pilot whales.
- Three on-effort visual sighting events were recorded; 1 sperm whale, 1 unidentified whale and 2 sperm whales. In addition, a group of 100–150 long-finned pilot whales (*Globicephala melas*) were sighted shortly after visual efforts had ceased on one survey day.
- Sperm whales were acoustically detected on four occasions comprising a total of nine individuals. Two sperm whale acoustic events contained a single individual, one event contained three individuals and one event contained four individuals.
- Sperm whale encounters occurred in water depths between 500 and 2000 m. Visual sightings were associated with two of the sperm whale acoustic detection events. In both cases, the number of individuals sighted was lower than detected acoustically, underlining the utility of passive acoustic monitoring for detecting deep diving species.
- The survey was conducted over a very short time period, and therefore, can only be considered a snap-shot of the occurrence of cetacean species in the survey area.
- Maximum entropy modelling was used to predict suitable sperm whale habitat in the GAB region using presence only data. Datasets modelled included historical whaling data, International Whaling Commission catch data, Marine Mammal Observer data collected during seismic surveys, and sightings data collated under the National Whale and Dolphin Sightings and Strandings Database.

- Further data on the temporal and spatial distribution of cetacean species in the shelf-break and slope regions of the GAB are required to assess potential impacts on these species if there is an increase in human activities in these areas.

7.2 Introduction

There have been few systematic surveys of cetacean species in these waters; these are restricted to a passive acoustic vessel based survey off Albany WA (Johnson et al. 2016), an aerial survey for sperm whales off Albany, WA (Carroll *et al.* 2014), aerial surveys for pygmy blue whales along the Bonney Upwelling coast and eastern GAB (Gill *et al.* 2015; Section 6) and a single visual and passive acoustic survey of the shelf and shelf-break west of Kangaroo Island (Marine Conservation Research International 2013). Systematic aerial and vessel based surveys of the eastern GAB have provided information on the at sea distribution and diversity of cetacean species in this region, and have recorded the occurrence of seven baleen whale species and seven odontocete species (Marine Conservation Research International 2013; Gill *et al.* 2015, Section 6).

There is a network of Commonwealth Marine Reserves within these marine bioregions, and in the Great Australian Bight (GAB) these include the Bremer Commonwealth Marine Reserve in the west, the GAB Commonwealth Marine Reserve in the central GAB, and the Western and Southern Kangaroo Island Commonwealth Marine Reserves, and the Murray Commonwealth Marine Reserve in the East (Figure 7.1). The GAB is also an important area for human activities, including commercial and recreational fishing, oil and gas exploration, and tourism. Petroleum exploration in the GAB has been undertaken since the late 1960s, and to date 24 wells have been drilled in the offshore waters of South Australia, and between 1966 and 2015, 130 seismic surveys were conducted (DSD 2016). Since 2011, a number of new permits have been released in the Ceduna and Duntroon Sub-basin's west of Kangaroo Island (Figure 7.1). Petroleum exploration and extraction increases anthropogenic noise in the ocean environment, including from an increase in vessel traffic to and from extraction sites (Hildebrand 2009). Improved information on the distribution, abundance and habitat use of cetaceans in the region will assist managers and regulators to assess and mitigate potential impacts of such activities on these species.

Pygmy blue whale

Blue whales are listed as Endangered under the EPBC Act and a recovery plan for this species came into effect in 2015 (DoE 2015a). The Bonney Coast Upwelling region and eastern GAB are significant areas for feeding aggregations of pygmy blue whales during the upwelling period between November and May each year (Gill *et al.* 2002, 2011). Pygmy blue whales are filter feeders that forage on neritic euphausiids which occur on shelf waters during the upwelling period (Gill *et al.* 2011). Aerial surveys for blue whales have been undertaken since late 2003 from western Bass Strait to the eastern GAB (Gill *et al.* 2011, Section 6).

In the eastern GAB, west of Kangaroo Island, blue whales have been sighted in both on-shelf and off-shelf waters (Gill *et al.* 2011). In this region, nutrient-rich upwelled water remains in an area known as the Kangaroo Island Pool until subsequent upwelling events (McClatchie *et al.* 2006). The formation of this pool appears to be linked to localised upwelling in shelf-break canyons south of Kangaroo Island (Kämpf 2010). These canyons, along with the Kangaroo Island Pool and adjacent shelf-breaks, are identified as a key ecological feature of the region (DoE 2015b). Feeding aggregations of pygmy blue whales also occur predictably in the area of the Perth Canyon in Western Australia where the canyon promotes localised upwelling (Rennie *et al.* 2009). Genetic analyses indicate that individuals feeding in the eastern GAB and Western Australia belong to a

single population (Attard *et al.* 2010), and individuals photo-identified in the Bonney Upwelling region have previously been sighted in the Perth Canyon and Geographe Bay, Western Australia. A pygmy blue whale that was satellite tagged in the Perth Canyon was tracked to the subtropical frontal zone, south of the GAB after it had returned from a migration to potential breeding grounds in Indonesian waters (Double *et al.* 2014).

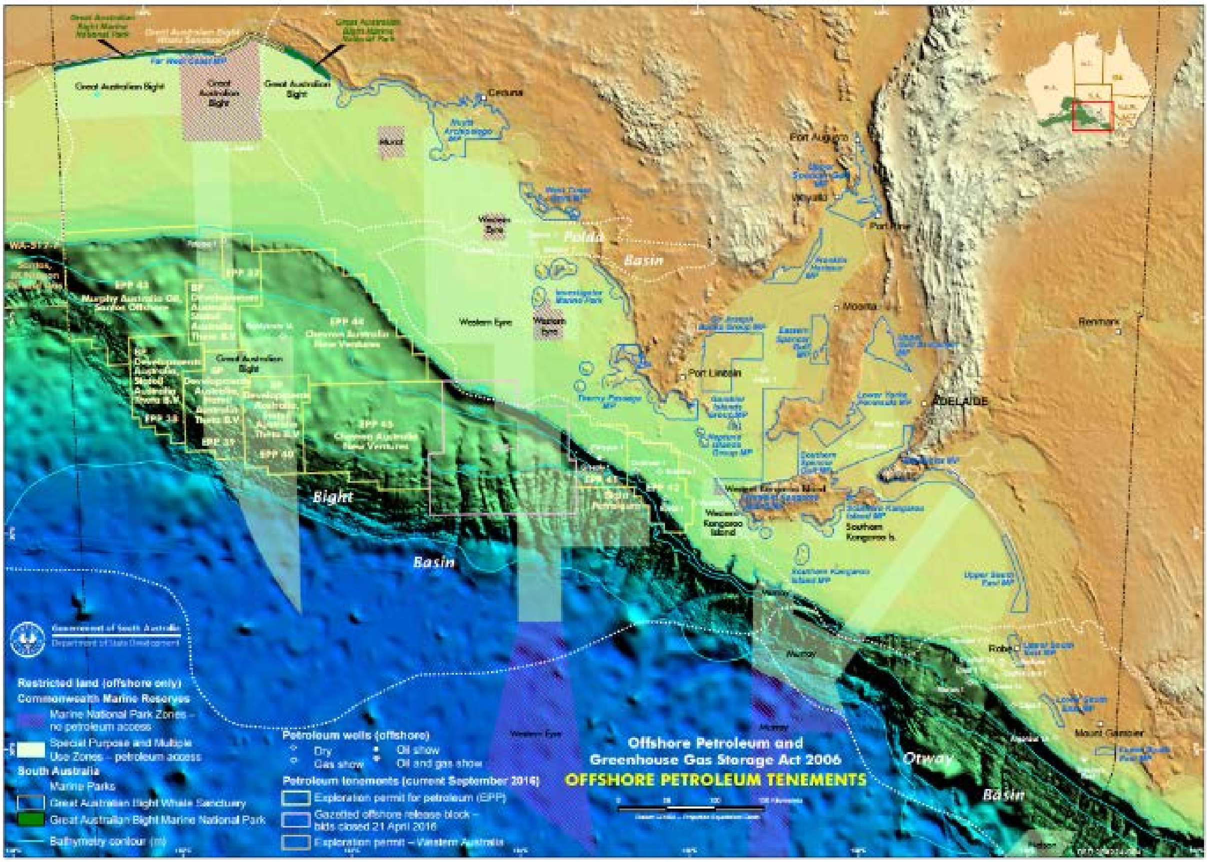


Figure 1. Map indicating Commonwealth Marine Reserves and Petroleum tenements in the central and eastern Great Australian Bight. Marine reserves are Great Australian Bight, Western Eyre, Western and Southern Kangaroo Island, and Murray Commonwealth Marine Reserve. © Department of State Development, Government of South Australia.

Southern right whale

Southern right whales are listed as Endangered under the EPBC Act and a recovery plan for the species was updated in 2012 (DSEWPaC 2012a). In contrast to pygmy blue whales, southern right whales migrate from higher latitude feeding grounds (between 40°S and 65°S) to Australia to calve and nurse in protected coastal waters (DSEWPaC 2012a). Whales begin to arrive at coastal aggregation sites from May and females spend 2-3 months nursing their calves in shallow sheltered waters before migrating offshore. Most southern-right whales leave these aggregation sites by October (Burnell and Bryden 1997). In the GAB region, the south-western southern right whale population is predominantly distributed between Cape Leeuwin, Western Australia and Ceduna, South Australia (Bannister 2011). Key coastal aggregation and calving grounds are Doubtful Island Bay and Israelite Bay areas in Western Australia, and the Head of Bight in South Australia. Coastal abundance of southern right whales is recorded annually during the peak of the calving season from aerial surveys conducted between Cape Leeuwin and Ceduna since 1976 (Bannister *et al.* 2011), and the Head of Bight aggregation has also been the focus of a long-term photo ID and census study

(Charlton *et al.* 2015). The current population estimate for the south-western population is 3,500 individuals (Bannister 2011). Aerial surveys of southern right whale distribution have also been conducted from Ceduna to the WA border (Mackay and Goldsworthy 2015) and near Ceduna and Coffin Bay (Section 5).

Sperm whale

The sperm whale is listed as migratory under the Bonn Convention, and currently there is no Recovery Plan for this species. Sperm whales were a key target species for whaling operations. Whitehead (2002) estimated that current global sperm whale populations were only 32% of their pre-whaling level. Sperm whales were heavily exploited in southern Australian waters and industrial whaling operations were conducted off Albany, WA, from April to November each year between 1955 and 1978 (Carroll *et al.* 2014). There is no current abundance estimate for this species and very little information on their temporal and spatial distribution and habitat use in Australian waters. Sperm whales have a wide distribution and are found in all oceans from the equator to both poles. Sperm whales segregate by sex and age; adult females and their immature offspring form long-term social units, while mature males (bulls) are typically solitary (Whitehead 2003). Long-distance movements of both male and female sperm whales have been recorded (Mizroch and Rice 2013), although females are thought to generally remain in tropical and temperate regions (Whitehead 2003), while sperm whales found at higher latitudes are generally large bulls. Sperm whale distribution has been shown to be associated with areas of high primary or secondary productivity, with topographic features such as sea mounts and canyons (Jaquet *et al.* 2000, Waring *et al.* 2001, Jaquet and Gendron 2002; Moulins *et al.* 2008; Pirotta *et al.* 2011; Di Tullio *et al.* 2016) and with oceanic areas of productivity such as the Sub-tropical frontal zone and Sub-arctic Frontal Zone (Mizroch and Rice 2013). In the eastern GAB, the canyons and adjacent shelf break off Kangaroo Island are a key location for sperm whales (Bannister 2008), and in the western GAB, the Albany canyon group and adjacent shelf break has been identified as an important feeding area (DSEWPaC 2015b). Opportunistic sighting records show the species occurring along the shelf-edge and slope region of the GAB (Kemper *et al.* 2014). The shelf-break of the central and eastern GAB, and off Albany have been identified as important areas for sperm whales where foraging is known to occur (DoE 2015b).

7.2.1 Passive acoustic monitoring

Of the seven odontocete species recorded during systematic surveys in the eastern GAB, four are deep diving species. These are the sperm whale, pilot whale (*Globicephala* sp.), and two beaked whales, Shepherd's beaked whale (*Tasmacetus shepherdi*) and southern bottlenose whale (*Hyperoodon planifrons*). As sperm whales and beaked whales forage at depth (Baird *et al.* 2006; Tyack *et al.* 2006; Watwood *et al.* 2006), the time that individuals are available for detection at the surface during visual aerial or vessel-based surveys is reduced. The likelihood of detection of these species can be increased by utilising passive acoustic monitoring (PAM) techniques (Barlow and Taylor 2005) which have advantages over solely visual methods as acoustic data can be collected 24 hours a day, and are less restricted by poor weather or sea-state conditions.

Sperm whale foraging dives can last up to an hour, with inter-dive surface intervals recorded to last eight to nine minutes (Watwood *et al.* 2006). Passive acoustic monitoring (PAM) works well with this species, as during foraging dives, sperm whales produce stereotyped loud, highly directional regular broadband (10 Hz–30 kHz) echolocation clicks that can be detected over large distances (Weilgart

and Whitehead 1998; Madsen *et al.* 2002). Beaked whale species are also deep divers which are generally difficult to detect visually as they behave inconspicuously at the surface. In the central and eastern GAB, at sea sightings of beaked whales have only been recorded for three species; Shepherd's beaked whale (Marine Conservation Research International 2013; Gill *et al.* 2015), southern bottlenose whale (Gill *et al.* 2015) and Cuvier's beaked whale (*Ziphius cavirostris*) (Kemper *et al.* 2014). This compares to a total of nine species of beaked whale that have been recorded from stranding records along the GAB (Groom *et al.* 2014; Segawa and Kemper 2015). For example, the most frequently stranded beaked whale species in South Australia and the western GAB to Albany, the strap-toothed whale (*Mesoplodon layardii*) (Groom *et al.* 2014; Segawa and Kemper 2015), has not been sighted at sea. Advances in acoustic detection capabilities mean that PAM can also be used to detect beaked whales (Yack *et al.* 2013). Although less information is known about beaked whale acoustic signals, species-specific echolocation pulses have been described for four species, including Cuvier's beaked whale (Yack *et al.* 2013; Zimmer *et al.* 2005, 2008).

While ongoing surveys of blue whales have provided important information on the occurrence and distribution of cetaceans on shelf-break and slope region of the eastern GAB, there is a substantial gap in information on the occurrence of cetaceans in offshore regions of the GAB. All cetacean species are protected in Australian waters under the EPBC Act; such data are essential to determine and assess the overlap of these species with commercial fishing and extractive industries and identify and manage potential risks. These data are also required to inform the ongoing implementation of marine bioregional plans and the management of marine reserves.

Key knowledge gaps identified for cetaceans in the region include baseline information on status and abundance, and information on distribution and habitat use (Rogers *et al.* 2013). These data are important to assess the risk of anthropogenic activities to these species, particularly with respect to the potential for increased noise and shipping in the shelf-break and slope areas of the GAB.

7.2.2 Objectives

The aim of this study was to investigate the diversity and distribution of cetacean species on the shelf break and slope areas of the eastern GAB using a systematic visual and passive acoustic vessel-based survey.

7.3 Methods

7.3.1 Survey design

The survey area covered the shelf-break and slope areas of the eastern GAB (131.4° to 136.4° E), and encompassed depths of 200–2000 m (Figure 7.2). The total survey area was sub-divided into five strata that ran in the same orientation as the shelf-break and slope. Random transect lines were generated within each survey block using the program Distance (http://distancesampling.org/). The aims of the design were to ensure equal survey coverage in the area, and to maximise time on transect within each survey block based on 14 days of ship time. The survey area was chosen to overlap with the western leg of the aerial surveys reported in Section 6.

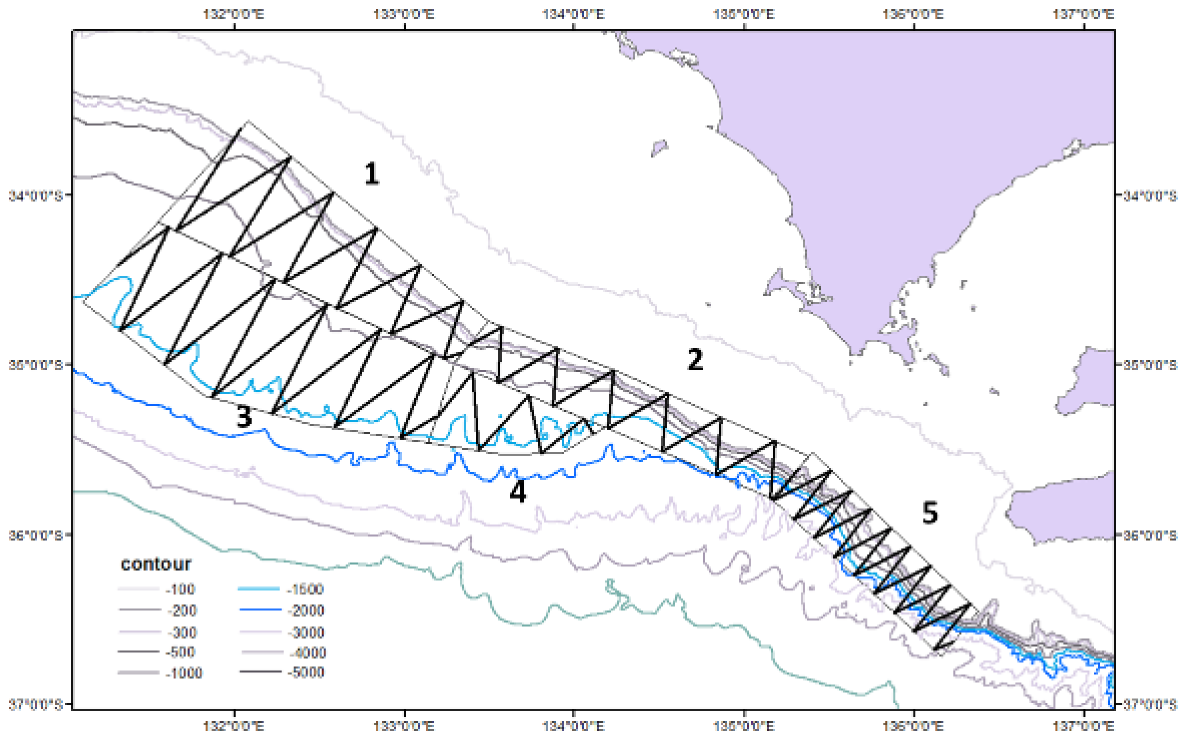


Figure 7.2. Planned survey transect lines for each of the five cetacean survey blocks, encompassing the eastern GAB shelf break and slope.

The survey team comprised four personnel including an experienced PAM operator. Two of the four personnel had extensive cetacean sighting and species identification experience, and visual observation rotation was scheduled so that one of these two observers was on deck at all times during visual observations. Observer locations were rotated between four personnel every hour to reduce the risk of observer fatigue.

7.3.2 Data collection

The survey was conducted aboard *RV Ngerin*. Passive Acoustic Monitoring (PAM) was undertaken 24 hours a day by towing a linear 250 m four channel Seiche^{TM} hydrophone array which comprised two 10 Hz–200 kHz broadband elements spaced 2 m apart, and a pair of 2kHz-200 kHz elements spaced 0.25 m apart and 13 m aft of the broadband elements (Figure 7.3). A depth gauge at the end of the array provided continuous data on hydrophone depth. The hydrophone was towed at a speed of 7–8 knots and at depths of 10–15 m.

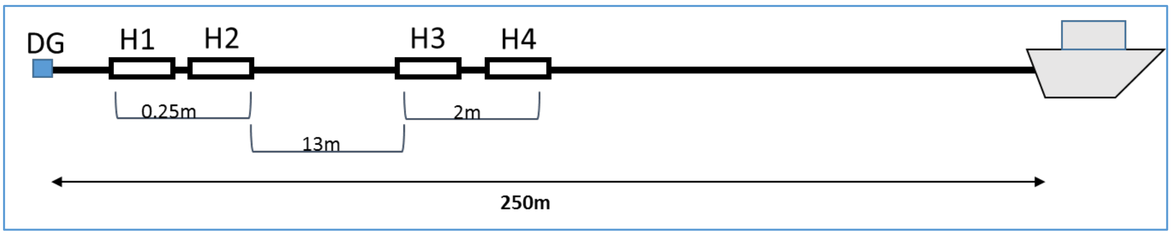


Figure 7.3. Schematic of towed hydrophone array, not to scale. Hydrophone elements are denoted by H1 to H4 and brackets show spacing between elements in metres. DG = Depth Gauge.

Digitised signal output from the hydrophone array was sent to a computer for signal processing, recording and real time display of acoustic data using PAMGuard (www.pamgaurd.org), as well as display and recording of continuous GPS and hydrophone depth data. Stereo recordings were written to the computer hard drive for post-survey analysis. During deployment, the hydrophone array was monitored aurally for a timed minimum of two minutes every hour to ensure that the acoustic system was operating correctly. During these periods, observers recorded the presence or absence of cetacean vocalisations. Except for short periods when the hydrophone was retrieved for inspection, acoustic data were collected and recorded continuously.

Visual surveys were conducted continuously during daylight hours and in sea states less than Beaufort 5. Two visual observers stood on the deck in front of the wheelhouse, ~ 4m above the water line. Each observer visually scanned the area from in front of the vessel to past the port or starboard beam, covering a ~90˚ angle. Data on wind speed, direction, sea state, swell height, visibility and glare were recorded every hour, or when any of these environmental variables changed. When cetaceans were sighted the species, group size, behaviour, distance and bearing to the vessel were recorded. Observers spent two hours undertaking visual observations (one hour on each side of the vessel) followed by two hours of rest and acoustic monitoring.

7.3.3 Acoustic data analysis

Post-survey analysis of acoustic recordings was conducted using PAMGuard version 1.15.08 Beta. All audio recordings were searched automatically for cetacean echolocation clicks using basic and modified PAMGuard modules for odontocete click and whistles detection. Detected clicks were written to binary files that were then visually inspected in PAMGuard Viewer version 1.15.08 Beta. Identified click trains were grouped to form events, and all events were confirmed by listening to the associated audio recording. All whistles detected automatically were also confirmed in this way. A subset of audio files was also aurally inspected for all survey periods where odontocete vocalisations had not been detected by the PAMguard software. Sperm whale clicks were assigned manually to individual click trains based on bearing and inter click intervals. Target motion analysis was undertaken to estimate detection distance to each sperm whale acoustic event.

7.3.4 Sperm whale distribution model

Maximum entropy modelling (Maxent: Phillips *et al.*; 2006, 2009) was used to predict sperm whale occurrence in the GAB region. The method uses species presence data, background data (pseudo-absences) and environmental predictor variables for the study region, using a machine-learning approach. The general approach of Maxent is to create a probability distribution by contrasting presence data with a random sample of background data (Phillips *et al.*; 2006, 2009). Based on a maximum likelihood method inherent to Maxent, a probability distribution over the pixels in a grid is generated, providing an indication of environmental suitability for a species. Higher values correspond to a prediction of better conditions and higher probability of occurrence. The model was developed using the package "dismo" in R (R Core Team 2015), and presence-only data from a number of sources, for the area of the GAB between 117˚W and 146˚E.

Sperm whale presence data

Table 7.1 provides a summary of sperm whale presence data that were used to develop the distribution model. Sperm whale presence data were collated from datasets that included:

- Digitised charts of Yankee whaling locations of sperm whale catches complied by Townsend (1935);
- International Whaling Commission (IWC) sperm whale catch data for the study region collated by Cherry Allison of the IWC Secretariat from the IWC Individual Catch Database version 6 (2016);
- Marine Mammal Observer (MMO) sightings data collected during seismic surveys of the GAB provided for the Ceduna Multi Client 3D Marine Seismic Survey (November 2011 to May 2012, November 2014 to April 2015);
- Nerites Multi Client3D Marine Seismic Survey (Jan- June 2014, Jan-Feb 2015).

Presence data that included a location and date were included in the final model. As the area of interest was the shelf-break and slope region, any sperm whale presence locations recorded in ≤200 m depth were removed. Figures 7.4 (a and b) show the location of MMO sperm whale and pilot whale sightings during these surveys, along with visual and or acoustic detections from the current survey, and the aerial surveys reported in Section 6.

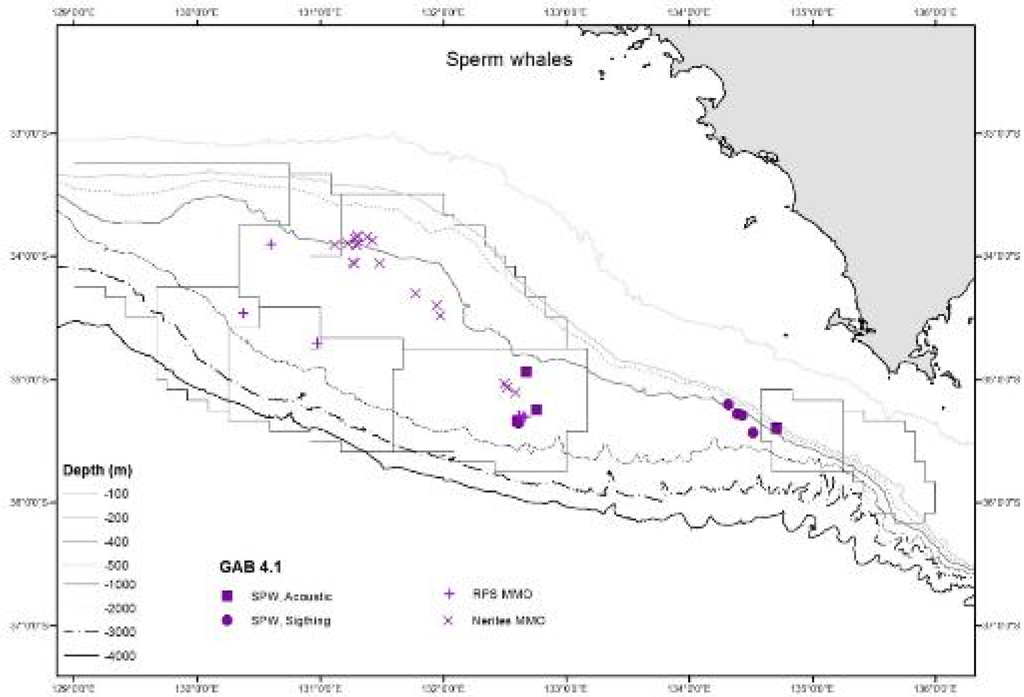
Background data and predictor variables

To deal with potential bias in the occurrence data, the background data in the model were manipulated to reflect the same sample selection bias as the occurrence data. This aims to achieve the same environmental bias in both data sets. Thus, the background data were selected in an area defined by computing the home range of sperm whales using the Minimum Convex Polygon estimator based on the sperm whale presence data.

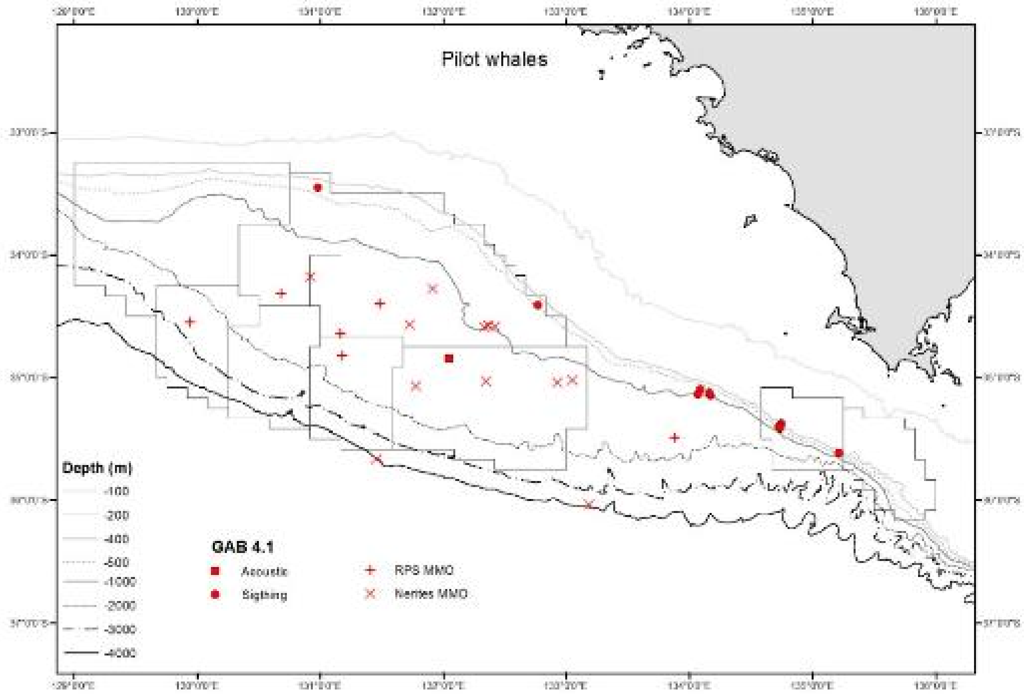
Table 7.1. Sperm whale datasets collated for presence only model.

Dataset	Date range	Source
Sightings data from aerial surveys	May 2013, December 2015, April 2016	Marine Conservation Research International (2013) Final report for a survey of cetaceans in the eastern Great Australian Bight 26 April–8 May 2013. The International Fund for Animal Welfare and Marine Conservation Research International. Section 6 this report
National Whale and Dolphin Sightings and Strandings Database Australian Antarctic Data Centre	1979–1992	Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/103150083) on 2016-11-30 and originated from iOBIS (http:www.iobis.org).
South Australian Museum and OZCAM	1915–2013	MV and SAM Mammals. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/103150083) on 2016-11-30 and originated from iOBIS (http:www.iobis.org).

Marine Mammal Observer data collected during seismic surveys	2011–2012, 2014–2015	Ceduna Multi Client 3D Marine Seismic Survey (November 2011–May 2012, November 2014–April 2015) Nerites Multi Client3D Marine Seismic Survey (Jan-June 2014, Jan–Feb 2015)
IWC individual catch data	1912–1978	Collated by Cherry Allison of the IWC Secretariat from the IWC Individual Catch Database version 6 (2016) and provided to the project by Dr Michael Double, Australian Marine Mammal Centre
Historical whaling data	1913	Yankee whaling charts (Townsend 1935), digitised by the Wildlife Conservation Society (WCS) in 2002. Woolmer, G. 2013. Historical distribution of whales shown by logbook records 1785–1913. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/885) on 2016-11-30.



a.



b.

Figure 7.4. Sperm whale (a) and pilot whale (b) sightings recorded by Marine Mammal Observers (MMO) during Ceduna MC3D Marine Seismic Survey (2011–2012, 2014–2015) and Nerites MC3D Marine Seismic Survey 2014–2015, and acoustic and visual sightings data collected during the current survey and aerial surveys reported in Section 6.

7.4 Results

7.4.1 Acoustic survey

The survey was conducted on six days between 22 April and 1 May 2015. Approximately 2,108 km of on-transect survey effort was completed, resulting in 56 hours of visual observations and 141 hours of PAM (Figure 7.5).

A strong weather system on 24 and 25 April meant the survey had to be halted. All transect lines were successfully surveyed in Blocks 1–4 with the exception of the shortening of one transect line in Block 3 as a seismic survey vessel was present in the northern part of that block. On route to survey Block 5, a further strong weather system developed preventing safe survey of this block. The survey was terminated due to the weather on 1 May 2015.

7.4.2 Cetacean sightings

During the survey, three on-effort visual sighting events were recorded: 1 sperm whale (*Physeter macrocephalus*), 1 unidentified whale and 2 sperm whales. In addition, a group of 100-150 long-finned pilot whales (*Globicephala melas*) were sighted shortly after visual efforts had ceased for the day. Figure 7.6 shows the location of all sightings during the survey.

Sighting conditions during most of the survey were not optimum. The average swell height was 1.5 m (range 0.5–3 m), and the sea state was Beaufort ≥3 during 48% of the visual effort. No visual effort was undertaken on 1 May 2015 as the sea state was Beaufort 5 during daylight hours. The sea state and swell resulted in relatively poor sighting conditions during much of the survey.

7.4.3 Acoustic detections

Odontocete vocalisations were detected during 15 discrete acoustic events, 73% of which occurred during periods with no visual effort. Eleven events contained non-sperm whale odontocete vocalisations, one of which was confirmed visually to be a group of pilot whales. Sperm whales were detected acoustically on four occasions with a total of nine individuals detected. Figure 7.7 shows the location of all acoustic detections. Four events were of distant odontocete vocalisations, when faint whistles were recorded.

Two sperm whale acoustic events contained a single individual, one contained three individuals and one contained four individuals. All sperm whale encounters occurred in water depths of 500 to 2000 m. Visual sightings were recorded in association with two sperm whale acoustic detection events, however the number of individuals sighted was lower in both cases than the number detected acoustically. The group of four sperm whales was associated with a sighting of a single individual, while the group of three sperm whales was associated with a sighting of two individuals.

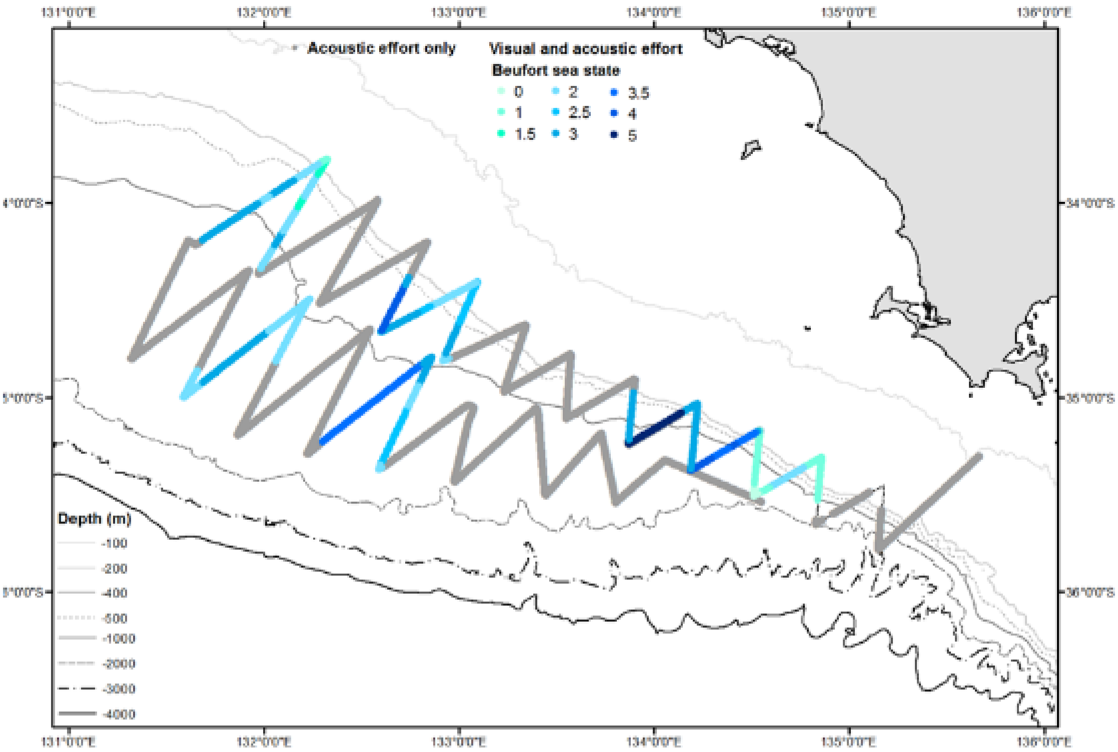


Figure 7.5. Map of completed survey tracks in the eastern Great Australian Bight. Grey lines indicate periods of acoustic only survey effort, blue lines were periods of combined acoustic and visual effort. Blue lines are scaled relative to Beaufort sea state. No visual surveys were conducted above Beaufort 5.

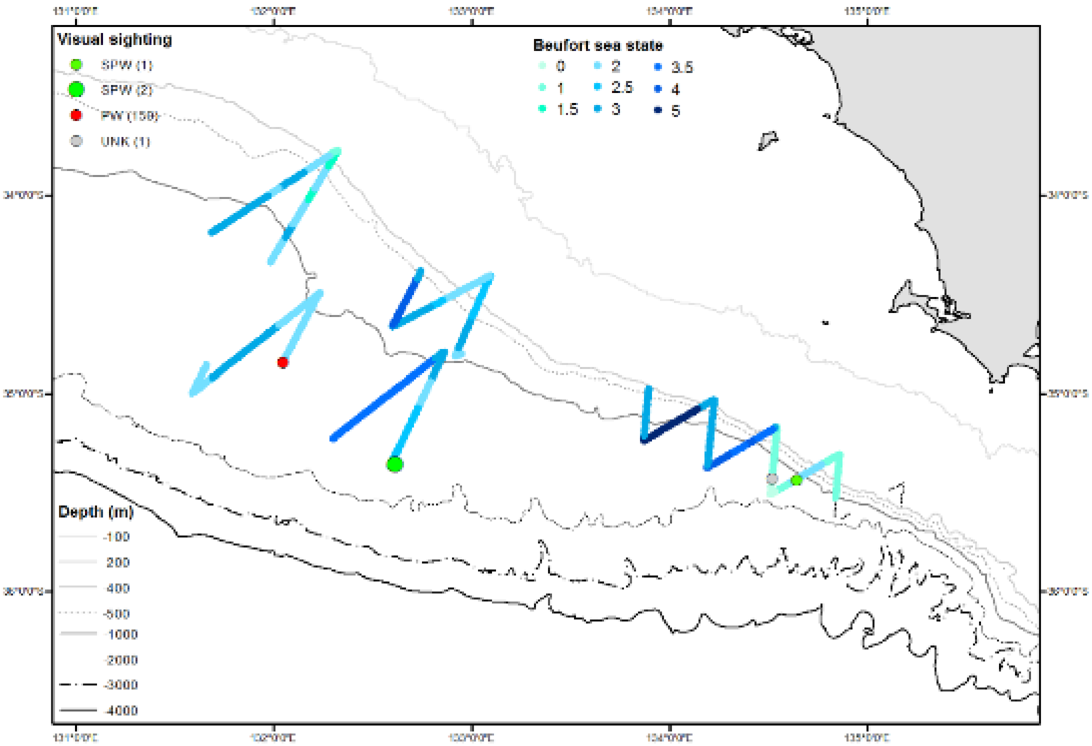


Figure 7.6. Location of three on-effort and one off-effort cetacean sightings in the eastern Great Australian Bight. SPW = sperm whale, UNK = unknown, PW = pilot whale. Numbers in parentheses indicated the best guess of group size. Blue lines indicate periods of visual survey effort. The pilot whale sighting occurred just after visual effort ended on that transect line.

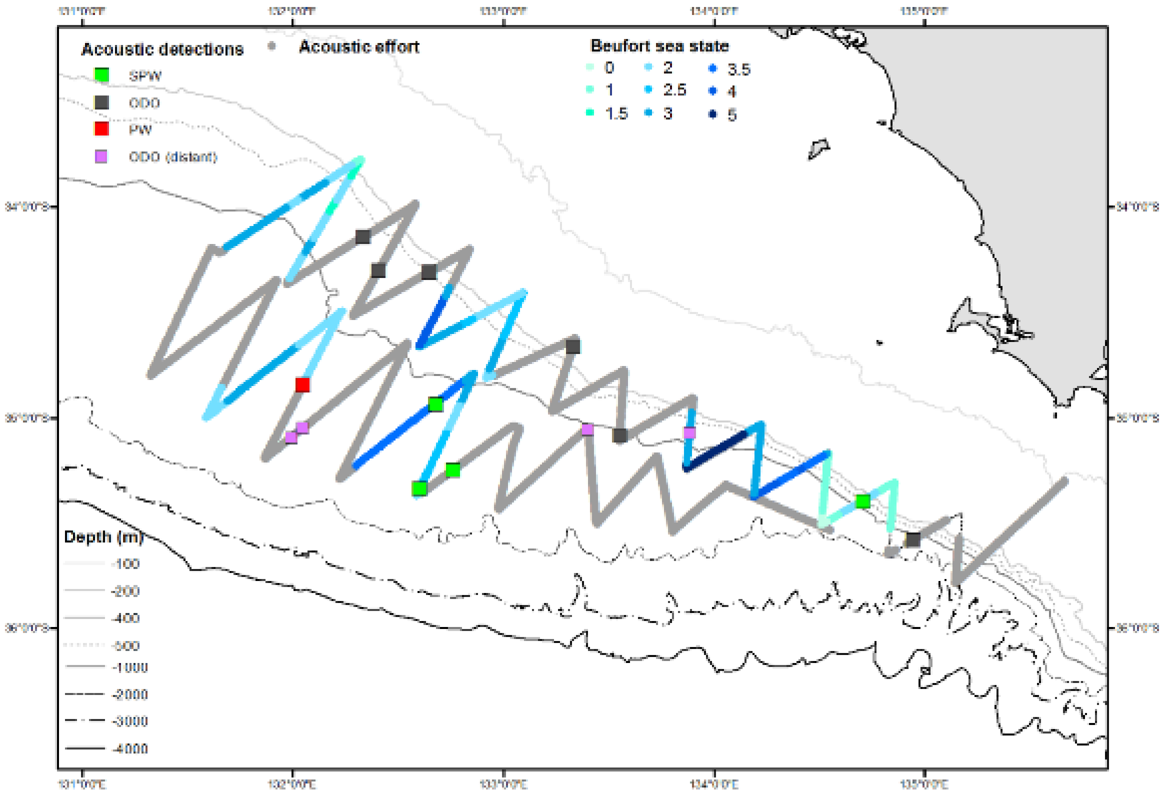


Figure 7.7. Location of odontocete acoustic detections in the eastern Great Australian Bight. SPW = sperm whale, ODO = odontocete vocalisation not classified to species, ODO (distant) = distant vocalisation, PW = pilot whale. Blue lines indicate periods of visual survey effort. The pilot whale sighting occurred just after visual effort on that transect line ended.

Sperm whale click trains are regularly spaced and the bearing of a click train, relative to the hydrophone, changes gradually as the vessel moves past the echolocating individual. Figure 7.8 provides an example of echolocation click trains of three sperm whales that were detected during one encounter and were manually assigned to individual trains in PAMGuard Viewer during data analysis. Acoustic detection distances were calculated using the Target Motion Analysis function in PAMGaurd for each sperm whale acoustic event. The average detection distance of an echolocating sperm whale was 4.6 km, and the furthest detection distance was estimated at 9.3 km. If the estimated strip half-width is estimated at 10 km, then the acoustic density of sperm whales was 0.21 individuals per 1000 km^2. Figure 7.9 shows the location of all cetacean detections in relation to Commonwealth Marine Reserves and oil and gas exploration leases.

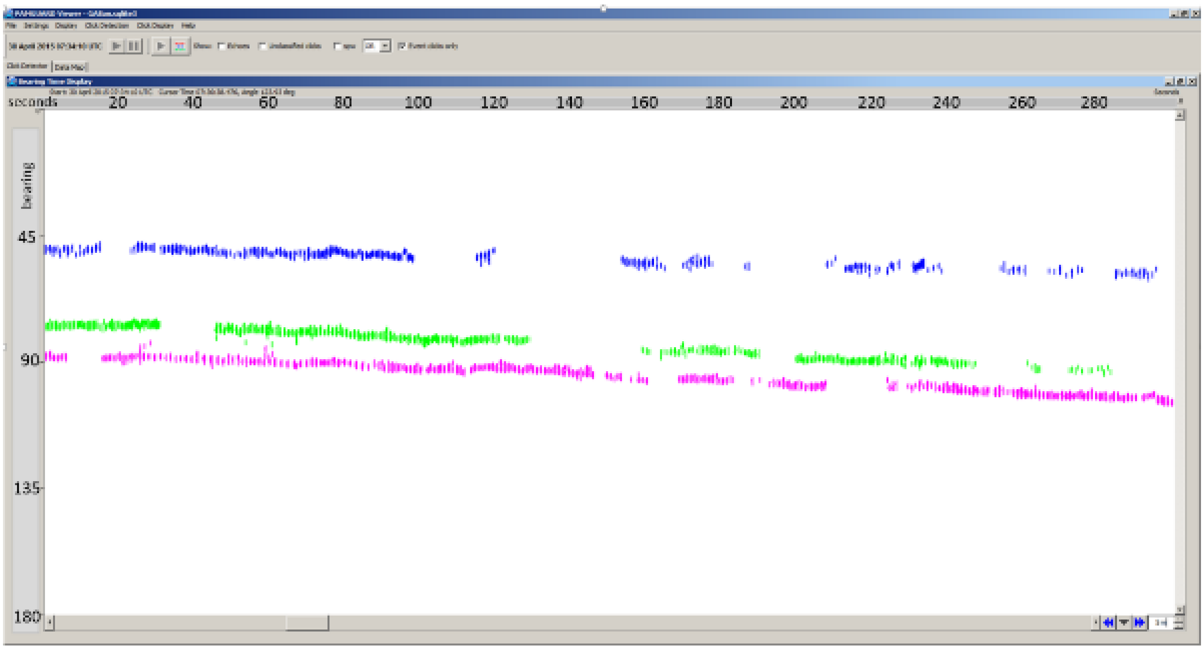


Figure 7.8. PAMGuard bearing-time display showing sperm whale echolocation click trains that have been manually assigned to individuals, with each colour representing a single sperm whale. X-axis shows time in five minute intervals and the y-axis shows bearing relative to the vessel with 0˚ being ahead of the hydrophone and 180˚ being directly behind.

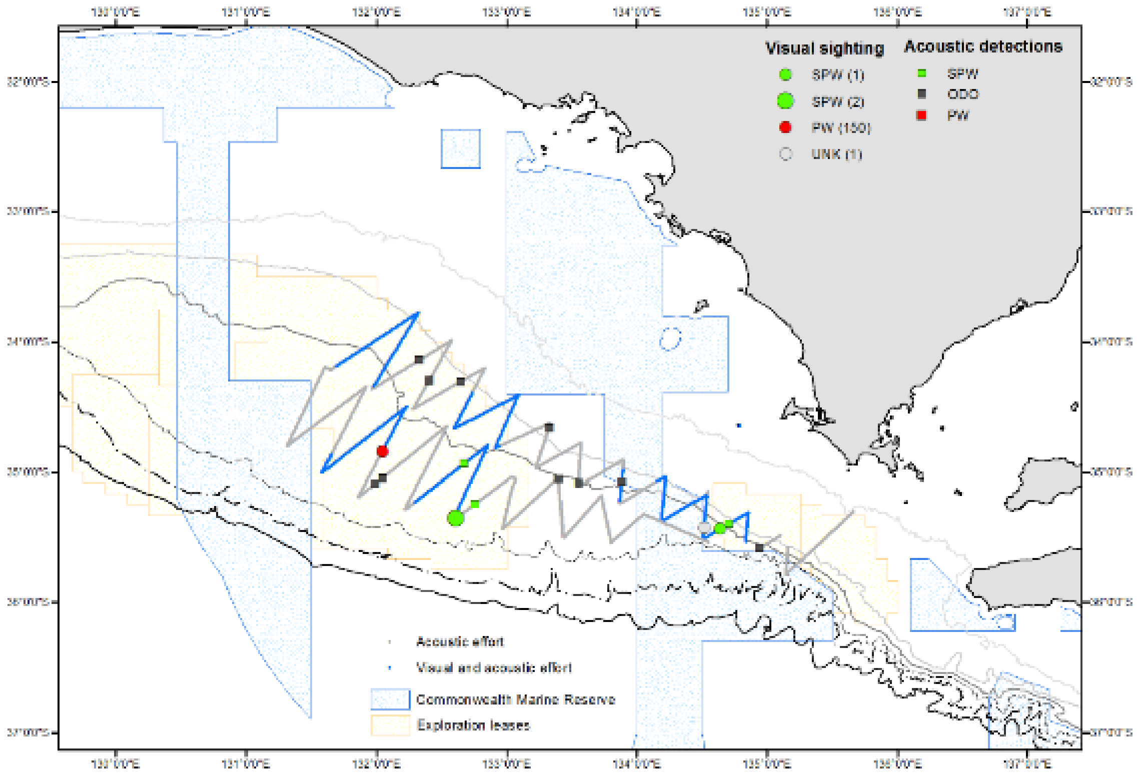


Figure 7.9. Survey track lines with visual sightings and acoustic detections in the eastern Great Australian Bight in relation to Commonwealth Marine Reserves and oil and gas exploration leases. SPW = sperm whale, PW = pilot whale, UNK = unidentified large odontocete, ODO = odontocete acoustic detection (whistles and echolocation clicks). Commonwealth Marine Reserve data © Commonwealth of Australia, Australian Government Department of the Environment and Energy, 2014.

7.4.4 Sperm whale distribution model

All sightings and whaling datasets were used in the final distribution model. The variable which had the largest contribution to the model was bathymetry (depth) (Figure 7.10). Predicted potential sperm whale distribution was highest along the shelf-break and slope (Figure 7.11). It was not possible to include environmental variables in the model as the broad temporal range of the presence data used in the model precluded the use of temporally and spatially dynamic variables such as sea surface temperature.

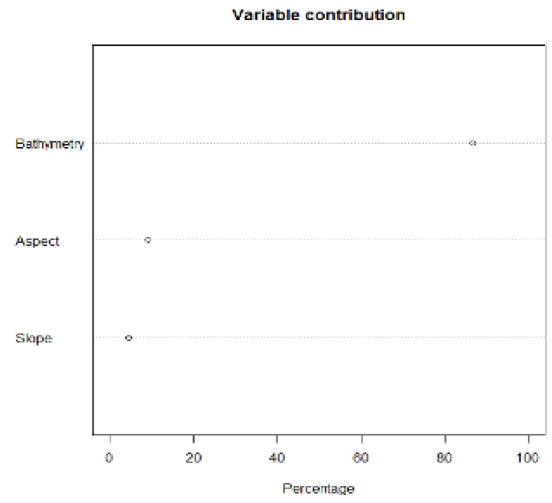


Figure 17.10. Percentage contribution of predictor variables used in the final model of the probability of occurrence of sperm whales in the Great Australian Bight based on presence only sighting and whaling data.

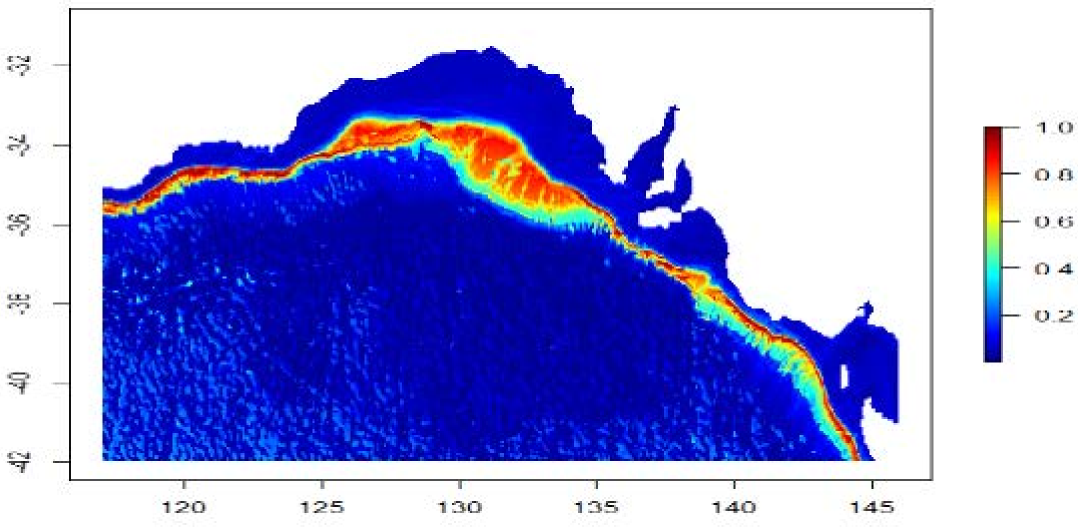


Figure 7.11. Probability of distribution of sperm whales in the Great Australian Bight predicted by a habitat suitability model based on presence only data and the variables bathymetry, aspect and slope. Warmer colours indicate higher probability of distribution.

7.5 Discussion

The results of this survey provide the first snap-shot of the distribution of odontocete cetaceans in a previously un-surveyed area of the eastern GAB in April 2015. The majority (60%) of survey effort was acoustic only effort, during which almost three quarters of all odontocete cetacean detections were recorded, highlighting the importance of incorporating passive acoustic monitoring in vessel-based surveys, particularly for deep diving species. Survey effort was limited by bad weather conditions that reduced the survey effort to six days. As a result, it was not possible to survey Block 5, the area of the shelf-edge south-west of Kangaroo Island.

7.5.1 Sperm whales

All visual and acoustic detections of sperm whales occurred between depths of 500 and 2000 m, and no sperm whales were detected in the area surveyed west of latitude 132.6˚E. The current survey was conducted during a period when a sea noise logger was deployed from 9 December 2014 to 17 November 2015 at a depth of 173 m, south west of Kangaroo Island; it did not detect sperm whales during the length of its deployment (McCauley 2016). However, sperm whales were sighted west of this point by Marine Mammal Observers during the Ceduna MC 3D Marine Seismic Survey in the central GAB in March 2015 (RPS 2015), and were sighted in December 2015 and April 2016 during the eastern GAB aerial surveys for blue whales, and a like sperm whale sighted during the February survey (see Section 6).

During the current survey, sperm whale group size ranged from 1 to 4 individuals. Most acoustic detections of sperm whales during the MCRI study off the south-west of Kangaroo Island were of one or two individuals (Marine Conservation Research International 2013). Gill *et al.* (2015) reported that the majority (68%) of the sperm whale sightings recorded involved solitary mature males, while the remaining groups ranged from 2–12 individuals that were of similar size which they proposed were possible bachelor groups. Male sperm whales typically leave their mothers around 10 years of age, and start to move to colder waters (Whitehead 2003). Adult male sperm whales are either solitary, or they may form loose aggregations of "bachelor groups" (Whitehead 2003). Males become sexually mature between 10 and 20 years of age but may not breed until their late twenties (Whitehead 2003). Males undertake long distance movements between low and high latitudes (Steiner *et al.* 2012). Sexually mature large males are thought to migrate from high latitude feeding grounds to breeding grounds where they move between social units of females in order to mate (Whitehead 2003).

Aerial surveys of the Bonney Upwelling coast and eastern GAB conducted during the upwelling season (2002–2013) had sperm whale visual encounter rates ranging from 0.31–0.62 individuals per 1000 km (Gill *et al.* 2015). The visual detection rate for sperm whales during the current survey was 1.4 individuals per 1000 km, while the combined visual and acoustic detection rate was 4.3 individuals per 1000 km. Based on an assumed half strip width of 10 km, the acoustic density of sperm whales was calculated as 0.21 individuals per 1000 km^2. The only other estimate of the acoustic density of sperm whales in the region was 0.35 individuals per 1000 km^2 from a visual and passive acoustic survey on shelf, shelf-break and offshore waters west of Kangaroo Island in April 2013 (Marine Conservation Research International 2013). Acoustic densities of sperm whales in other regions where sperm whales appear to be present throughout the year include 0.16 individuals per 1000 km^2 in the Tongue of the Ocean, Bahamas (Ward *et al.* 2012), and 0.6–12.1 individuals per 1000 km^2 in the northern Gulf of Mexico (Hildebrand *et al.* 2012).

The IWC commercial whaling records show that 75% (n = 13,249) of the sperm whales taken from 1955 to 1978 between longitudes 117-146˚E were male. These data also show that, although taken in lower numbers, catches of female sperm whales were distributed along the shelf edge and slope of the GAB, and both sexes were taken in all months of the year. Both male and female sperm whales were taken by USSR whalers in the area of the eastern GAB covered by the current survey.

A recent mass stranding of sperm whales at Ardrossan, Yorke Peninsula in December 2014 contained six mature and one immature female (Kemper *et al.* 2015). Three mass strandings of sperm whales in Tasmania in February 1998, totalling 115 individuals, were predominantly composed of mature females, with only 13% recorded as male, all of which were juveniles or calves (Evans *et al.* 2002). Biopsy samples of sperm whales encountered around the Albany Canyon group indicated both males and females were present in the area (Johnson *et al.* 2016) and aerial surveys in that region in 2009 recorded groups of females and immature individuals (Carroll *et al.* 2014).

Adult female sperm whales form social units with other females and can spend their lives in the same social unit (Whitehead 2003). These social units also contain calves and immature animals of both sexes, but do not include mature males. Female sperm whales reach sexual maturity around nine years of age and produce a calf approximately every five years. Sperm whale female social units have generally been found to contain an average of ten individuals (Whitehead 2003). These social units may aggregate with other units to form larger groups that travel or forage together for periods of hours to days (Whitehead 2003). In the Atlantic Ocean, recorded group sizes generally reflect the size of a single social unit, i.e. 8-10 individuals, while in the Pacific Ocean, recorded group sizes were around 28, meaning that groups contained 2-3 different social units (Whitehead *et al.* 2012). The range of female sperm whales has been shown to vary between oceans, with individuals tagged in the Gulf of Mexico shown to range between 200 and 700 km in one year (Ortega-Ortiz *et al.* 2012), while, home ranges of about 2000 km have been recorded in the Atlantic Ocean with occasional long distance movements by some individuals of up to 4,000 km (Whitehead *et al.* 2008).

Bannister (1974; cited in Carroll *et al.* 2014) estimated that 3000 to 5000 sperm whales were caught annually in the southern Australian region, with the main target being mature adult males. By 1979 Bannister *et al.* (1980) estimated that male and female sperm whales in Division 5, of nine southern hemisphere management divisions, had been reduced by 74% and 9%, respectively, of their estimated abundance in 1947. Division 5 extended from the ice-edge to the equator and between longitudes 90°E and 130°E. A recent aerial survey off Albany, WA compared sperm whale bull sighting rates to those recorded by commercial whaling aerial spotting before whaling ceased, and found no evidence of population recovery (Carroll *et al.* 2014). Sperm whales have been detected in the GAB in all months when there has been either dedicated survey effort or MMO sightings effort. A tendency for sperm whales to travel east to west within a season has been reported along the coast off Albany (Banister 2008).

Evans and Hindell (2004) examined the stomach contents of 36 sperm whales from two mass stranding events in Tasmania and found they were dominated by oceanic cephalopod species. Jaquet *et al.* (2000) found that the relative abundance of sperm whales off Kaikoura, New Zealand was relatively stable across years. However, distributions were significantly different between summer and winter seasons, and these changes in distribution were thought to reflect changes in seasonal availability of squid. In the Gulf of California, seasonal abundance of sperm whales was similar between two consecutive spring-summer periods, but there were strong differences in the distribution and densities of sperm whales that may have been linked to changes in the distribution and abundance of a known prey species, the jumbo squid (Jaquet and Gendron, 2002). A strong

correlation between sperm whale distribution and jumbo squid has been recorded in the region (Gallo-Reynoso *et al.* 2009).

Seasonal differences in the distribution of sperm whales on the continental slope off south-eastern and southern Brazil are also thought to be related to the distribution of short-fin squid (Di Tullio *et al.* 2016). At the Kelvin Seamount in the Sargasso Sea, western North Atlantic Ocean, sperm whales occurred more frequently in spring than winter, and their occurrence was linked to increased productivity in the area (Wong and Whitehead 2014). Therefore, seasonal variability in sperm whale distribution in some regions may be linked to changes in primary productivity and it is possible that such seasonal differences occur in the GAB also.

The continental shelf of the GAB is inundated with cross-shelf canyons which are associated with localised upwelling and primary productivity. Higher densities of cetaceans have been found associated with canyons relative to shelf-slopes in a number of marine ecosystems. For example, cetacean abundance was found to be higher in the largest submarine canyon off eastern Canada, the Sable Gully, than other parts of the shelf and slope areas of the Scotian Shelf (Hooker *et al.* 1999). Waring *et al.* (2001) also found higher densities of sperm whales associated with canyons than in surrounding shelf-waters. In the Mediterranean, higher sperm whale densities were associated with canyons, the continental slope and an area with a depth exceeding 2500 m (Moulins *et al.* 2008), and in the Balearic region bottom depth and aspect were significantly correlated with sperm whale distribution (Pirrota *et al.* 2011).

Johnson *et al.* (2016) reported that the variable with the greatest influence on a presence-only model predicting sperm whale distribution off south-western WA was distance to the 1000 m isobath, and identified the submarine canyons offshore of Albany and Perth as critical areas for sperm whales. In the current study, depth was the variable that had the greatest influence on the presence-only model, with the highest probability of distribution of sperm whale predicted at the shelf-edge and slope region. These results are consistent with the expected distribution of sperm whales in the GAB given the bathymetry of the region and topographic features such as canyons and areas of localised upwelling. Biologically important areas for sperm whales in the GAB have been identified for the shelf-break and slope south of Albany, and the shelf-break and slope from the central GAB east to Kangaroo Island (DSEWPaC 2012b), but there is a paucity of data on the abundance and distribution of sperm whales in this region.

Threats to sperm whale populations include collision with vessels, impacts of ocean noise (such as seismic activity) and pollution. For example, sperm whales have been shown to exhibit reduced foraging rates in the presence of seismic activity (Miller *et al.* 2009), and mortality related to the ingestion of marine debris has been reported (de Stephanis *et al.* 2013). Ship strikes with sperm whales have been recorded in Australian waters (Peel et al. 2016).

7.5.2 Pilot whales

During the current survey a large group (~150) of pilot whales, including calves, was sighted and acoustically detected in waters greater than 1000 m in depth. Gill *et al.* (2015) also reported that pilot whale groups in their survey area often also contained calves, and that sightings predominantly occurred on the shelf or close to the shelf-break. The mean water depth where pilot whales were sighted during the April 2016 aerial survey for blue whales in the eastern GAB was 515 m (Section 6 this report).

Both short-fin pilot whales and long-finned pilot whales have been recorded stranded in South Australia, although the latter species is more numerous in the records (Segawa and Kemper 2015). Short-finned pilot whales tend to be recorded in waters north of 30˚S, while long-finned pilot whales

have been recorded from sub-Antarctic waters to Australia. Pilot whales occur in oceanic waters and areas of high productivity along continental slopes, and seasonal movements are thought to occur in response to movements of prey species (Bannister *et al.* 1996). Pilot whales predominantly prey on cephalopods and a number of squid species have been recorded in the stomach contents of animals stranded in Tasmania and Western Australia. Records of pilot whale sightings collated from available MMO data show pilot whale occurrence from the shelf-break out to depths of almost 4000 m. There is no information on the abundance or spatial or temporal distribution of pilot whales in the GAB or in wider Australian waters.

7.5.3 Beaked whales

One unidentified whale was sighted during the survey, in waters deeper than 1000 m to the SW of Kangaroo Island. Given the size and colouring of the whale it was most likely a beaked whale. Beaked whales are difficult to detect at sea using visual methods, as they tend to show inconspicuous behaviour whilst at the surface. Studies on a limited number of beaked whale species have shown that deep foraging dives can last up to an hour at depths that range up to 1800 m and more (Tyack *et al.* 2006; Baird *et al.* 2006). A tagged Cuvier's beaked whale off southern California, USA, was recorded to undertake a dive to over 2900 m in depth that lasted over two hours (Schorr *et al.* 2014).

The most frequently recorded beaked whale species in the stranding records in South Australia is the strap-toothed whale (Segawa and Kemper 2015). However, there are no records of at sea sightings of this species in the region. A further five beaked whale species have been recorded from stranding records in South Australia (Segawa and Kemper 2015). At sea sightings of Shepherd's beaked whale and southern bottlenose whale have been recorded during dedicated surveys in the eastern GAB (Marine Conservation Research International 2013, Gill *et al.* 2015), and a sighting of a Cuvier's beaked whale was recorded by MMOs during seismic operations in the central GAB in 2011. In the western GAB, predation on beaked whales by killer whales, most likely Gray's and or strap-toothed beaked whales, has been observed at Bremer Canyon, WA (Wellard *et al.* 2016).

Passive acoustic monitoring using a towed hydrophone array has successfully been used to detect and identify beaked whale habitat (Boisseau *et al.* 2011, Yack *et al.* 2013, Trickey *et al.* 2015). The lack of beaked whale acoustic detections during the short survey conducted under the current study are not necessarily indicative of an absence of beaked whales in the survey area. It has been shown that a number of different species of beaked whale do not begin to produce echolocation clicks until they reach depths of > 200 m (Johnson *et al.* 2004, Zimmer *et al.* 2005, Timpert *et al.* 2014). During the 2013 visual and acoustic survey of the shelf, shelf-break and slope west of Kangaroo Island, no beaked whale echolocation clicks were detected during a two-hour encounter with a group of three Shepherd's beaked whales (Marine Conservation Research International 2013). While there are no published records of Shepherd's beaked whale echolocation clicks, acoustic recordings of a number of beaked whale species show they produce frequency-modulated (FM) upsweep pulses of ultrasonic clicks that can be used to identify them from other species. (Zimmer *et al.* 2005, Johnson *et al.* 2008, Gillespie *et al.* 2009, Yack *et al.* 2013). Zimmer *et al.* (2008), noted that the ability to detect beaked whales acoustically is dependent on the passive acoustic detection (PAD) system being used, the distance to the echolocating whale, background noise level and environmental factors that affect sound propagation.

Although beaked whales are probably the least well understood group of cetaceans, resident populations may occur in certain regions. For example, there is a resident population of Blainville's beaked whales in the Bahamas (Claridge 2006) and of Blainville's and Cuvier's beaked whales in Hawaii (McSweeney *et al.* 2007). As with sperm whales, the distribution of beaked whales has been

associated with localised upwelling and topographic features such as canyons (Hooker *et al.* 1999, Waring *et al.* 2001, Moulins *et al.* 2008, Boisseau *et al.* 2011). The two sightings of Shepherd's beaked whales recorded in the eastern GAB were associated with the shelf-break west of Kangaroo Island (Marine Conservation Research International 2013, Gill *et al.* 2015).

7.5.4 Cetacean diversity in the Great Australian Bight

This was the first systematic survey of cetaceans on the shelf-edge and slope in the central GAB and provides a snapshot of the relative density and occurrence of sperm whales in the surveyed area. Acoustic detections of other odontocete species were not identified to species level, but based on the types of calls recorded, at least three of the eleven non-sperm whale acoustic events were likely produced by larger odontocete species such as pilot whales, Risso's dolphins or potentially killer whales.

In total, 15 cetacean species have been recorded at sea in the eastern and central GAB (east of 131° 30' E) during dedicated surveys including Risso's dolphin and killer whales (Gill *et al.* 2015, Section 6 of this report), mostly from long-term multi-year aerial surveys for blue whales. These do not include short-beaked common dolphin (*Delphinus delphis*) and bottlenose dolphin (*Tursiop*s sp.) which occur in the area but have only been surveyed in shelf waters out to 100 m.

Given the very low survey effort in the GAB region, and the additional 20 species reported in the strandings records (Groom and Coughran 2012, Groom *et al.* 2014, Gill *et al.* 2015, Segawa and Kemper 2015), cetacean diversity in the GAB is likely to be higher than recorded from survey data alone. Although some strandings may represent rare or vagrant species for the region, such as spectacled porpoise and southern right whale dolphin, a number of species are frequently recorded in the stranding records, such as the dwarf sperm whale and strap-toothed beaked whale (Segawa and Kemper 2015).

To get a true indication of cetacean diversity in the GAB, repeated surveys over different seasons and/or years are required. Data generated from multi-year surveys have recorded at sea occurrence of 30 cetacean species in the Eastern Tropical Pacific Ocean, of which 24 are considered resident (Balance *et al.* 2006), 32 cetacean species in the Gulf of California and Mexican Pacific (Rosales-Nanduca *et al.* 2011), 22 in Monterey Bay, California (Burrows *et al.* 2012), 20 in the California current ecosystem (Barlow and Forney 2007) and 19 in the North Pacific (Kanaji *et al.* 2016).

7.5.5 Key Knowledge Gaps and Threats

The results of the current survey, in combination with data collected during aerial surveys for blue whales (Gill *et al.* 2015, Section 6), and a visual and passive acoustic survey conducted south-west of Kangaroo Island (MCR 2013), provide information on cetacean species occurrence on the shelf-break and slope region of the eastern GAB. However, key data remain lacking on the diversity and spatial and temporal distribution of cetaceans in the shelf-break and slope region of the GAB.

It is possible that some species, such as beaked whales, may be resident in the GAB, but baseline information on the degree of residency and spatial and temporal distribution along the shelf-break and slope remain extremely limited. Sperm whales were detected acoustically at distances up to 9 km, showing the utility of passive acoustic monitoring for detecting this deep diving species. Integration of survey data, MMO and publically available sightings data, and historical and commercial whaling data show that the potential habitat for sperm whales extends across the shelf-break and slope region of the GAB. This area of the shelf-break and slope is inundated with many cross-shelf canyons, and these features have been shown to be associated with higher densities of

species such as sperm whales and beaked whales (Moors-Murphy 2013). The importance of canyons and slope habitats in the GAB for odontocete species needs to be determined, particularly given the potential for the presence of resident populations of some species in the area.

Further data on the temporal and spatial distribution of cetacean species in the shelf-break and slope regions of the GAB is required to assess potential impacts on these species if there is an increase in human activities in these areas. Such data are required to provide information to management agencies and regulators in order to assess and mitigate risks from these activities. The potential impacts of increased noise from shipping, seismic surveys and construction on cetacean species in the region need to be considered.

Vessel noise can overlap with the frequency range of acoustic signals produced by large whales, and can result in acoustic masking of whale signals (Hatch *et al.* 2012), or in whales changing the frequency and or magnitude of vocalisations and call rate (Parks *et al.* 2007, 2011, Castellote *et al.* 2012). Physiological responses to noise have also been reported, with decreases in stress hormones in North Atlantic right whales linked to decreases in underwater noise due to reduced shipping in the Bay of Fundy (Rolland *et al.* 2012). Increased shipping can also lead to increased risk of ship strike occurring in the area. A draft National Strategy for Mitigating Vessel Strike of Marine Mega-fauna has been developed which aims to identify areas where the risk of vessel collision is high. (Commonwealth of Australia 2016). The draft strategy notes that the majority of reported ship strikes in Australian waters from 1997 to 2015 involved humpback and southern right whales, but also include sperm, blue and fin whales. Several studies outside Australia have documented behavioural responses of cetacean species to seismic surveys. These include abandonment of habitat by fin whales (Castellote *et al.* 2012), changes in vocalization rates of fin, blue and humpback whales (Di Iorio and Clark 2009; Castellote *et al.* 2012; Cerchio et al. 2014), and reduction in foraging behaviour of sperm whales (Miller *et al.* 2009). In Australia, experiments to quantify the behavioural response of humpback whales to seismic air gun noise found decreased dive time, elevated respiration rate and changes in surface behaviour to a full commercial array (Dunlop et al. 2016)

Beaked whales have been shown to be sensitive to anthropogenic noise, and the effect of naval sonar on beaked whales was identified as being of potential concern after a number of mass strandings were recorded that were temporally and spatially associated with naval sonar exercises (Cox *et al.* 2006). Controlled experiments to investigate the acoustic and movement behaviour of a number of different beaked whales to playbacks of active sonar signals have shown strong responses including changes in movement patterns, changes in diving behaviour and cessation of echolocation clicks (Tyack *et al.* 2011; De Ruiter *et al.* 2013; Miller *et al.* 2015). These data show that beaked whale species are highly sensitive to acoustic disturbance. Concerns have also been raised that seismic surveys may also impact beaked whales (Cox *et al.* 2006), however the effects of seismic airgun sound on the acoustic or movement behaviour of beaked whales are currently unknown. Other threats include bycatch, and a record of a strap-toothed beaked whale entanglement in fishing gear exists in the GAB (Segawa and Kemper 2015).

Seismic surveys have been undertaken in the GAB region, with 130 seismic surveys conducted in waters off South Australia between 1966 and 2015 (DSD 2016, Figure 7.12), therefore it is likely that whales in the GAB have been exposed to seismic activity over long periods. In the Gulf of Mexico, another region where extensive seismic surveys have been conducted, sperm whales were not found to exhibit major changes in surface behaviour of movement during start up or approach of a seismic airgun array (Miller *et al.* 2009). On the other hand, echolocation buzz rates, a proxy for foraging, decreased substantially (Miller *et al.* 2009). Immediately prior to the current survey being conducted, full power seismic acquisition had been undertaken in the GAB area as part of the

Nerites MC3D Marine Seismic Survey. It is not possible to know if or how recent seismic survey activity in the area may have affected the distribution of cetaceans during the survey. As there is limited baseline information, particularly with regards to degree of residency of odontocete species in the GAB, there is no way to assess if there have already been population consequences of a long-term exposure to seismic activities. In a review relating to the management of marine seismic surveys and ocean noise, it was noted that without sufficient baseline data, regulators do not have the information required to reliably assess the risk to marine life from marine seismic surveys (Nowacek *et al.* 2015).

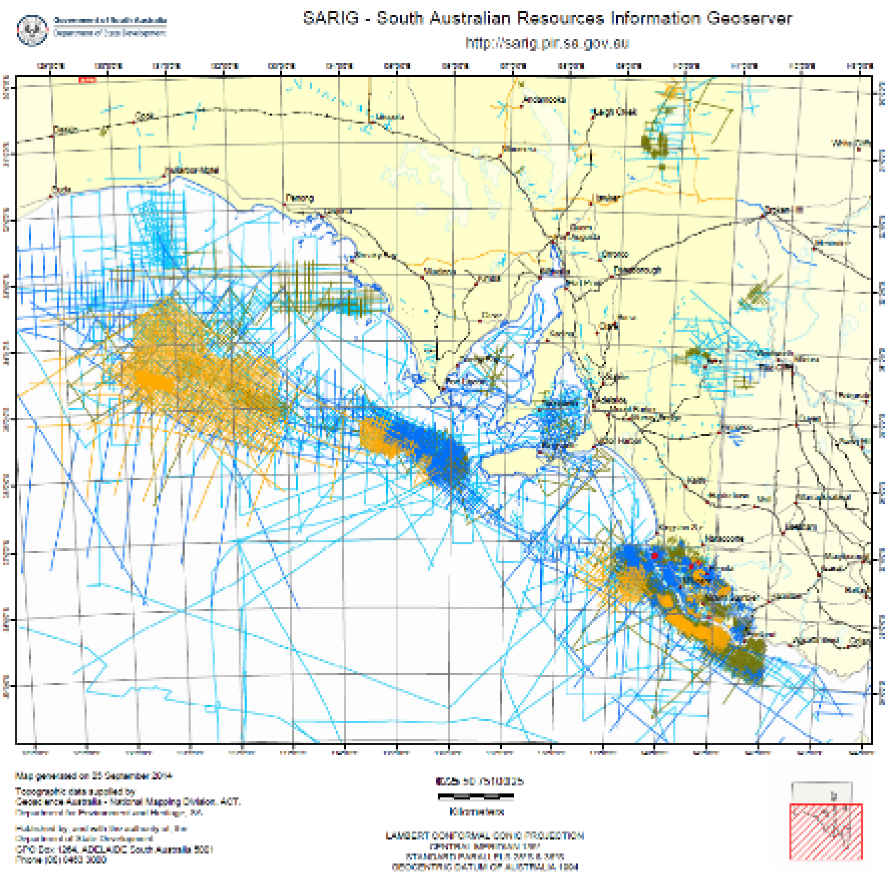


Figure 7.12. Map showing the location of seismic survey lines completed in the Great Australian Bight between 1955 and 2011. Light blue lines: 1955 to 1979, green lines: 1980 to 1989, dark blue lines; 1990 to 1999, yellow lines: 2000 to 2009; red lines: 2010 to 2011

7.6 Conclusion

All cetaceans are protected under the EPBC Act, and Commonwealth Marine Reserves in the GAB region are considered important foraging and / or migration areas for a number of cetacean species. Potential pressures of concern identified in the South-west Marine Bioregional Plan (DSEWPAC 2012b) include noise pollution, vessel collision and marine debris. An increase in human activities in the GAB associated with population growth, such as shipping, or with additional gas and oil exploration and extraction will increase the potential for these pressures to occur. Higher resolution data on the occurrence and distribution of cetacean species, and identification of habitats or areas of high use are required to understand the diversity and spatial and temporal distribution of cetaceans in the shelf-break and slope area of the GAB. These data will allow management agencies

and regulators to better assess and mitigate potential risks from these activities to cetacean species in the GAB.

7.7 Acknowledgments

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Survey Personnel: Dr Alice Mackay and Mr Sol Kraitzer (SARDI), Ian Roberts (CSIRO), Dave Donnelly (BPM).

8. OFFSHORE PELAGIC SHARK SURVEY

Biodiversity, distributions and habitat use of pelagic sharks in the Great Australian Bight

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8.1 Executive summary

- An offshore pelagic survey was conducted in the Great Australian Bight (GAB) during May 2015.
- The survey applied a combination of pelagic long-line survey and satellite telemetry techniques, and represented the first dedicated effort to investigate the biodiversity, distributions and habitat use of pelagic sharks in offshore waters of this region.
- Seven long-line sets were completed between the du Couedic Canyon, south-west of Kangaroo Island, and the continental shelf-break area south of Head of Bight.
- Five pelagic and oceanic shark species belonging to four families were recorded.
- Nine blue sharks *Prionace glauca*, six shortfin makos *Isurus oxyrinchus*, one common thresher *Alopias vulpinus*, one bigeye thresher *A. superciliosus*, and two school sharks *Galiorhinus galeus* were caught during longline sets.
- The highest species diversity and abundance of pelagic sharks occurred at the eastern-most location adjacent to the head wall of the du Couedic Canyon.
- Blue sharks between 180 and 250 cm total length (TL) were geographically widespread in the GAB. Satellite telemetry data were collected for 14 individuals of four shark species. The largest N-S and E-W movements by blue sharks occurred during spring and summer.
- Blue sharks traversed areas with median depths ranging from 1505–5179 m; 67% exhibited fidelity in regions with higher variability in depth gradients as compared to areas used as transit paths.
- Time-spent-per-area (TSA) analyses indicated focal areas for blue sharks were those with bottom depths >1000 m in oceanic zones beyond the lower continental shelf slope in the eastern and central GAB, Bonney Upwelling Region, and Tasman Sea.
- Shortfin mako was the second-most widespread species.
- The spatial range occupied by the shortfin mako tagged in the GAB extended to the offshore Indian Ocean ~211 km from North West Cape, Exmouth, Western Australia (WA).
- TSA analyses of the shortfin mako track indicated areas of highest use were the continental shelf break and slope adjacent to the Lacepede Shelf, Murray Canyons to the south of Kangaroo Island, and outer shelf, shelf break and upper shelf slope areas between the 100 to 300 m isobaths in the western GAB.

- A female bigeye thresher (~500 cm TL) was captured and tagged at the upper continental shelf slope to the south of Fowlers Bay. This species is rare in southern and south-western Australian waters, and the study region was not previously considered to be part of its known distribution (Last and Stevens 2009).
- The bigeye thresher spent ~84% of the tracked time below the average estimated mixed layer depth (MLD) of 103.5 ± 25.9 m. Minimum and maximum depths occupied by the bigeye thresher ranged from the surface to 1240 m. Average minimum and maximum daily depths were 13.7 ± 9.0 m and 661.3 ± 152.9 m, respectively.
- Five free-swimming white sharks were tagged at the South Neptune Islands using pop-up satellite tags.
- White sharks exhibited substantial variation in depth and thermal habitat use. Depth profiles and tag pop-up locations inferred that southern Spencer Gulf and the continental shelf and slope areas were important to the individuals tracked.
- Displacement distances of white sharks from the tagging site were 19–1,931 km. North- and west-ward extents of movements ranged from Spencer Gulf, to the upper shelf slope SSW of Cape Leeuwin, WA. Southern and eastern movements were limited.
- Estimated minimum displacement distance of the bigeye thresher was 3263 km; it travelled from the GAB to the 1800 m isobath at the Exmouth Plateau, 353 km offshore from the North West Cape, near Exmouth, WA.
- Highly migratory pelagic shark populations represent considerable value to the community and regional economies of southern Australia and neighbouring Pacific and Indian Ocean regions.
- Fundamental gaps remain in diet data-sets for sharks in offshore habitats of the GAB, and these are required to understand and explain ecological functioning, trophic relationships and potential ecological impacts of anthropogenic stressors.

8.2 Introduction

8.2.1 Overview

Oceanographic and physical features that support the Great Australian Bight (GAB) pelagic ecosystem include upwelling in coastal and shelf waters (Kämpf *et al.* 2004), fronts that form at the interfaces between coastal water masses and the in-flowing tropical Leeuwin Current and warm water masses originating in the shallow shelves (McClatchie *et al.* 2006), and seasonal up- and down-welling events in the coastal, neritic, and shelf slope habitats (Middleton and Cirano 2002; Kämpf 2007; Middleton and Bye 2007). The oceanographic and physical features of the GAB support highly migratory pelagic sharks, including the core habitats and movement pathways of several listed, threatened, endangered and protected species, including the white shark (Bruce *et al.* 2006), shortfin mako (Rogers *et al*. 2015a), and gulper sharks *Centrophorus* spp. (Williams *et al.* 2012; Daley *et al.* 2014).

Collection of fishery-independent information on the spatial distribution of pelagic sharks can be challenging due to the large extent of their oceanic habitats combined with their highly migratory behaviour. While there are substantial logistical challenges associated with conducting research on these large predator species in isolated oceanic areas, other global examples include pelagic long-line based surveys by the US National Oceanographic and Atmospheric Administration (NOAA) to assess the status of juvenile pelagic shark populations in the Southern California Bight (Vetter *et al*. 2006; Runcie *et al*. 2016), and in the north-west Atlantic Ocean (Simpfendorfer *et al.* 2002; NOAA 2016). A large part of the scientific understanding of the pelagic shark assemblage in the eastern Indian Ocean and south-west Pacific Ocean has been gleaned from analyses of fishery data from domestic and high seas fishery observer programs, and patterns largely reflect spatial and temporal trends in fishery effort (Stevens 1992; Bruce *et al.* 2014).

In response to the need to maximise opportunities when accessing the distant areas inhabited by pelagic and oceanic sharks, we developed a survey design that could be undertaken in a fast, cost-effective vessel to optimise data collection during short periods of suitable weather. Central to this strategy was the application of satellite telemetry to enable collection of high-resolution tracking data following the survey, to understand species distributions and overlaps with human processes, movements and habitat use in relation to oceanographic, environmental and seasonal factors.

8.2.2 Background and Need

Pelagic sharks exert top-down foraging pressure on lower trophic levels of marine ecosystems, including other benthic and pelagic fishes, squids, and marine mammals in the GAB (Rogers *et al.* 2012; Goldsworthy *et al.* 2013). Despite what we understand about their broader roles in ecosystems, there remain substantial gaps in available information on species diversity, patterns of distribution, and habitat use by the pelagic shark assemblage in the GAB (Rogers *et al.* 2013). Also lacking is information on species overlaps with commercial industries (e.g. fishery and petroleum lease areas) and spatially managed areas aimed at maintaining national marine habitat and biodiversity values (e.g. marine reserves).

The assemblage in the GAB comprises species also found in other eastern and western boundary current ecosystems, and includes the white shark, shortfin mako, longfin mako (*I. paucus*), porbeagle (*Lamna nasus*), blue shark (*Prionace glauca*), bronze whaler (*Carcharhinus brachyurus*), dusky shark (*C. obscurus*), common thresher (*Alopias vulpinus*), bigeye thresher (*A. superciliosus*), smooth hammerhead (*Sphyrna zygaena*), and school shark (*Galeorhinus galeus*). The white shark, shortfin mako, longfin mako,

and porbeagle have varying levels of protection under the Australian Commonwealth Government *Environment Protection and Biodiversity Conservation Act*, EPBC Act (1999), and in the case of the white shark, the species is also protected under State fisheries legislation. Two thresher sharks, *A. vulpinus* and *A. superciliosus,* have management status that is pending current national and international assessment processes.

8.2.3 Objectives

1. Assess the biodiversity and composition of the pelagic shark assemblage in shelf slope and offshore regions of the GAB.

2. Determine the spatial and temporal distributions of pelagic sharks in shelf slope and offshore regions of the GAB.

3. Identify key habitats of pelagic sharks in the shelf slope and offshore regions of the GAB.

4. Collect dietary information for pelagic sharks in the shelf slope and offshore regions of the GAB to contribute to aligned trophodynamic models for this region in Theme 7 of the Great Australian Bight Research Program.

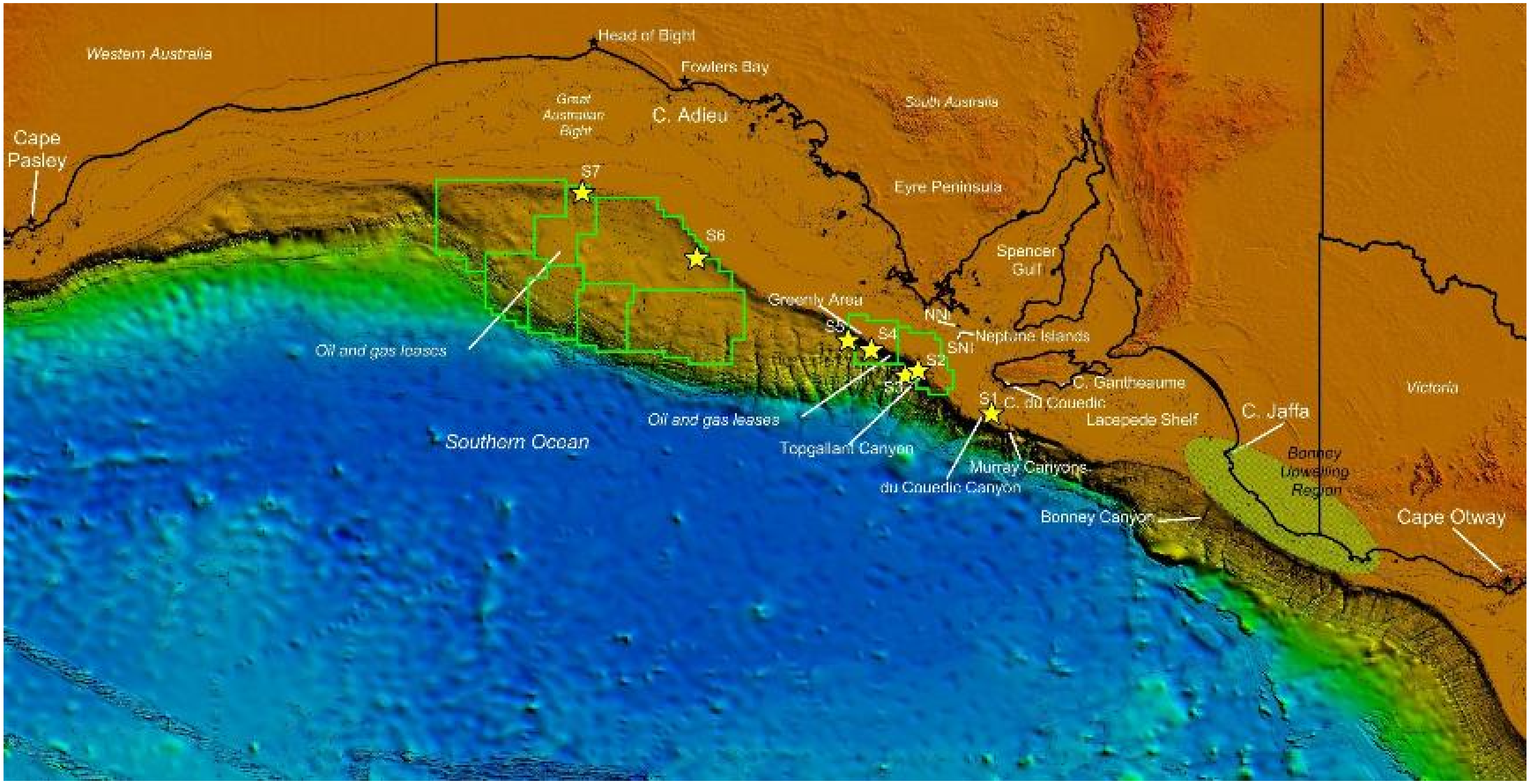


Figure 8.1. Locations of pelagic survey sets S1–S7 (yellow star symbols) conducted in the GAB during May 2015. The green area boundaries show the leases of BP Statoil, Murphy Santos, Chevron and Bight Petroleum Pty Ltd. South and North Neptune islands are indicated by the acronyms SNI and NNI, respectively. The Bonney Upwelling Region is shown as a green ellipse. The orange layer shows the ≤200 m isobaths, light orange-yellow shows the 200–1000 m isobaths, green to dark blue shows 1000–5000 m isobaths (The Australian bathymetry and topography grid 250 m, Geoscience Australia).

8.3 Methods

8.3.1 Survey design, equipment and approach

The pelagic survey was conducted from *FPV Southern Ranger* during May 2015. Survey locations were in the eastern and central GAB (Table 8.1, Figure 8.1). Seven pelagic long-line sets (S1–S7) were completed. Operational dates and vessel tracks during the two survey legs are shown in Appendix 8.1. Descriptions of pelagic long-line set locations are provided in Table 8.1. Set locations were du Couedic Canyon (S1), Topgallant Canyon (S2 and S3), 'Greenly area' south-west of southern Eyre Peninsula (S4 and S5), shelf break and upper slope to the south of Fowlers Bay (S6), and Head of Bight (S7) (Figure 8.1). Survey set location details, dates, depth ranges, sea-surface temperatures, and habitat types are shown in Table 8.1.

Site selection during the survey was based on depth strata, proximity of submarine canyons, patterns in currents and sea-surface temperatures (oceancurrent.imos.org.au), and satellite telemetry data. This information was examined to identify areas where combinations of suitable habitat variables combined and were hypothesised to support pelagic predator species. Survey locations were selected within and outside the oil and gas lease areas (Figure 8.1).

Pelagic long-line equipment comprised a 4 mm monofilament main-line, with 4 m long, 2 mm diameter wire branch-lines attached to 16/o tuna circle hooks and v-notch stainless steel long-line clips. Circle hooks were spaced along the main-line at ~40–50 m intervals. The number of hooks deployed per set ranged from 60 to 120 (mean = 98 ± 23). Surface floats (~30 cm diam.) with Xenon™ strobes with 8 m rope dropper lines were attached at intervals of one float per five hooks. Each long-line was set at depths of ~24–40 m.

A Taiyo™ radio beacon and direction finder were used to maintain contact between the vessel and the terminal end of the long-line during the sets. Floats (40 mm diameter) with high visibility flags on poles were attached to the line at intervals of 30–40 hooks. Hooks were baited manually using thawed frozen Australian salmon (*Arripis trutta*), arrow squid (*Nototodarus gouldi*), and southern bluefin tuna (*Thunnus maccoyii*). During each set, the line was soaked for ~2 hours (from time of last hook set) to maximise survivorship of sharks. At the end of each set, the long-line was retrieved on the starboard side of the vessel as it travelled at speeds of ~2–3 knots.

Table 8.1. Physical and oceanographic characteristics of offshore pelagic shark survey set locations S1–S7. Sea-surface temperatures sourced from http://oceancurrent.imos.org.au/

Set location	Date	Depth range (m)	SST (°C)	Habitat type	Canyon area
S1	1 May 15	120–170	18	Shelf break	du Couedic Canyon
S2	3 May 15	2000+	17–18	Oceanic	Topgallant Canyon
S3	14 May 15	213–394	17	Upper slope	Topgallant Canyon
S4	15 May 15	182–694	17	Shelf break to lower slope	Greenly area
S5	15 May 15	139–804	18	Shelf to lower slope	Greenly west
S6	16 May 15	199–265	18	Shelf break to upper slope	Fowlers South
S7	17 May 15	190–226	18	Shelf break to upper slope	South Head of Bight

Seabird bycatch mitigation techniques were adopted during the setting and retrieval process (Appendix 8.2). Wheel-house data describing each set were collected, including latitude and longitude of sets, time, wind speed, and bottom depth at start and end positions. Seabird and marine mammal species observed at and near each set location were recorded (Appendix 8.3).

In addition to the long-line survey, white sharks were counted at the Neptune Islands while the vessel was at anchor during poor weather.

8.3.2 Shark capture and handling

Small to medium sharks (≤ 2.5 m total length; TL) captured on the long-line were lifted from the water using a sling with a solid, rectangular aluminium frame and inner platform covered in soft netting and smooth canvas. Once on-board, the gills of each shark were aerated using a reinforced deck-hose and their eyes were covered with a wetted micro-fibre cloth. The posture of each shark was supported using a wetted, high-density foam mattress. Sharks were identified, measured, sexed and fin-clips were taken for genetics. External copepod parasites were sampled from some individuals. Maturity of each shark was assessed based on methods of Francis and Duffy (2005). Bolt-cutters were used to cut and remove hooks prior to the release of tagged sharks. Individuals that were not satellite tagged were sampled and/or released in the water by cutting the leader. Specimens >2.5 m TL were tagged while in the water using 4 m tag poles and their sizes were estimated based on known lengths on the vessel's gunwale. Moribund and dead specimens were dissected to collect biological data and samples for ecosystem modelling studies in Theme 7.

8.3.3 Satellite tag deployments

Satellite tags were mounted on the first dorsal fin of blue sharks and the shortfin mako captured during the long-line sets. Tags deployed on these species were Sirtrack™ K2F161A, and Wildlife Computers smart position or temperature (SPOT) tags (Table 8.2). Dorsal fin-mounted satellite tags were attached using two 3.5 mm diameter stainless steel bolts, nylex lock-nuts and washers. Lock-nuts were fastened through two or three small holes made in the dorsal fin using a cordless drill and deep socket.

Wildlife Computers™ (WC) miniature pop-up archival transmitting tags (mini-PAT) were deployed on white sharks and a big-eye thresher using a 4 m aluminium tag pole. The mini-PATs were deployed on sharks that were either free-swimming next to the vessel in the case of the white sharks, or captured on the long-line in the case of the big-eye thresher. Deployment summary details are provided in Table 8.2. The mini-PATs were tethered to sharks using a plastic umbrella dart attached to 200–250 mm of 2 mm diameter plastic coated 316 stainless steel multi-strand wire. Umbrella darts tethered to mini-PATs were inserted into the dorsal musculature of each shark to depths of 5–10 cm using a stainless steel applicator attached to the tag pole.

8.3.4 Data analyses

Species distributions: survey information

Spatial analyses of species distributions were prepared using count data collected during the long-line sets. Patterns were shown using MapInfo Ver. 11.5 geographical information software (GIS) (MapInfo Corporation, New York).

Spatial and temporal distributions: telemetry

Satellite tags transmitted signals to satellite network receiver stations, which were forwarded to Argos centres in France and the USA (Argos, 2008). Position estimates were downloaded in seven location quality classes (cls) ranging from highest to lowest manufacturer predicted accuracies of 3 = <250 m, 2 = 250–500 m, 1 = 500–1500 m and 0–B = >1500 m, Z = no position (www.argos-system.org). Position error has been compared to GPS positions and the 68th percentile errors were 3 = 0.49 km, 2 = 1.01 km, 1 = 1.2 km, 0 = 4.18 km, A = 6.19 km, and B = 10.28 km (Costa *et al*. 2010). Extreme outliers, positions on land and those with unclassified error estimates (cls-Z) were removed. Positions were mapped using MapInfo GIS software. Initial mini-PAT pop-up locations were taken as the first position estimates (cls 3–1).

Table 8.2. Summary of satellite tag deployments during the offshore pelagic shark survey. Refer to deployment location codes shown in Figure 8.1. M = male, F = female, NS = not sexed. Mini-PAT = miniature pop-up satellite archival tag, SPOT = smart position or temperature satellite tag, ST = Sirtrack satellite tag.

Shark ID	Argos freq.	Tagging date	Species	Tag type	Deployment location	Size	Sex
B1	148956	1 May 15	*P. glauca*	SPOT	S1	200	F
B2	134878	3 May 15	*P. glauca*	ST	S2	180	M
B3	148954	3 May 15	*P. glauca*	SPOT	S2	224	F
B4	148957	15 May 15	*P. glauca*	SPOT	S4	208	M
B5	148955	15 May 15	*P. glauca*	SPOT	S4	233	M
B6	148965	15 May 15	*P. glauca*	SPOT	S5	235	M
B7	148962	16 May 15	*P. glauca*	SPOT	S6	250	M
S1	148963	17 May 15	*I. oxyrinchus*	SPOT	S7	232	F
W1	148949	2 May 15	*C. carcharias*	mini-PAT	SNI	420	F
W2	148953	2 May 15	*C. carcharias*	mini-PAT	SNI	330	M
W3	148950	6 May 15	*C. carcharias*	mini-PAT	SNI	220	NS
W4	148951	6 May 15	*C. carcharias*	mini-PAT	SNI	300	NS
W5	148952	6 May 15	*C. carcharias*	mini-PAT	SNI	420	F
BET1	148948	16 May 15	*A. superciliosus*	mini-PAT	S6	500	F

State-space models (SSM) were used to filter the raw Argos data (Jonsen *et al.* 2005). Locations were interpolated along each filtered track to reduce sampling bias due to irregular transmission of the Argos data. Estimation errors associated with Argos quality classes vary through time. Argos-derived locations are observed irregularly through time, which can impose an artificial perspective on the movement processes, which is why Bayesian filtering methods tend to be used. For each individual track, the raw satellite derived Argos locations were filtered using Bayesian SSM following the methods of Jonsen *et al.* (2005). The state-space distribution models are time-series methods that allow unobserved assumed behavioural states and biological parameters to be estimated from data observed with position estimation error. This approach enables the management of the biological and statistical complexities associated with satellite tracking data.

We used hierarchical switching models (hDCRWS) that account for these features of the data and allow both filtering spatial positions and estimating behavioural states (Jonsen 2016). The model was fitted using Markov Chain Monte Carlo (MCMC) methods to approximate the multi-dimensional integration required in Bayesian analyses. Because behavioural patterns estimate is a discrete parameter — values can only be 1 or 2 — we used the means of the MCMC samples as a convenient way to visualize behavioural switches. We therefore delineated the behavioural modes by adopting cut-offs at 1.25 and 1.75, where estimates <1.25 were assumed to represent transit or migratory behaviours and those >1.75 were assumed to represent area restricted search (ARS) or fidelity related behaviours (see Jonsen *et al.* 2007 for details). Estimates between 1.25 and 1.75 were treated as uncertain as per Jonsen *et al*. (2007). Spatial models were fitted using JAGS 3.1.0 (Just Another Gibbs Sampler, http://martynplummer.wordpress.com; http://mcmc-jags.sourceforge.net) accessed from R (R Core Team 2014) using the package 'bsam' (Jonsen *et al.* 2014). Two Markov chains with a total of 50,000 simulations were computed, with only one out of ten samples kept to minimise sample autocorrelation.

Analyses used a time-step of 4 hours and generated 25,000 samples per chain for each position. A 0.4° x 0.4° grid was drawn over the study area. From the filtered tracks, the time spent by each individual in each square of the grid (Time-spent-per-area) was calculated using the function 'tripGrid' (package 'trip', R Core Team 2014), and subsequently the percentage of the total record duration each individual spent in spatial areas of management interest. Estimated positions were allocated to the Austral seasons: summer = December, January and February; autumn = March, April and May; winter = June, July and August, and spring = September, October and November. Movement statistics are reported as mean ± standard error with 25th and 75th percentiles, and medians unless otherwise stated.

Habitat use

To describe environmental correlates during fidelity (ARS) and transitory (migratory) behavioural states extracted from the eight satellite tracks for the blue sharks and shortfin mako, we interrogated available bathymetry and remote-sensed data. Bathymetry data were extracted using the ETOPO1 database, sea-surface temperature data were extracted using NOAA's Optimum Interpolation data (https://www.ncdc.noaa.gov/oisst), and sea-surface height were extracted from AVISO Satellite Altimetry Data (www.aviso.altimetry.fr). Bathymetry, sea-surface temperature and sea-surface height gradients were calculated in R using the 'terrain' function from the package 'raster'. Sea-surface height and gradient represent indicators of proximity to eddies and associated meso-scale processes that support pelagic production (Bakun 2006). Anti-cyclonic warm core eddies have higher sea-surface height

values than the surrounding ocean, compared to cyclonic cold core eddies that have lower sea-surface height values (Bakun 2006).

8.3.5 Vertical habitat distributions

The vertical habitats of sharks tagged with mini-PAT tags were characterised using time at depth (TAD) summaries and high resolution depth and temperature time series data transmitted via the Argos satellites. Mini-PATs were programmed to release from the sharks after a 100 day deployment. Upon release, the mini-PAT tags floated to the surface and transmitted data to Argos satellites as per the SPOT tags. Data were analysed at the individual level.

8.4 Results

8.4.1 Species composition and diversity

Five species of pelagic sharks were recorded during the long-line survey, representing four families: Lamnidae (1 sp.), Alopiidae (2 spp.), Carcharhinidae (1 sp.), and Triakiade (1 sp.). Pelagic sharks encountered during the long-line sets were nine blue sharks, six shortfin makos, one common thresher, one bigeye thresher, and two school sharks. Figure 8.2a shows species by percentage during the survey long-line sets. A total of 12 white sharks were sighted whilst sheltering from bad weather in the South Neptune Islands anchorage on 2, 3, 6 and 13 May 2015.

Spatial distributions of species during survey

Species presence and abundance varied between sites in the GAB during the survey. The equal highest species diversity (n=3) and count of individual sharks (n=8) per set occurred at the eastern-most location at du Couedic Canyon during S1 (Figures 8.1 and 8.2a, b). This set was conducted at the continental shelf break, across the inner northern face of the canyon, where bottom depths ranged between 120 m and 170 m (Figure 8.3). No sharks were sampled during S3 at the upper slope, along the north-western side of Topgallant Canyon (Figure 8.1).

Blue sharks were geographically widespread during the survey (Figure 8.4). A total of nine blue sharks were recorded that ranged in size between 180 and 250 cm TL. Blue sharks comprised six males, two females and one unsexed individual (released alive and untagged). This species was present during all survey sets except S3 (Figure 8.4) with two caught at S1, S2 and S4, and one caught at S5, S6 and S7 (Figure 8.4). The shortfin mako was the second-most geographically widespread species sampled. A total of six shortfin makos ranging in size from a juvenile of ~70 cm TL to an adult of ~300 cm TL were caught at three of the seven set locations (S1, S4 and S7). One female shortfin mako of 232 cm TL was tagged at S7 (Figure 8.4).

One large common thresher of ~460 cm TL was caught at S6, located to the south of Fowlers Bay (Figure 8.4). The common thresher was released alive and untagged, as all electronic tags of a suitable size and configuration (e.g. mini-PAT) for the species had been deployed by that stage of the survey. This shark species is uncommon in southern Australian waters. A large shark >280 cm fork length (FL) escaped from the long-line at S1 following a sighting at ~10 m below the vessel. The head shape, blue-grey dorsal and white colouration on the ventral side suggested this specimen was also a large common thresher,

however the species could not be verified. One large, mature sized female bigeye thresher of ~500 cm TL was identified and satellite tagged at S6 (Figure 8.4).

Two female school sharks of 143 cm and 150 cm TL were captured and retained dead at S1 (Figure 8.4). School sharks were not present at S2–S7. No white sharks were encountered during the pelagic long-line sets.

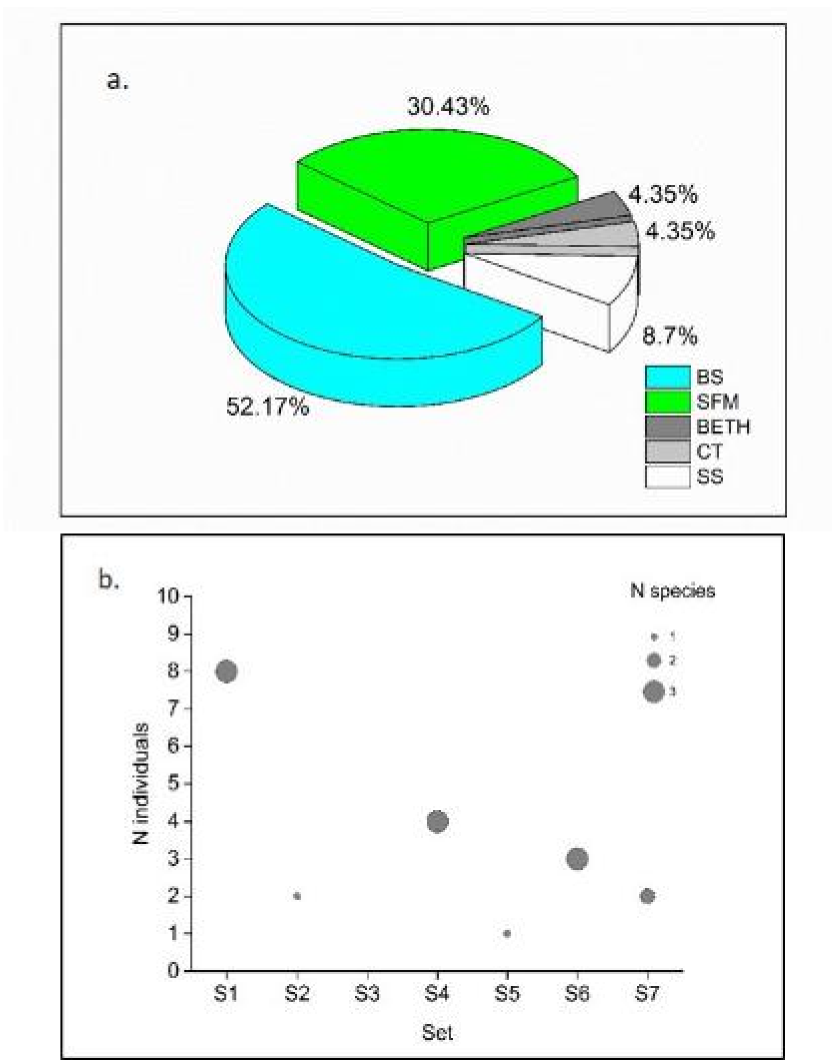


Figure 8.2. A. Pelagic shark species encountered by proportion in the GAB during the offshore pelagic shark survey sets. Blue shark = BS, shortfin mako = SFM, bigeye thresher = BETH, Common thresher = CT, and school shark = SS. B. Species diversity and numbers of individuals encountered by set.

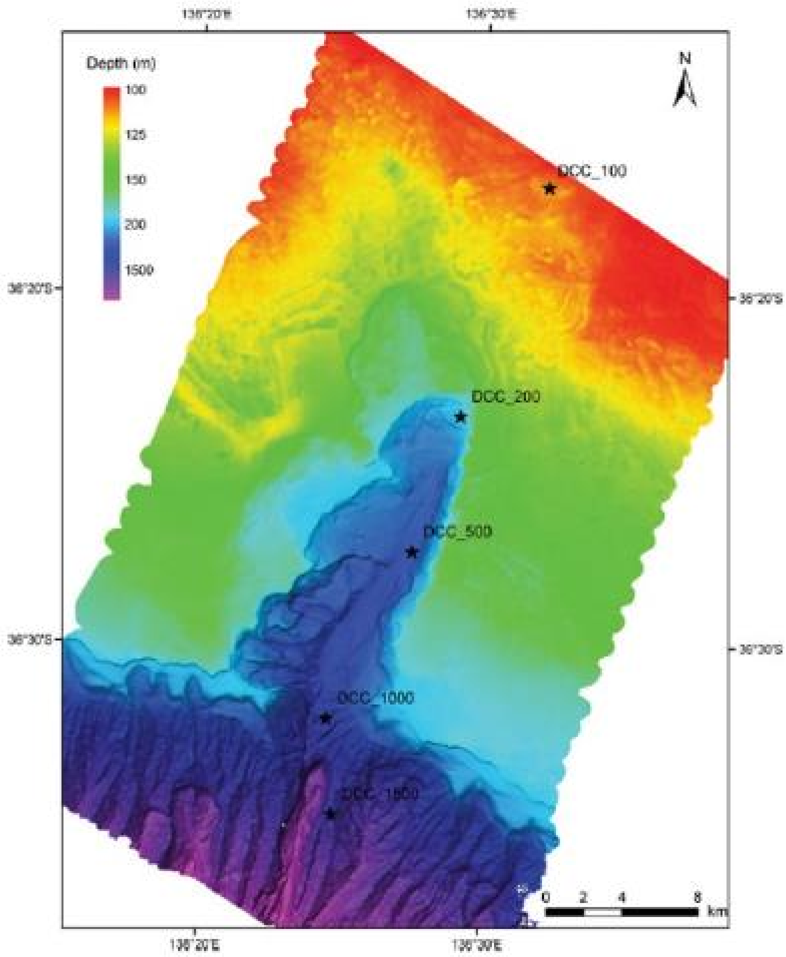


Figure 8.3. Bathymetry of the du Couedic Canyon. The black symbol shows the location of S1 relative to the canyon front wall. Stars show approximate depths. (Image courtesy of Currie and Sorokin 2014).

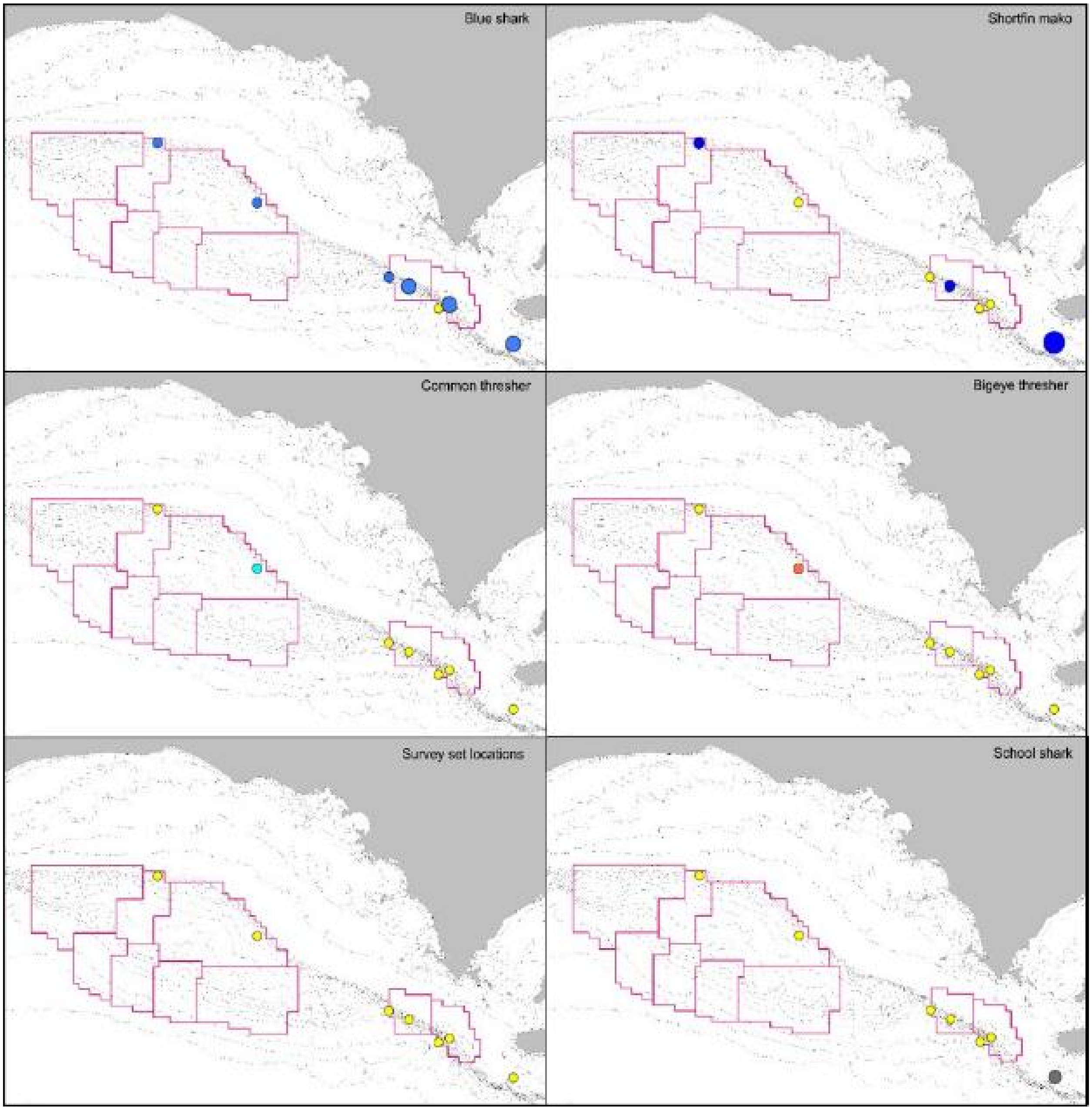


Figure 8.4. Spatial patterns of distribution of six pelagic shark species during the during the offshore pelagic shark survey sets. Symbol size represents the count of individuals during each set (small = 1, medium = 2, large = 4). Yellow symbols show set locations where no individuals of that species were caught. Shapes outlined in red show oil and gas lease areas.

8.4.2 Electronic tag deployments

Satellite tags were deployed on 14 pelagic sharks of four species. Data describing tag types, tagging location, size and sex are provided in Table 8.2. Deployments included five mini-PATs on white sharks between ~220 and 420 cm TL (pole tagged at South Neptune Islands), one mini PAT on a bigeye thresher (~500 cm), seven SPOT tags on blue sharks of 180–250 cm TL and one SPOT tag on a large female shortfin mako of 230 cm TL (Figure 8.5). Blue sharks and shortfin makos spend considerable time swimming at the surface and this allows the platform terminal transmitter (PTT) tags (e.g. SPOT and Sirtrack tags) sufficient time to send signals to the polar orbiting Argos satellite network.

Figure 8.5. Clockwise from top left. Blue shark, shortfin mako and bigeye thresher during satellite tagging in the Great Australian Bight.

8.4.3 Tag performance

Initial status checks on 20 May 2015 showed no mini-PATs deployed on white sharks and the bigeye thresher had reported to satellites immediately following the survey, indicating 100% survival of the mini-PAT tagged sharks. All dorsal-fin mounted satellite tags had reported position estimates indicating functionality of the eight tags and survival of all tagged sharks. Tables 8.2 and 8.3 provide a summary of tag deployment information.

Satellite tags deployed on blue sharks (B1–B7) (Table 8.3) provided data for 997 PTT days (PTT days = days platform transmitted) (mean = 142 ± 81, median = 167 days), and comprised 4057 position estimates (mean = 581 ± 394, median = 642 days) of quality classes 3–b.

The satellite tag deployed on the shortfin mako (S1) provided 258 PTT days and 1181 satellite position estimates of quality classes 3–b. This tag was transmitting regular position estimates at the time of preparation of this report (February 2016).

The mini-PAT tag deployed on the bigeye thresher (BET1) released on the programmed date after 100 days and reported high resolution time series depth records (n = 25959), daily binned time spent at temperature and depth histogram frequency data (94% data recovery), daily min-max temperature profiles (n = 97), and sea-surface temperature (SST) values (n = 104). This tag surfaced in an oceanic area and was not recovered.

All five mini-PATs deployed on white sharks W1–W5 transmitted summary data to Argos (Table 8.3). The tag on shark W3 dislodged after 64 days, which was 26 days prior to the programmed pop-up date. Three tags, including those deployed on W1, W2 and W4 surfaced within two days of the programmed dates. The five mini-PATs deployed on white sharks reported binned time spent at depth and temperature histogram frequency data for 295 of the 500 (59%) pre-programmed days. Data included time series depth records (n = 75,398), daily min-max temperature profiles in 16 depth layers (n = 282), SST values (n = 820) at 0–4 m, and mixed layer depth and temperature data (n = 296). Only one, possibly erroneous temperature summary data point for 27 July was transmitted by the tag on shark W5, which surfaced and transmitted late after 125 days. Temperature and depth data reported by the mini-PAT on W1 were transmitted 2 days late, and only comprised records for the first 14 days. We suggest this individual moved offshore and possibly damaged and removed the tag before it drifted ashore in northern Spencer Gulf and transmitted late, or the tag was damaged or malfunctioned during day 14 of the deployment, and the animal subsequently travelled to the northern Spencer Gulf location where the tag released. This tag didn't record temperature and depth data for the remaining 86 days of the deployment. Transmitted water temperatures suggest the tag was drifting near the surface as shown by the pressure/depth data. Two tags were recovered from the shoreline at Marion Bay, southern Yorke Peninsula and Louth Island, Boston Bay in southern Spencer Gulf following transmission of summary data. Archived data will be analysed in Project 4.2.

8.4.1 Spatial, temporal and seasonal distributions: telemetry

Blue shark

Six satellite tags deployed on blue sharks B1–B3, B5–B7 transmitted for periods ranging from 221 to 317 days (mean = 242 ± 97.86, median = 288 days). The tag on blue shark B4 provided data for 34 days (Table 8.3). Maximum distal displacement distances traversed by individual blue sharks ranged between

535–4190 km (during 15 and 196 days, respectively) (mean = 1952 ± 1384, median = 1440 km) (Table 8.4). Spatial ranges occupied by blue sharks B1–B7 were expansive (Figure 8.6). Tables 8.3 and 8.4 provide summary statistics describing the extent of movements.

Telemetry data indicated a seasonal component to latitudinal movements of blue sharks into and away from the GAB (Figure 8.7a, b). The smallest spatial extents of movements by blue sharks occurred in autumn, the season in which the survey was conducted (Figure 8.7a, b). The largest latitudinal movements by blue sharks occurred during spring (24.6° S to 42.9° S) and summer (13.9° S to 41.5° S). Longitudinal movements by blue sharks were also greatest in spring (103.5° E to 160.5° E) and summer (88.4° E to 149.8° E). Seasonal patterns in movements are summarised in Figure 8.8. Blue shark B2 migrated to the central Indian Ocean and B6 travelled to the Tasman Sea and central SW Pacific Ocean between Australia and New Zealand (Figure 8.6).

Shortfin mako

The tag deployment duration on the shortfin mako was 298 days (Table 8.3). Estimated distal displacement distance from the tagging site was 2910 km (Table 8.4). The spatial range occupied by the shortfin mako extended from the tagging location in the central GAB to an oceanic area of the Indian Ocean located ~211 km west-south-west of North-west Cape, Exmouth, Western Australia (22.13° S, 112.16° E) (Figure 8.6). The highest variation in latitudinal and longitudinal movements by the shortfin mako occurred during spring and summer when it migrated to the offshore (~174 km from land) oceanic area in the north-east Indian Ocean near Exmouth, Western Australia (Figure 8.6 and 8.8).

White shark

Satellite tag deployment durations on white sharks ranged from 64 to 125 days (mean = 99 ± 22, median = 102 days) (Table 8.3). Minimum displacement distances travelled by white sharks ranged between 19 and 1,931 km (mean = 568 ± 793, median = 279 km) (Table 8.4). Movements extended from the South Neptune Islands to 280 km north (33.3° S) in Spencer Gulf, and to 34.9° S and 114.9° E off Western Australia (Figure 8.9). The largest movement extended from South Neptune Islands to the continental shelf slope region located 62 km SSW of Cape Leeuwin, Western Australia (Figure 8.9). The pop-up location of the tag deployed on shark W2 (330 cm TL male) was at the 300 m isobath, and showed a westward movement during winter 2015 (Figure 8.9). Southern and eastern movements by white sharks were limited. White shark W5 (420 cm TL female) moved west into the central GAB, and covered a minimum distance of 569 km. The tag surfaced on 8 September 2015 at a position between the 60 m and 80 m isobaths and due south of Head of Bight.

Bigeye thresher

The mini-PAT deployment duration on the bigeye thresher was 100 days (Table 8.3). Estimated minimum displacement distance was 3263 km (Table 8.4). The tag surfaced at the 1800 m isobath at the Montebello Saddle and Exmouth Plateau, 353 km offshore from North West Cape, near Exmouth, Western Australia (Figure 8.10). Patterns of vertical habitat use indicated the bigeye thresher used shelf slope and oceanic habitats during a substantial west- and north-ward tropical migration during autumn and winter.

Table 8.3. Summary of information on deployments and performance of satellite tags deployed on white sharks (W1–W5), blue sharks (B1–B7), a shortfin mako (S1) and a bigeye thresher (BET1) in the GAB. NSG = northern Spencer Gulf, SSG = southern Spencer Gulf, ST = Sirtrack, SPOT = smart position or temperature tag, mini-PAT = miniature pop-up archival transmitting tag.

Shark ID	Tag	Tag ID	Date deployed	Popup date	Date last pos	Days at liberty	Pop-up lat	Pop-up long	Pop-up region/location	Last lat	Last long
B1	SPOT	148956	1 May 15	-	12 Mar 16	317	-	-	-	-40.58	135.03
B2	ST	134878	3 May 15	-	22 Feb 16	294	-	-	-	-34.10	89.60
B3	SPOT	148954	3 May 15	-	26 Feb 16	298	-	-	-	-15.86	110.86
B4	SPOT	148957	15 May 15	-	17 Jun 15	34	-	-	-	-33.72	129.93
B5	SPOT	148955	15 May 15	-	27 Feb 16	288	-	-	-	-35.69	121.80
B6	SPOT	148965	15 May 15	-	21 Dec 15	221	-	-	-	-39.90	148.63
B7	SPOT	148962	16 May 15	-	14 Jan 16	244	-	-	-	-34.09	132.39
S1	SPOT	148963	17 May 15	-	10 Mar 16	298	-	-	-	-37.06	137.72
W1	mini-PAT	148949	2 May 15	11 Aug 15	-	102	-33.24	137.82	NSG	-	-
W2	mini-PAT	148953	2 May 15	11 Aug 15	-	101	-34.88	114.86	Cape Leeuwin, WA	-	-
W3	mini-PAT	148950	6 May 15	9 Jul 15	-	64	-35.39	136.31	SSG	-	-
W4	mini-PAT	148951	6 May 15	15 Aug 15	-	102	-35.18	136.56	SSG	-	-
W5	mini-PAT	148952	6 May 15	8 Sep 15	-	125	-32.31	131.15	Central GAB	-	-
BET1	mini-PAT	148948	16 May 15	23 Aug 15	-	100	-20.14	111.27	Exmouth, WA	-	-

Table 8.4. Summary of information on deployments and data collected by satellite tags on white sharks (W1–W5), blue sharks (B1–B7), a shortfin mako (S1) and a bigeye thresher (BET1) in in the GAB. Ptt days = days of data for each platform transmitter terminal (tag), ST = Sirtrack, SPOT = smart position or temperature tag, mini-PAT = miniature pop-up archival transmitting tag. Deployment locations represent sets S1 to S7, and South Neptune Island (SNI).

Shark ID	Tag	Tag ID	Deploy loc.	cls 3	cls 2	cls 1	cls 0	cls a	cls b	cls z	All cls3-b	Ptt days	Max displ. dist. (km)
B1	SPOT	148956	S1	8	19	63	32	76	442	2	642	167	3150
B2	ST161	134878	S2	9	20	28	22	34	88	1	202	63	1440
B3	SPOT	148954	S2	13	61	127	94	113	306	0	714	196	4190
B4	SPOT	148957	S4	0	2	3	1	6	20	0	32	15	535
B5	SPOT	148955	S4	5	22	140	87	125	548	3	930	230	1186
B6	SPOT	148965	S5	6	11	37	22	64	266	1	407	114	2560
B7	SPOT	148962	S6	28	78	116	64	141	715	0	1142	212	600
S1	SPOT	148963	S7	36	103	111	60	176	695	5	1186	258	2910
W1	mini-PAT	148949	SNI	-	-	-	-	-	-	-	-	-	279
W2	mini-PAT	148953	SNI	-	-	-	-	-	-	-	-	-	1931
W3	mini-PAT	148950	SNI	-	-	-	-	-	-	-	-	-	19
W4	mini-PAT	148951	SNI	-	-	-	-	-	-	-	-	-	43
W5	mini-PAT	148952	SNI	-	-	-	-	-	-	-	-	-	569
BET1	mini-PAT	148948	S6	-	-	-	-	-	-	-	-	-	3263

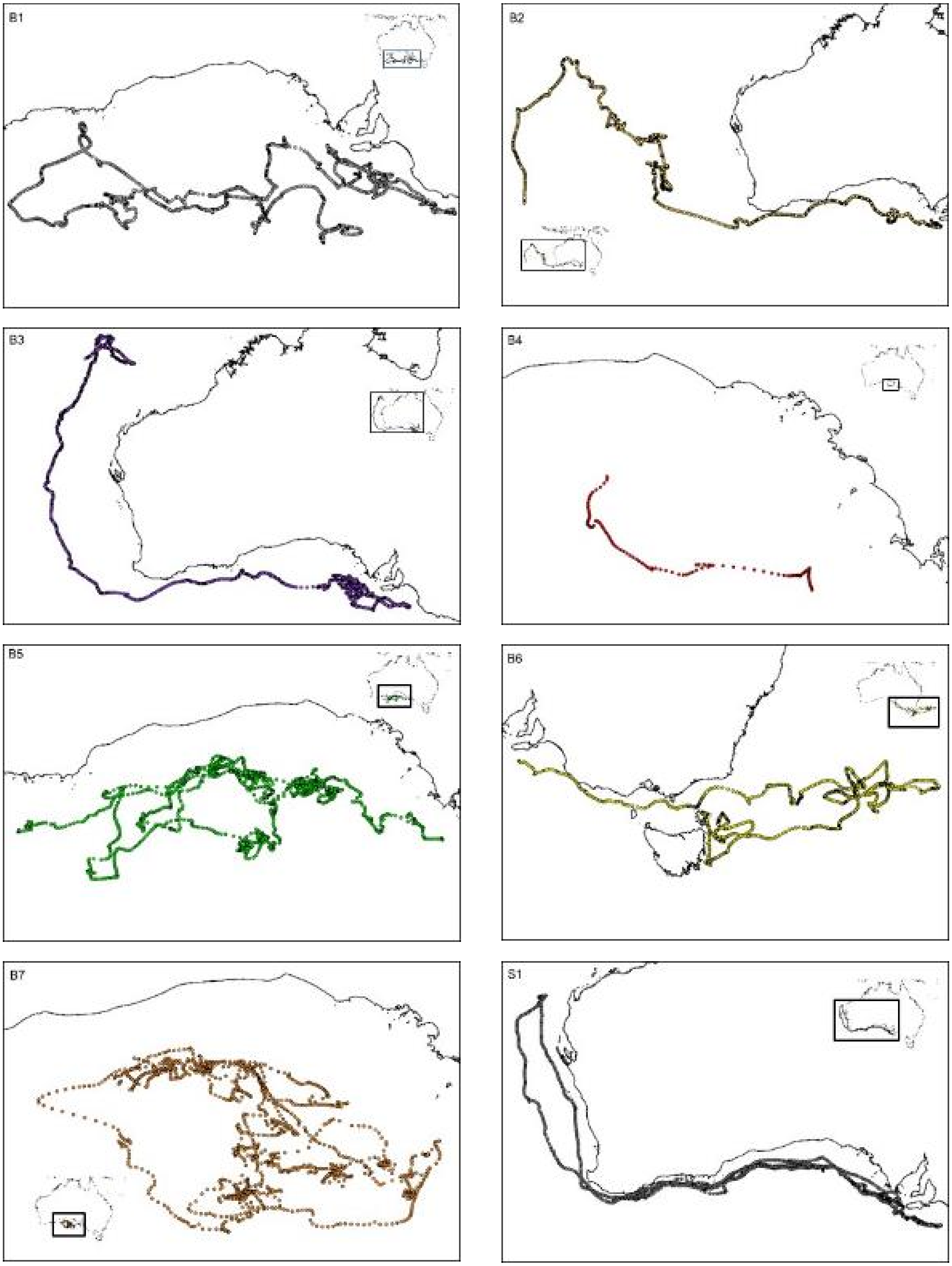


Figure 8.6. Spatial distribution of blue sharks B1–B7 and shortfin mako S1 tracked following the offshore pelagic shark survey in the GAB in 2015.

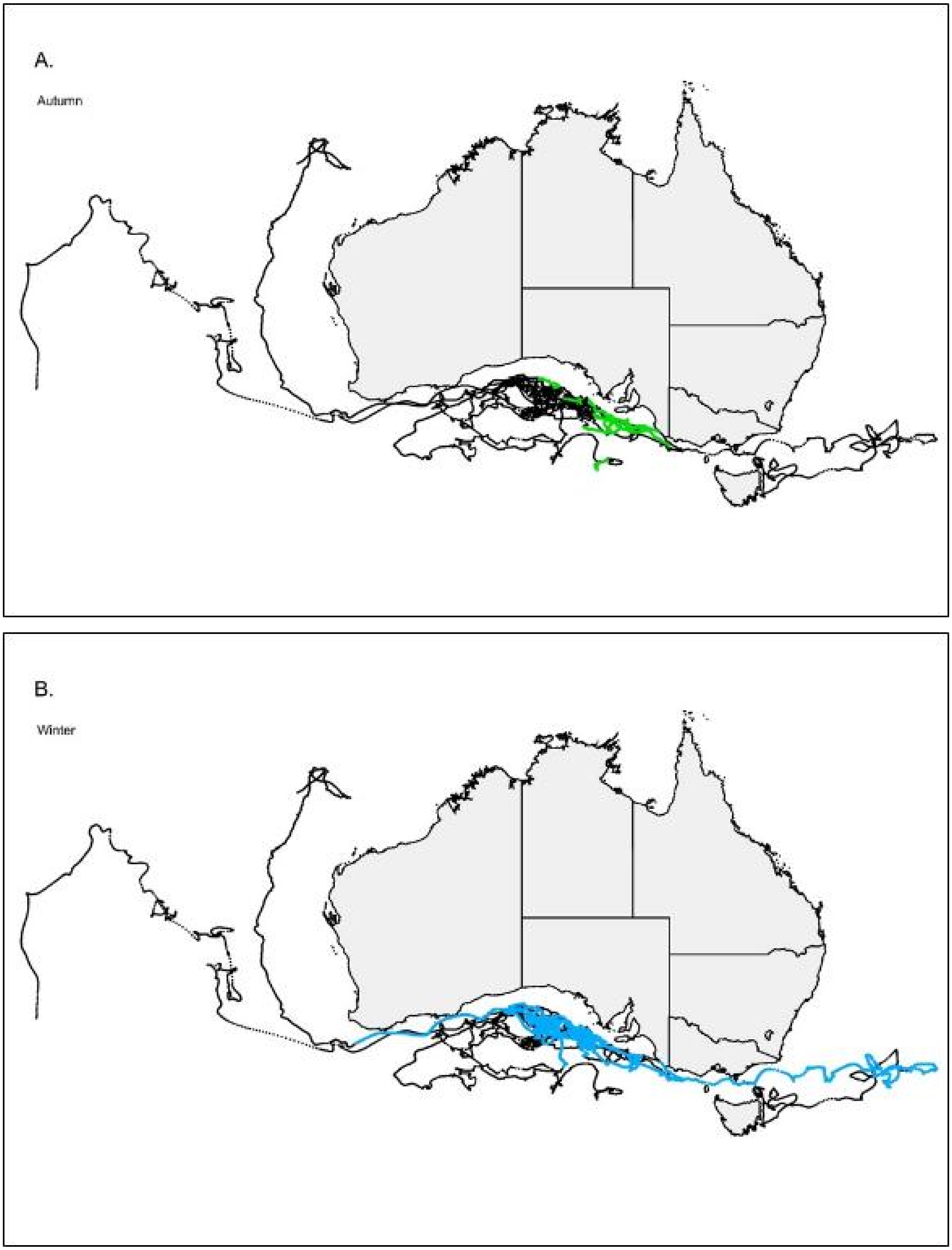


Figure 8.7. Seasonal distribution of blue sharks in the GAB during 2015 and 2016. A. Autumn 2015 (green symbols), B. Winter 2015 (blue symbols).

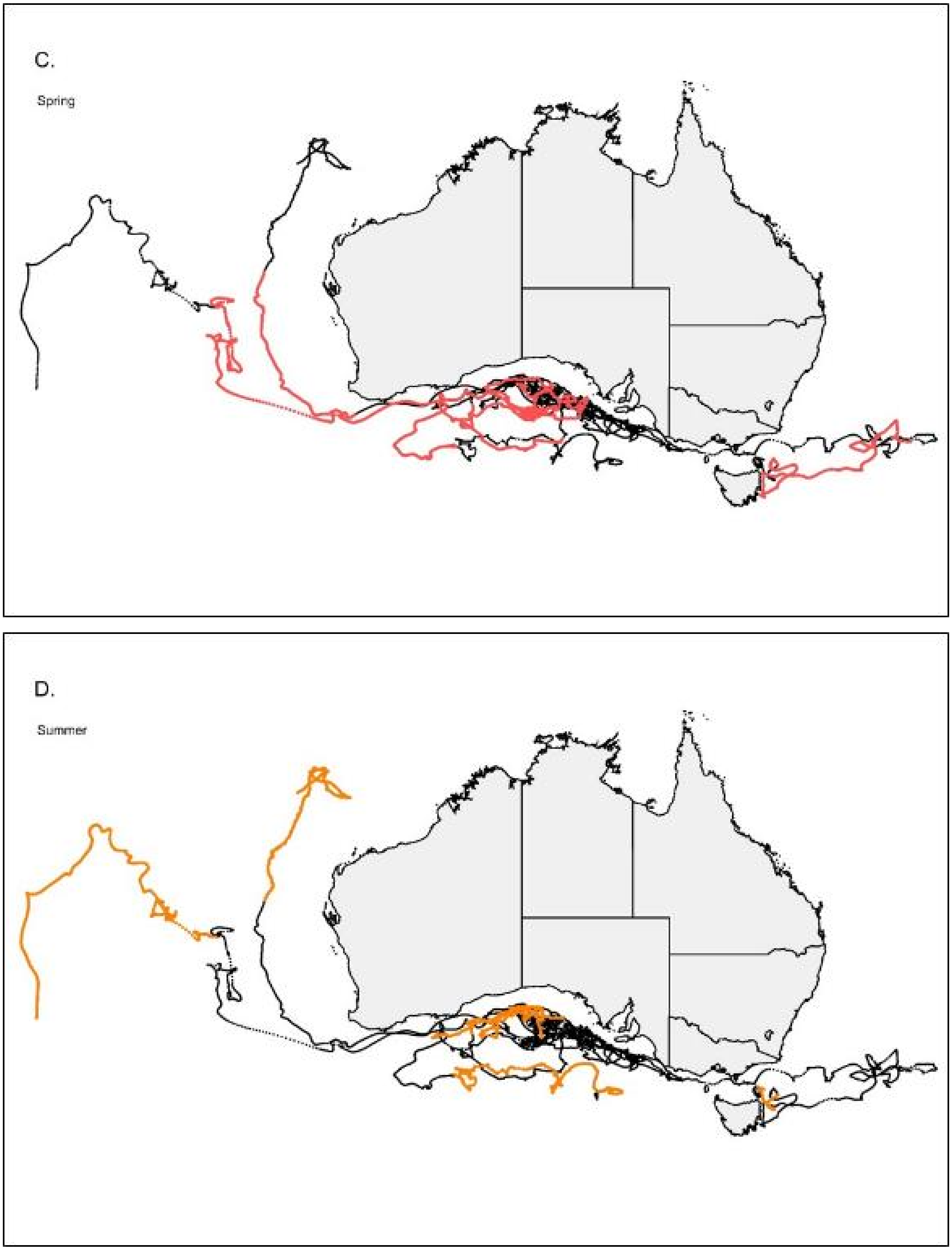


Figure 8.7. (cont.). Seasonal distribution of blue sharks in the GAB during 2015 and 2016. C. Spring 2015 (red symbols), and D. Summer 2015–16 (orange symbols).

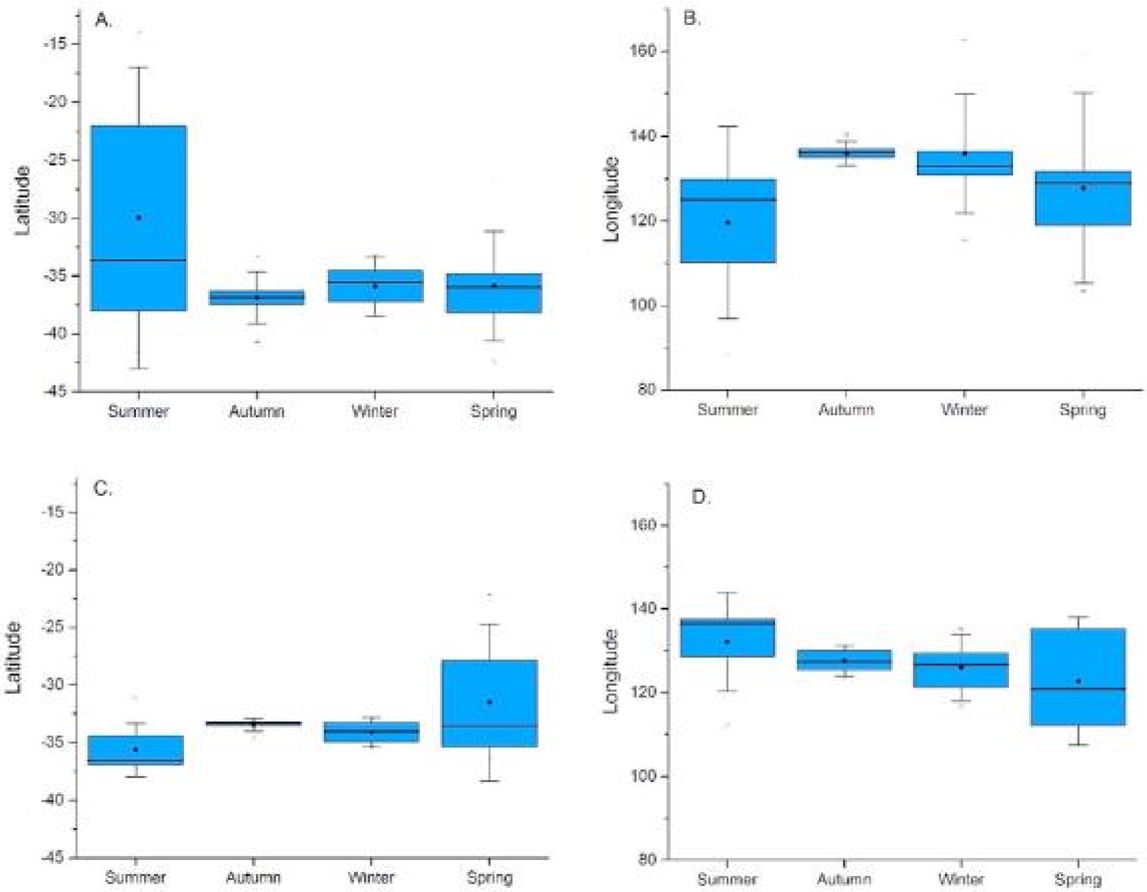


Figure 8.8. Seasonal patterns in latitude (A) and longitude (B) of positions of blue sharks (B1–B7), and latitude (C) and longitude (D) of positions of the shortfin mako (S1) in 2015–16. The symbols used are: mean (circle symbol), error bars are standard deviation, median (slash in box), 25 and 75 percentiles (box upper and lower bounds), 1 and 99 percentiles (cross symbol), maximum and minimum values (dashed line above and below error bars).

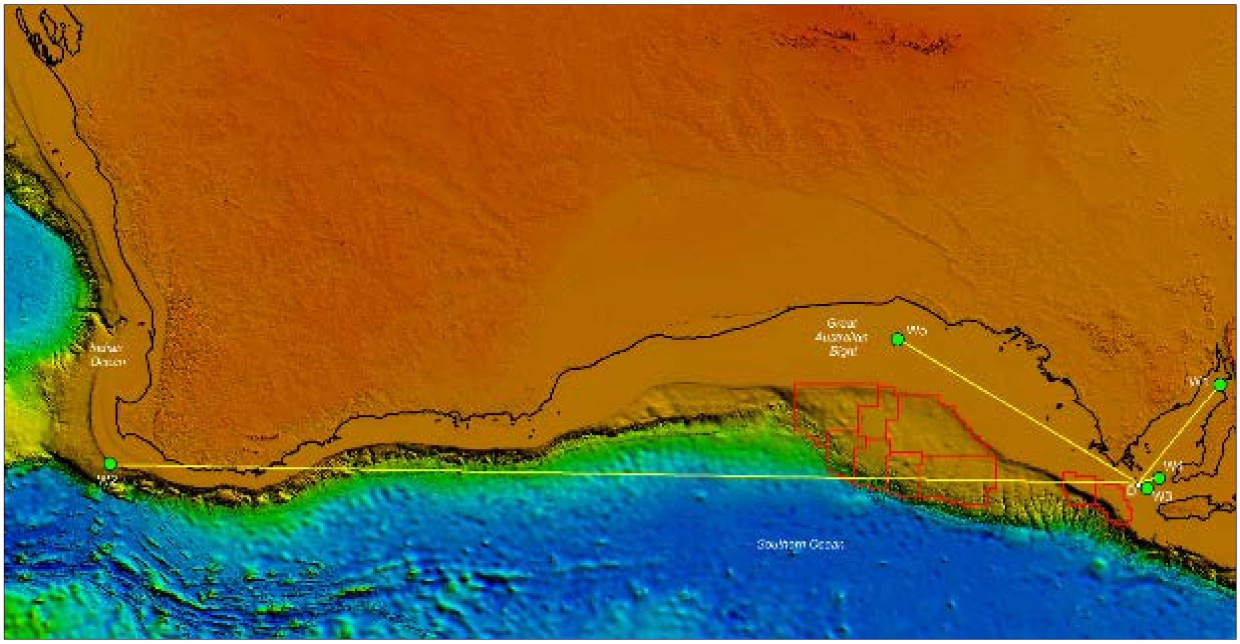


Figure 8.9. Map showing tagging location (white D) and pop-up locations (green symbols W1–W5) showing movements of white shark into the GAB, southern and northern Spencer Gulf, and to the continental shelf slope off Cape Leeuwin, Western Australia. Petroleum exploration lease areas are shown as red lines.

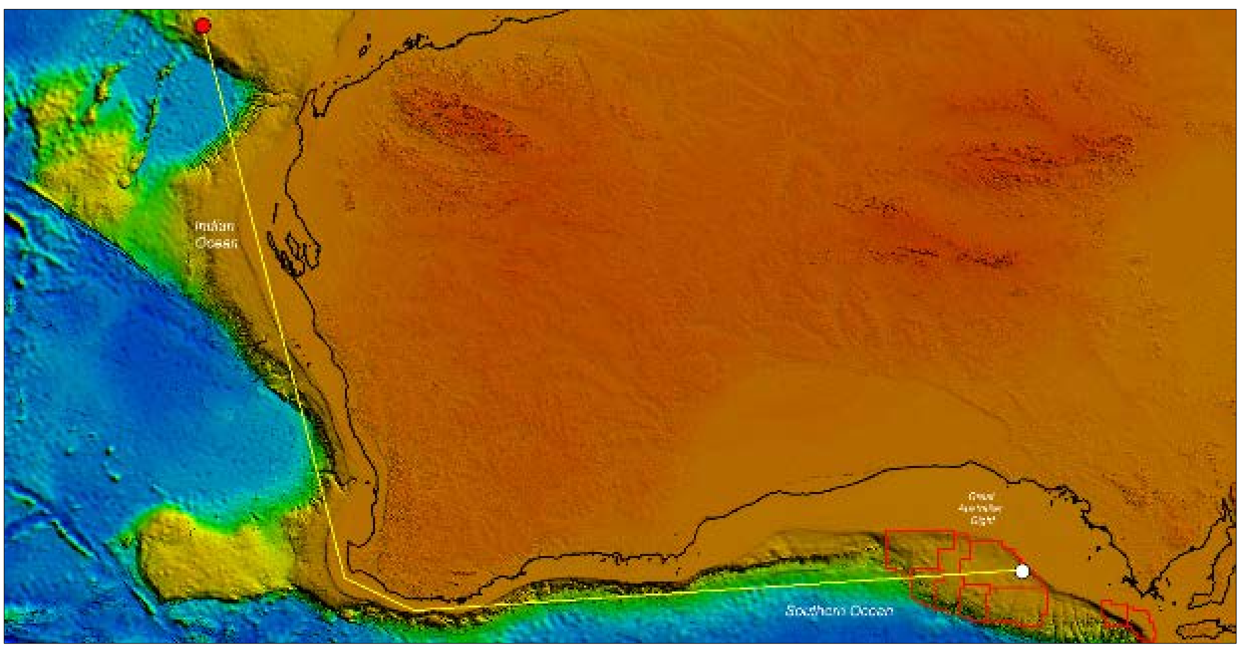


Figure 8.10. Map showing tagging location (white symbol) and pop-up location (red symbol) for the bigeye thresher which shows movement from the GAB to the Montebello Saddle, Indian Ocean. Petroleum exploration lease areas are shown as red lines.

8.4.2 Overlap with spatial management regions

Time-spent-per-area (TSA) analyses of the blue shark (n=7) telemetry data indicated focal areas of habitat use correlated with bottom depths >1000 m in oceanic areas beyond the lower continental shelf slope (Figure 8.11–17). They included, but were not restricted to the regions directly adjacent to the eastern (134.5° E) and central GAB (129.5–131° E), Bonney Upwelling Region (138°E), and Tasman Sea (155–160°E). Several tracked blue sharks visited oceanic regions to the north of the Sub-tropical Front (STF) and south of the eastern, central, and western GAB (36–40°S), which were characterised by bottom depths ≥5000 m. Oceanic areas between 34°S, 130°E and 36°S, 130°E; represented key regions for three tracked blue sharks (B4, B5 and B7) (Figures 8.14, 8.15 and 8.17).

TSA analyses of the shortfin mako tracking data (Table 8.5) for the (S1) (Figure 8.18) indicated areas of highest habitat use were the continental shelf break and slope adjacent to the Lacepede Shelf, Murray Canyons to the south of Kangaroo Island, and outer shelf (100 m), shelf break (160–200 m) and upper shelf slope (300 m) areas in the western GAB. The cline of high relief bathymetry between the 80–130 m isobaths, which is considered to be the ancient coastline of the Last Glacial Maximum (~15–25,000 years before present) (Mulvaney and Kamminga 1999) was visited by this shark.

Individual-based TSA analyses for blue sharks and the shortfin mako were undertaken to quantify overlap with Commonwealth marine reserves, and with oil and gas lease areas in the GAB (Figures 8.11–18, Table 8.5). Time spent in the oil and gas lease areas by individual blue sharks ranged between 0 and 120 days (mean = 43 ± 51 days, median = 23 days) (Figures 8.11–17, Table 8.5). Time spent by the blue sharks in the central GAB lease area (BP-Statoil, Chevron and Murphy leases combined) ranged between 0 and 34 days (mean = 10 ± 13 days, median = 3 days) (Table 8.5).

Time in the oil and gas leases by the shortfin mako was 2 days in the central GAB BP-Statoil, Chevron and Murphy leases, and 32 days in the lease areas (all combined) (Table 8.5). Blue sharks B4, B5 and B7 spent 66.7% (14 days), 43.1% (120 days) and 48.9% (115 days) of their tracked time in the lease areas, respectively (Figures 8.14, 8.15 and 8.17, Table 8.5). Blue sharks B1–B3, and B6 each spent <10% of their tracked time inside leases (Figures 8.11, 8.13 and 8.16). Time spent by blue sharks in the central GAB Marine Reserve, which overlaps with oil and gas lease areas, ranged between 0 and 38 days (mean = 11 ± 14 days, median = 4 days) (Table 8.5). A similar pattern was observed in the Western Eyre Commonwealth Marine Reserve in the eastern GAB, where blue sharks spent 0–50 days (mean = 10 ± 18 days, median = 3.5 days).

The shortfin mako spent 4 days in the GAB Marine Reserve, and 6 days in the Western Eyre Commonwealth Marine Reserve where the oil and gas leases overlap with the Great Australian Bight Marine Reserve (Table 8.5). Blue sharks spent between 0 and 34 days in this multi-use jurisdiction (Figures 8.11–16), while the shortfin mako spent 2 days in the same offshore zone (Figures 8.18), reflecting their greater preference for the mid and outer continental shelf and shelf-break.

Table 8.5. Percentage time-spent-per-area by blue sharks (B1–B7) and a shortfin mako (S1) in petroleum leases and Commonwealth Marine Reserves (GAB Marine Reserve and Western Eyre Reserve) in the GAB.

Shark ID	Duration (days)	Time in leases (days)	%	Time in GABMR (days)	%	Time in Western Eyre Res. (days)	%	Time in GAB lease (days)	%
B1	315	4	1.3	0	0	4	1.3	0	0
B2	294	23	7.8	14.5	5	7	2.4	11	3.7
B3	297	28	9.4	4	1.3	50	17	0	0
B4	21	14	66.7	3	14.3	0.2	1	3	14.3
B5	278	120	43.1	19	6.8	3	1.1	19	6.8
B6	208	0	0	0	0	0	0	0	0
B7	235	115	48.9	38	16.2	3.5	1.5	34	14.5
S1	297	32	10.8	4	1.3	6	2	2	0.7

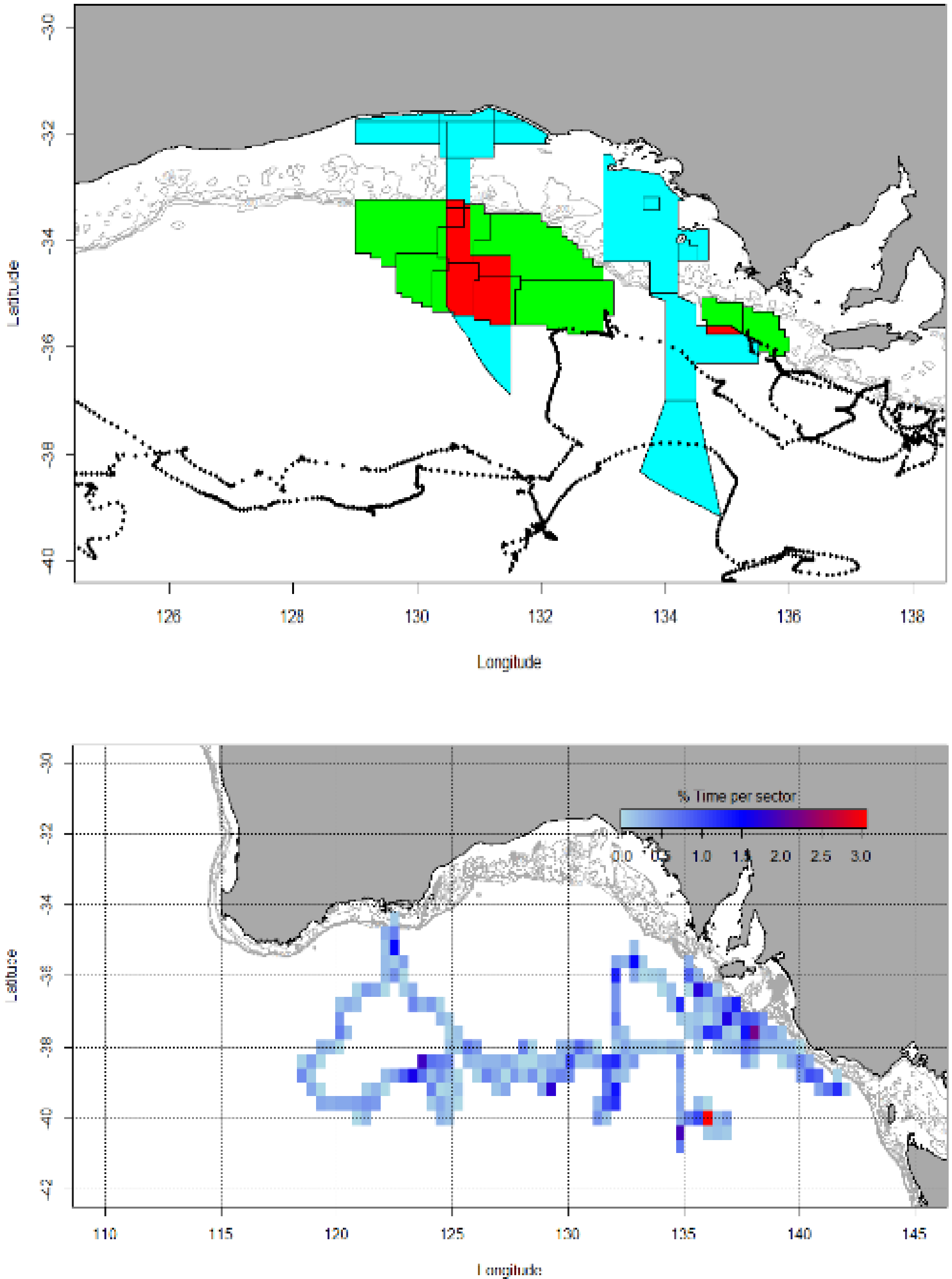


Figure 8.11. Bottom map shows time-spent-per-area for blue shark B1 (200 cm female) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

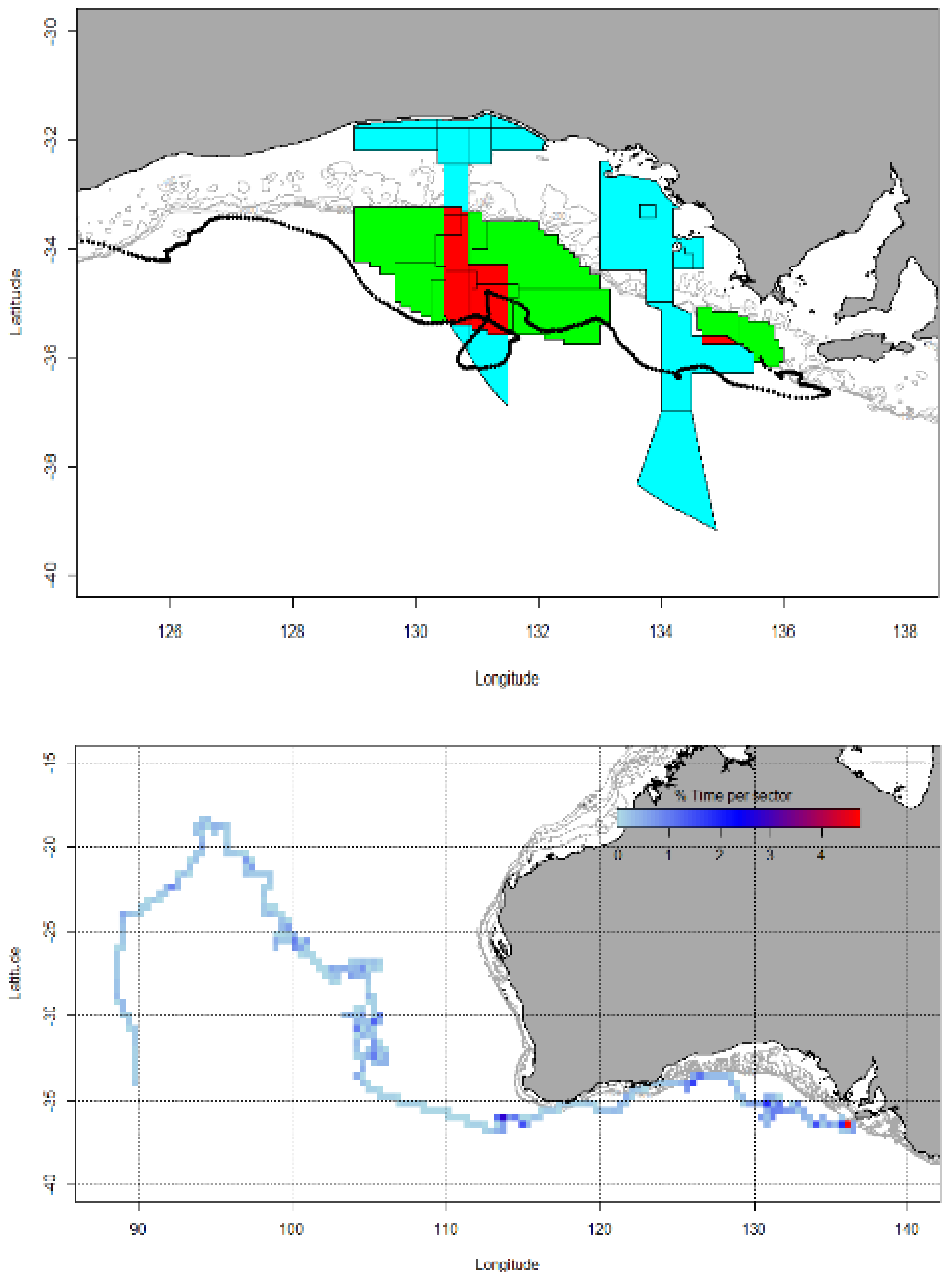


Figure 8.12. Bottom map shows time-spent-per-area for blue shark B2 (180 cm male) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

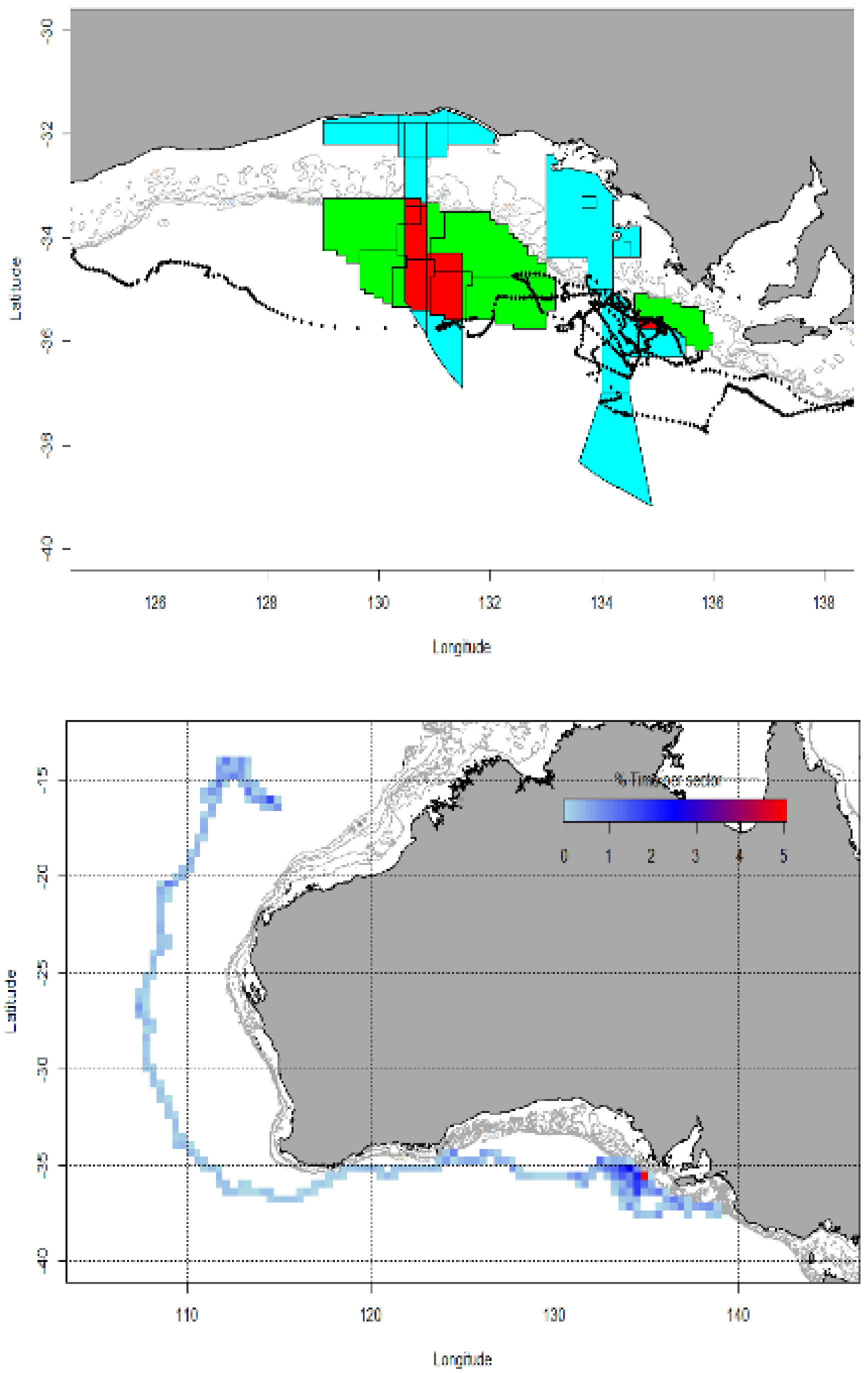


Figure 8.13. Bottom map shows time-spent-per-area for blue shark B3 (224 cm female) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

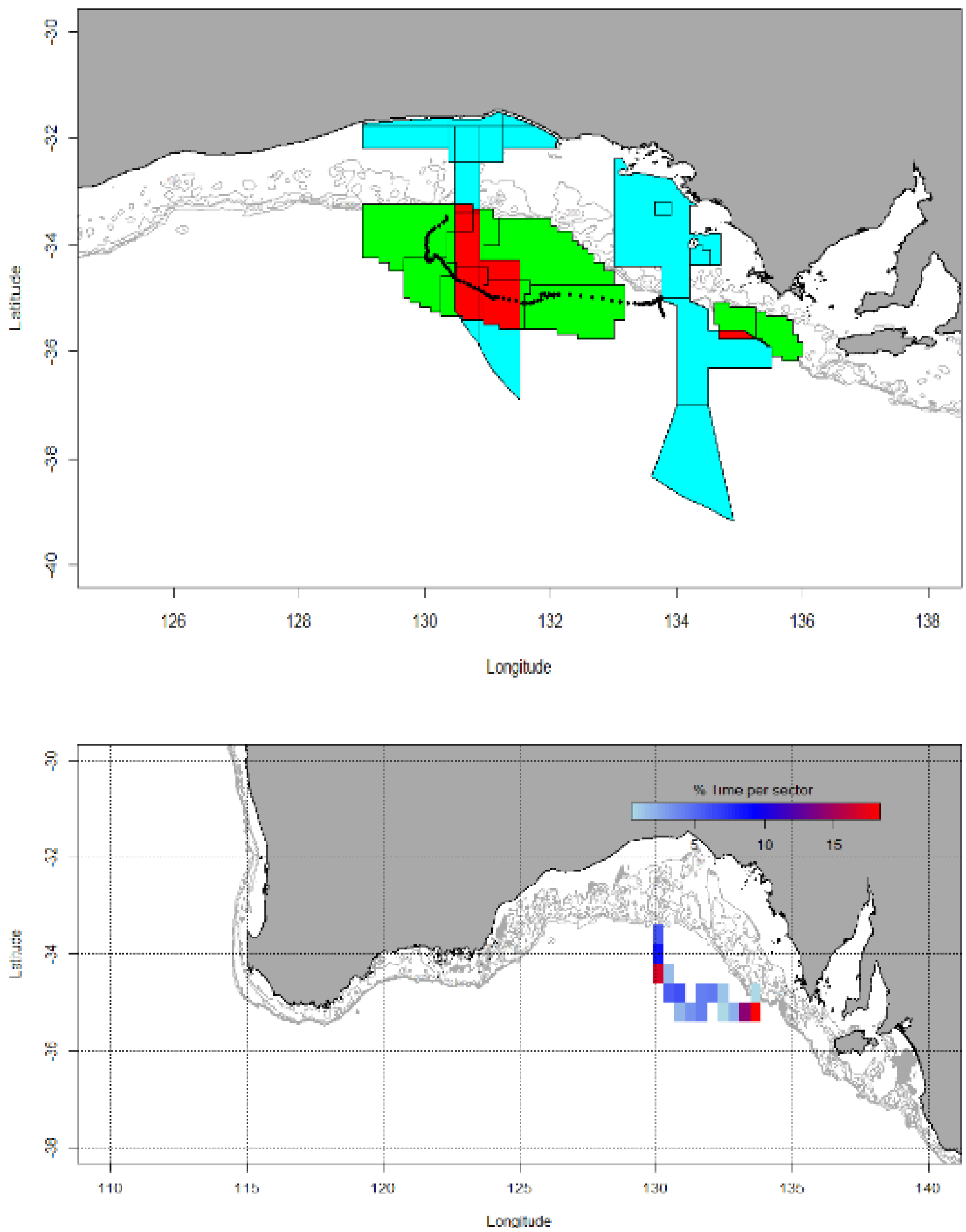


Figure 8.14. Bottom map shows time-spent-per-area for blue shark B4 (208 cm male) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

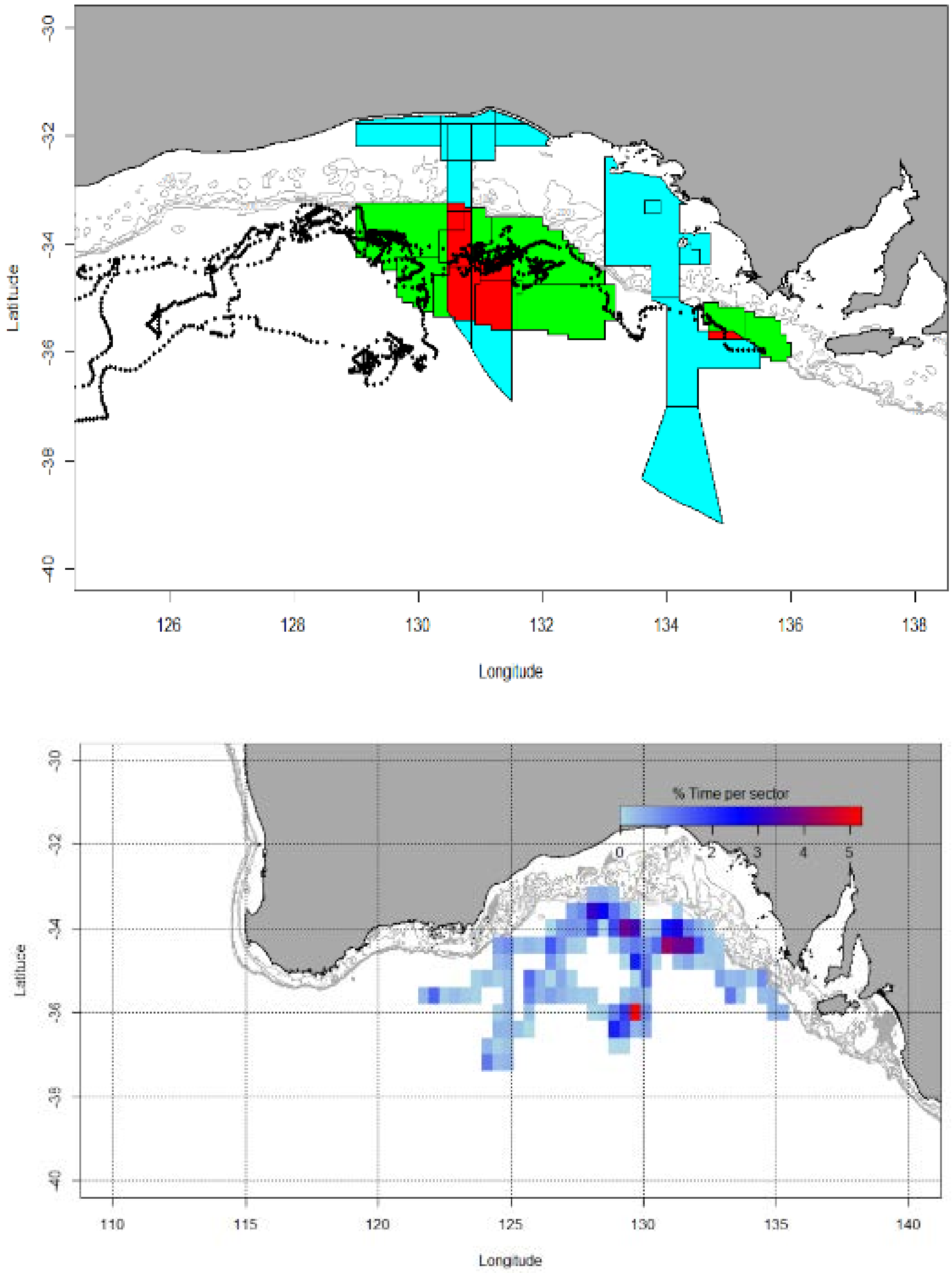


Figure 8.15. Bottom map shows time-spent-per-area for blue shark B5 (233 cm male) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

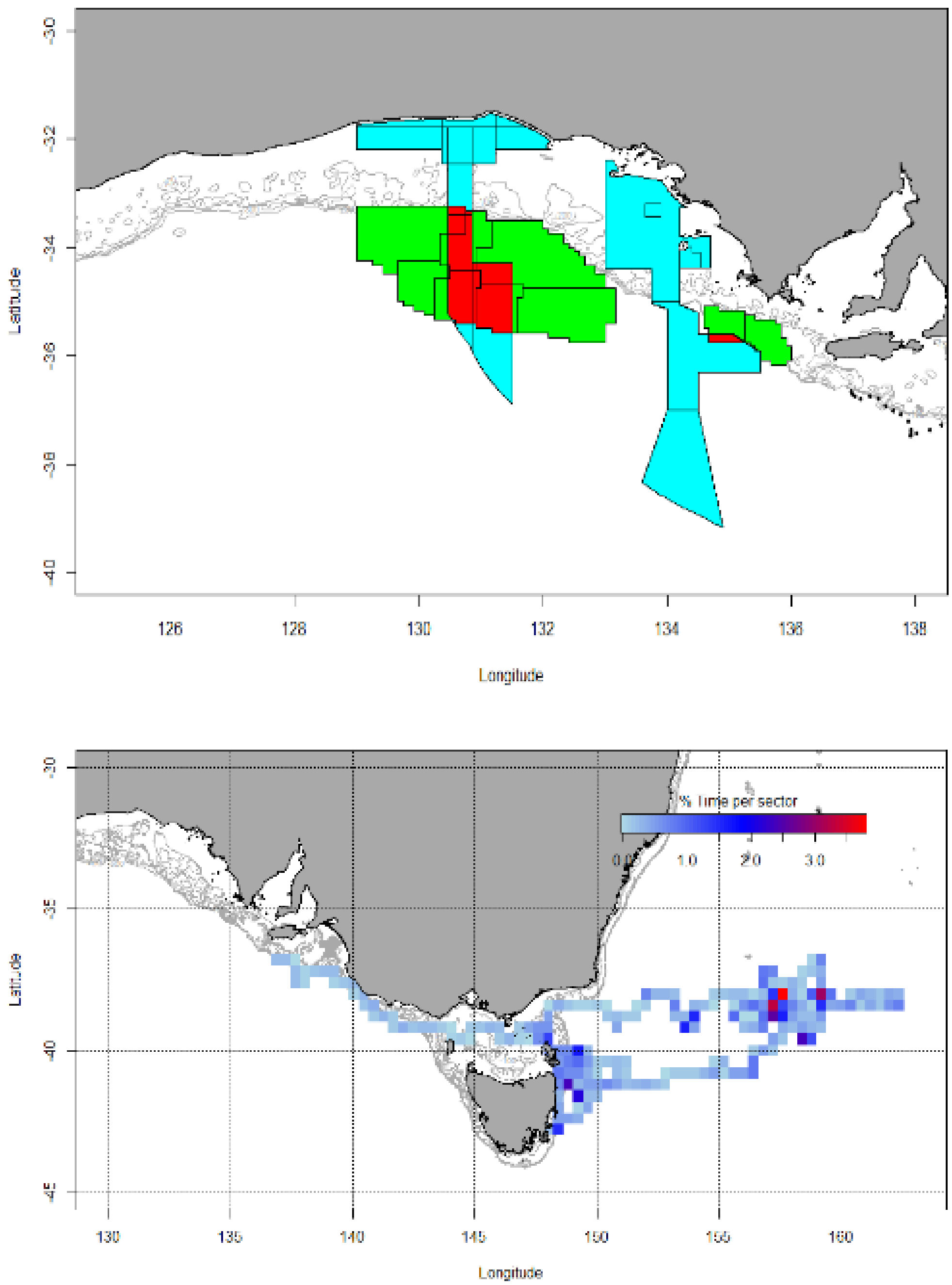


Figure 8.16. Bottom map shows time-spent-per-area for blue shark B6 (235 cm male) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

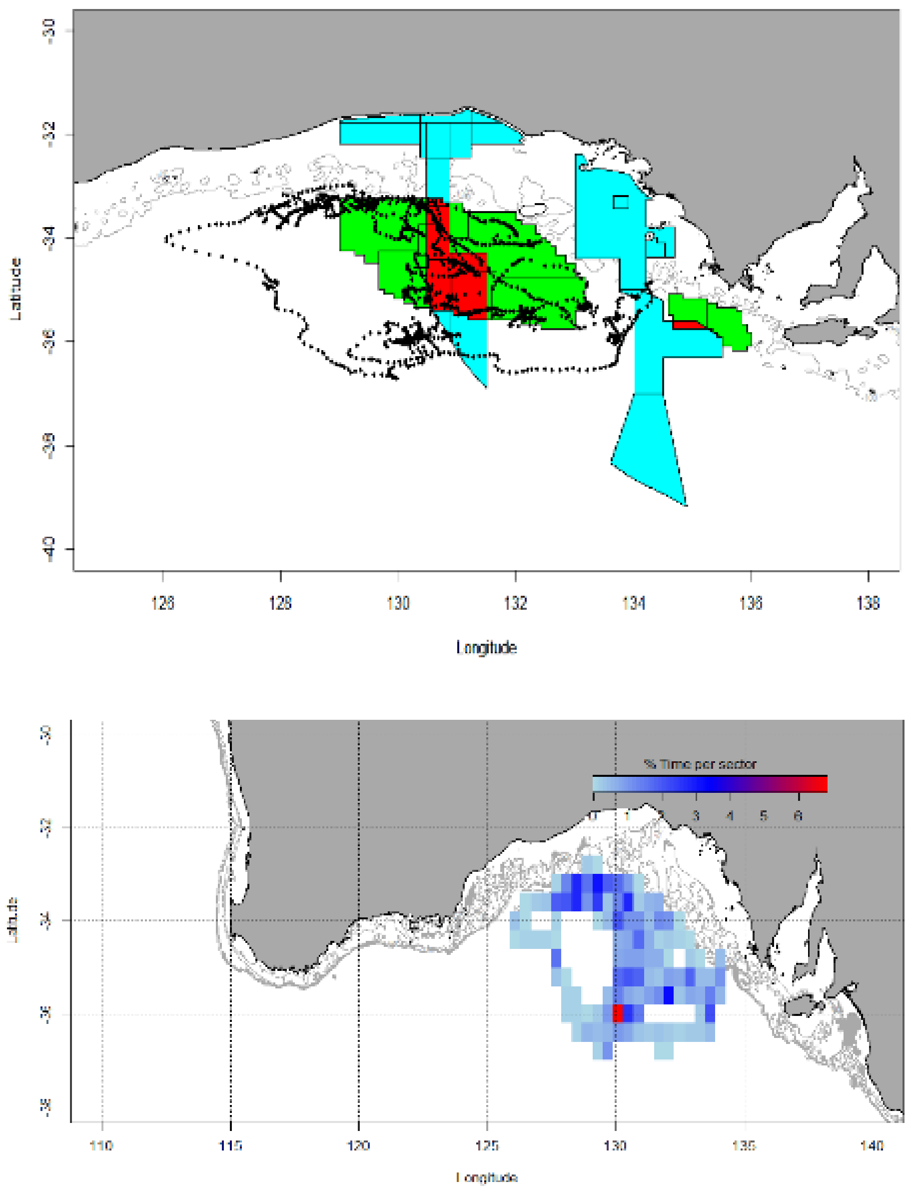


Figure 8.17. Bottom map shows time-spent-per-area for blue shark B7 (250 cm male) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

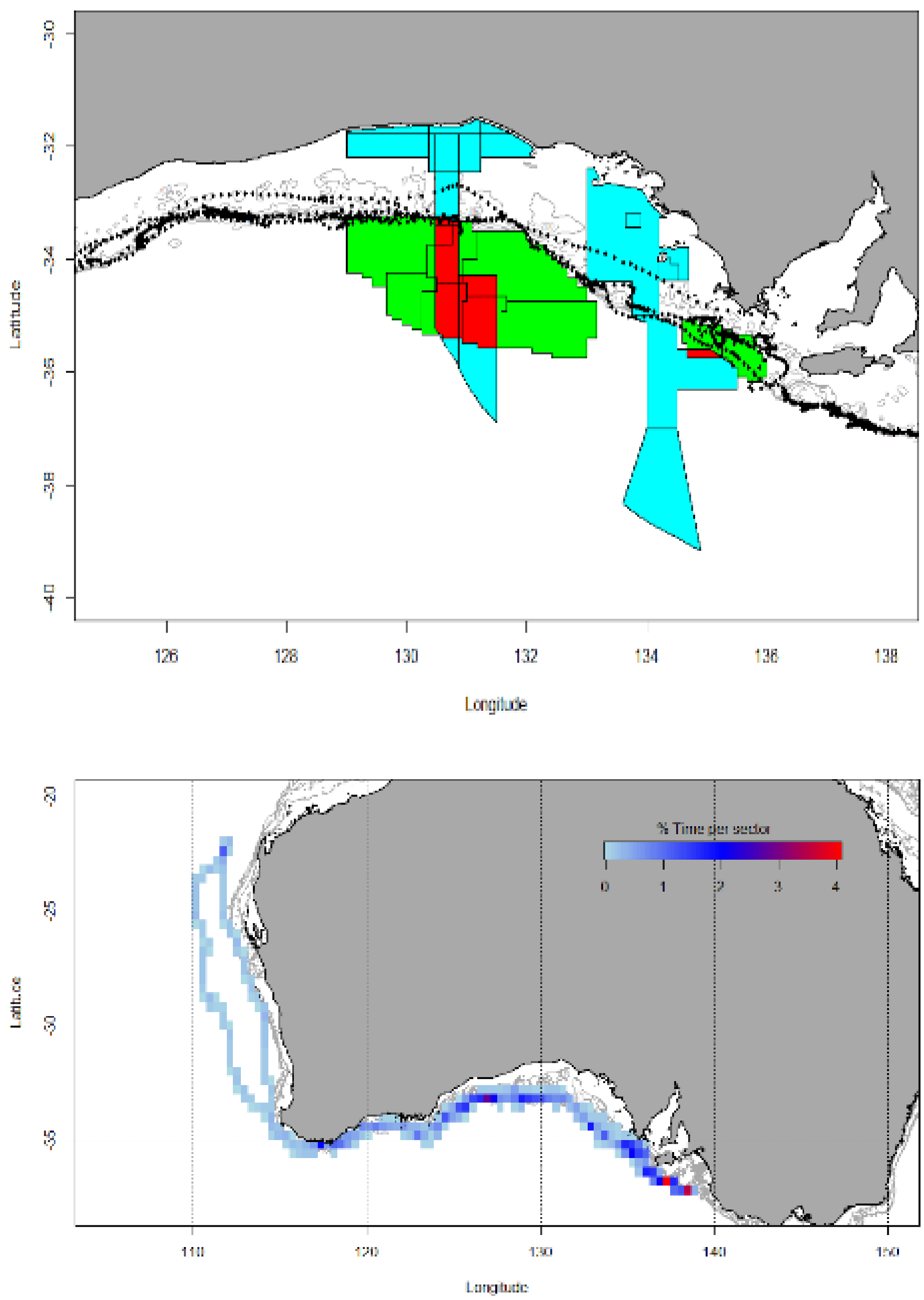


Figure 8.18. Bottom map shows time-spent-per-area for the shortfin mako S1 (232 cm female) for the extent of the track in the GAB and Southern Ocean. Top map shows spatial overlap of the shark track (dotted black line) with the petroleum lease areas (green), two Commonwealth marine reserves in the GAB (blue), and the lease areas that intersect both management regions (red).

8.4.3 Habitat use

Depth and bathymetry gradient

Blue sharks

Blue sharks traversed areas with maximum water depths of 6250 m (mean = 3603 ± 1769 m) (Figure 8.19, Table 8.6). Habitat plots show median depths ranged from 1505–5179 m; the lower end of the range should be interpreted cautiously as B4 was a short duration deployment (< 50 days) (Figure 8.19). Four of the six blue sharks for which there were long-term tracks (excluding B4) preferred shallower, oceanic areas during fidelity or area restricted search (ARS) (fidelity) movement stages (Figure 8.19). Blue sharks traversed a varied array of habitats where bathymetric slopes ranged from 0.01 to 15.85 degrees (mean = 1.98 ± 1.99 degrees) (Figure 8.20, Table 8.6). Four of the six (67%) animals (excluding the short track of B4) exhibited area restricted search classified movements in regions with higher variability in depth gradients as compared to areas used as transit paths (Figure 8.20).

Shortfin mako

The shortfin mako inhabited areas characterised by mean bottom depths of 755 ± 1344 m, s.d.; median = 206 m, and maximum bottom depths in oceanic areas of 5845 m (Figure 8.19, Table 8.6). The shortfin mako inhabited areas with shallower mean depths during ARS classified movements, than during transit.

Position estimates at the surface corresponded to bathymetric gradients ranging from 0 to 16.50 m (mean = 2.10 ± 1.04 m) (Figure 8.20, Table 8.6). This individual exhibited area restricted search classified movements in regions characterised by larger mean, median and ranges of depth gradients when compared to areas it used as transit paths (Figure 8.20).

Table 8.6. Summary of physical and oceanographic habitat variables describing areas used by tracked blue sharks (combined) and the shortfin mako. The parameters are: depth = bottom depth (m), bathymetry gradient (m), SST = sea-surface temperature (°C), SST grad = sea surface temperature gradient (°C), SSH = sea-surface height (m), SSH grad. = sea-surface height gradient (m).

Species	Parameter	N	Mean	sd	Median	Min.	Max.
Shortfin mako S1	Depth	1784	755	1344	206	1	5845
	Bathymetry gradient	1782	2.01	2.84	1.04	4.97E-17	16.50
	SST	1784	18.1	2.2	18.4	13.6	24.2
	SST grad	1726	0.00047	0.00032	0.00041	0.000033	0.0019
	SSH	1784	0.57	0.16	0.55	0.38	0.95
	SSH grad	1753	0.000049	0.000035	0.000041	0.0000016	0.00025
Blue shark B1–B7	Depth	9895	3603	1769	4359	0	6250
	Bathymetry gradient	9891	1.99	1.99	1.40	0.0063	15.86
	SST	9896	17.2	3.5	16.2	12.1	30.1
	SST grad	9844	0.00057	0.00040	0.00048	0.0000052	0.0030
	SSH	9896	0.61	0.13	0.57	0.28	1.26
	SSH grad	9871	0.000056	0.000047	0.000045	0.00000046	0.00066

Sea-surface temperature and gradient

Blue sharks

Blue sharks occupied areas where sea-surface temperatures ranged from 12.1 to 30.1 °C (mean = 17.2 ± 3.5 °C; median = 16.2 °C) (Figure 8.19, Table 8.6). The high variability directly reflected the broad scale movements (1000s of km) of blue sharks into the Indian, Southern and SW Pacific Oceans. Most blue sharks exhibited area restricted search classified movement in areas with lower median sea-surface temperatures. Periods when sharks were transiting were mostly characterised by areas with high variability in sea-surface temperatures (Figure 8.19).

The mean sea-surface temperature gradient that correlated with satellite positions of blue sharks was 0.00047 ± 0.00032 °C (median = 0.000041 °C) (Figure 8.20, Table 8.6). The range of this parameter spanned several orders of magnitude, indicating blue sharks inhabited a diverse range of water masses and frontal features (Table 8.6). As for correlations with sea-surface temperature, over half (67%) the tracked individuals exhibited movements classified as area restricted search in regions with low variability in the sea surface temperature gradient, yet higher mean and median values (Figure 8.20, Table 8.6).

Shortfin mako

The shortfin mako inhabited areas where sea-surface temperatures ranged from 13.6 to 24.2 °C (mean = 18.1 ± 2.2 °C; median = 18.4 °C) (Table 8.6), and exhibited movements classified as area restricted search in regions with lower mean and median sea-surface temperatures (Figure 8.19) and marginally lower variability, as compared to transited regions. Mean sea-surface temperature gradient for the shortfin mako was 0.0005 ± 0.0003 °C (Figure 8.20). This shark displayed movements that were classified as area restricted search in regions with low variability in sea surface temperature gradient when compared to the areas it transited across with higher directionality. Median values were similar during area restricted search and transit stages (Figure 8.20, Table 8.6).

Sea-surface height and gradient

Blue sharks

Blue sharks occupied areas where sea-surface height anomaly values ranged from 0.28 to 1.26 m (mean = 0.61 ± 0.13 m; median = 0.57 m) (Figure 8.19, Table 8.6). State space model fits indicated four of the six sharks (67%) exhibited area restricted search classified movements in regions with comparatively low variability in sea-surface height as compared to areas they used as transit paths. This was similar to patterns observed for sea-surface temperature and its gradient. No observable pattern was apparent in the state space modelled position and sea-surface height gradient data, with high individual level variation between area restricted search and transit stages. Overall, the individual-level estimate of variability in sea-surface height gradient was highest during the transit stages of sharks B2, B3 and B6 (Figure 8.20, Table 8.6).

Shortfin mako

The shortfin mako inhabited areas where sea-surface height anomaly values ranged from 0.38– 0.95 m (mean = 0.57 ± 0.12 m; median = 0.55 m). The shortfin mako exhibited area restricted search classified movements in regions with lower mean and median sea-surface heights than for transited areas (Figure 8.19). Variability in sea-surface height was substantially lower in areas where the shortfin mako exhibited area restricted search classified movements when compared to areas the individual transited across with higher directionality. The large range of sea-surface height observed reflected the expansive spatial area of the migration that extended from the temperate waters of the central GAB to the sub-tropical waters of the Indian Ocean. Mean and median sea-surface height gradient (Figure 8.20) were similar for transit and restricted search stages, while variability was highest in the areas used as transit paths.

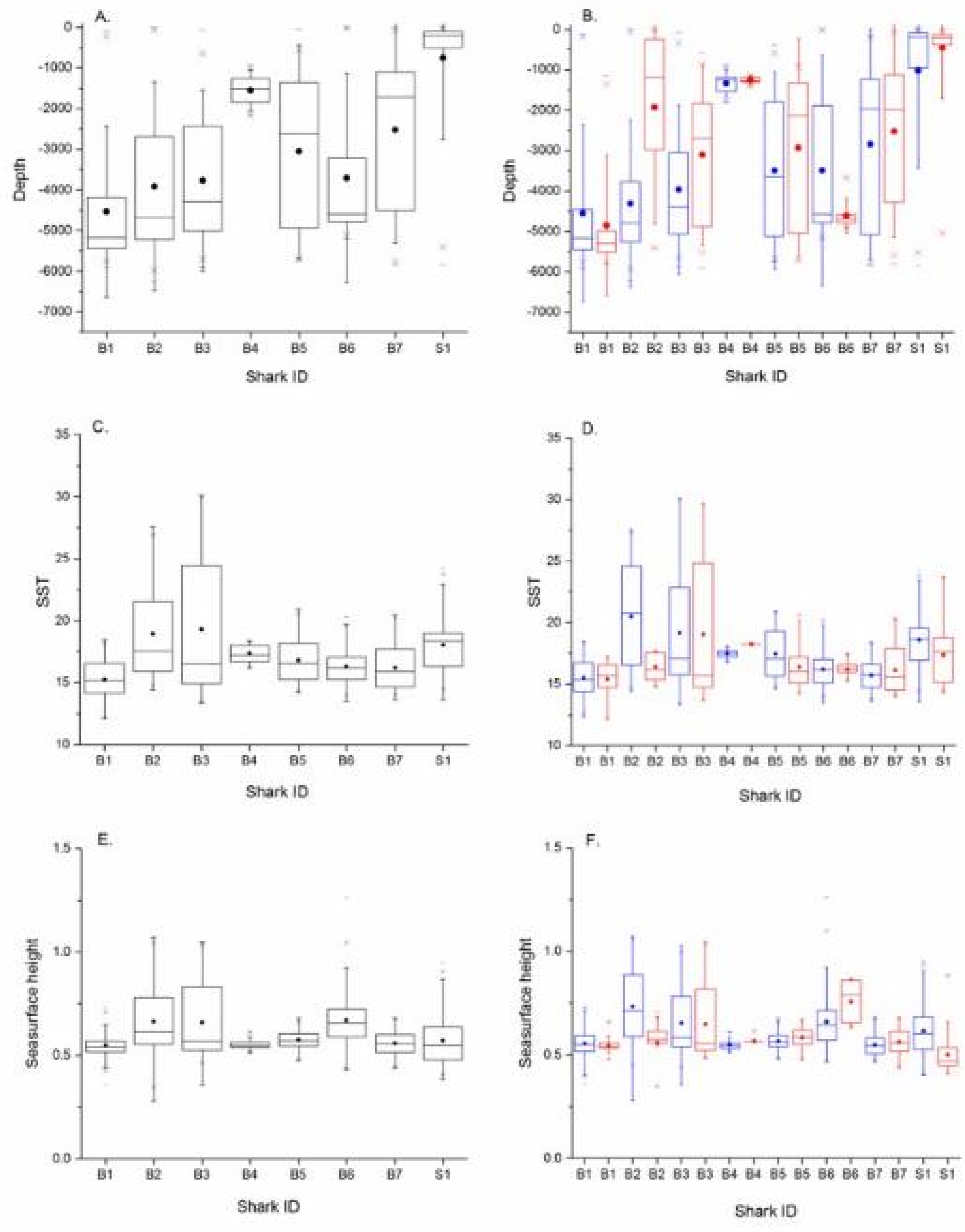


Figure 8.19. Habitat summary plots for blue sharks B1–B7 (combined), and the shortfin mako, S1 showing patterns of depth use (A and B), sea-surface temperature (C and D), sea-surface height (E and F). Plots B, D and F show the parameters during area-restricted search and transit classified movements where blue = transit and red = fidelity (searching) classified positions. Plots show mean (circle symbol), median (slash in box), 25 and 75 percentiles (box upper and lower bounds), outliers are error bars, 1 and 99 percentiles (cross symbol), maximum and minimum values (dashed line above and below error bars).

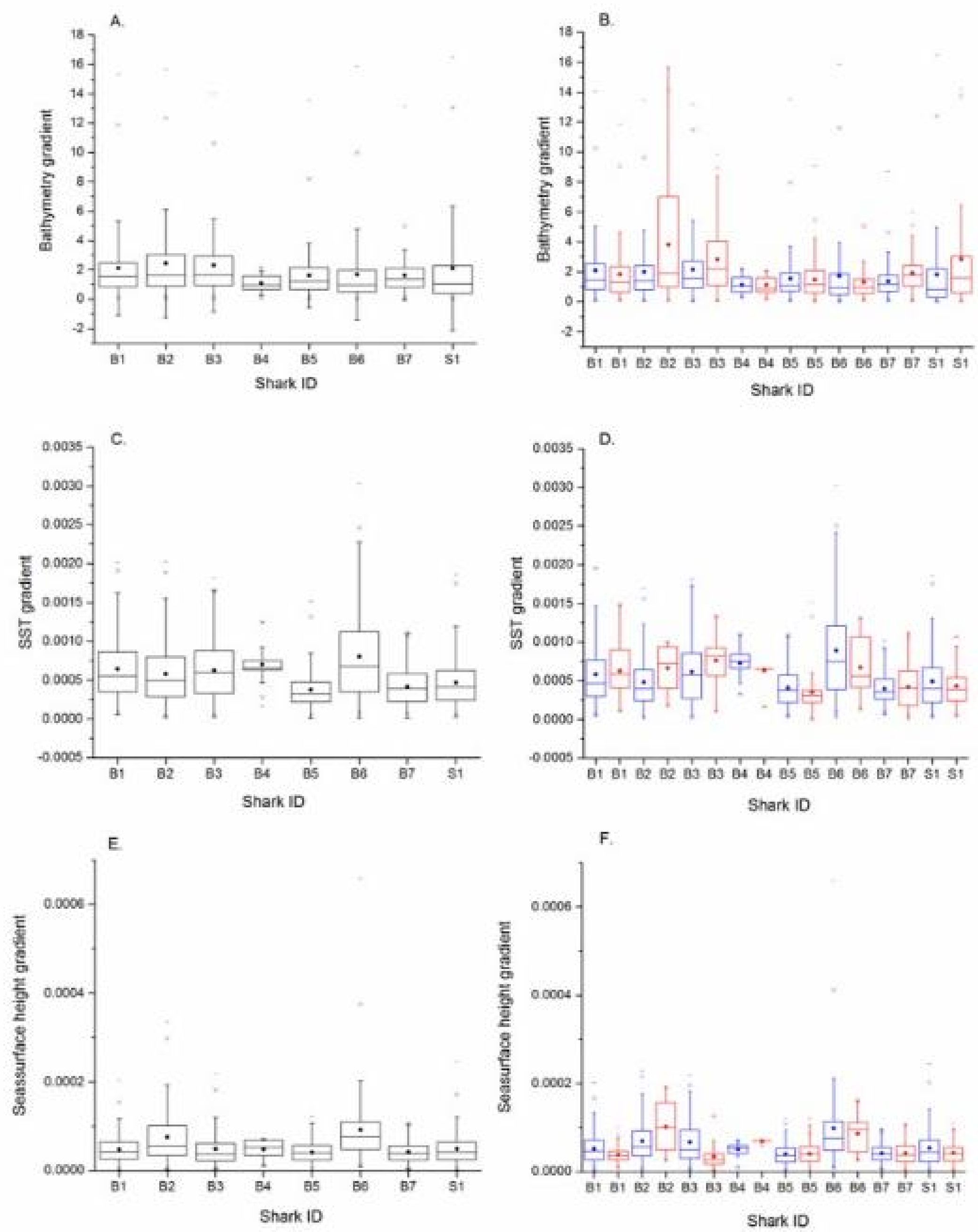


Figure 8.20. Habitat summary plots for blue sharks, B1–B7 and the shortfin mako, S1. Plots show gradients of bathymetry (A and B), sea-surface temperature (C and D) and sea-surface height (E and F). Plots B, D and F show the parameters during area-restricted search and transit classified movements where blue = transit and red = fidelity (searching) classified positions. Box plots show mean (circle symbol), standard deviation (error bars), median (slash in box), 25 and 75 percentiles (box upper and lower bounds), 1 and 99 percentiles (cross symbol), max and min values (dashed line above and below error bars).

8.4.4 Vertical habitat use

White sharks

Depth and temperature data provided by mini-PATs on five white sharks during deployments of 64 to 102 days duration showed individuals inhabited a diverse range of depth and thermal environments characteristic of regions ranging from the shallow gulfs to the lower continental shelf slope (Table 8.7). Based on the depths inhabited and the surfacing locations of the pop-up tags, we can infer that southern Spencer Gulf and its entrance were important habitats for white sharks W1, W3 and W4, whereas sharks W2 and W5 migrated to shelf and continental shelf slope waters.

A total of 62,296 depth records (2077–26,668 per shark) were transmitted by the five mini-PATs deployed on white sharks. White sharks that remained in the vicinity of the gulf and its approach (W1, W3 and W4) inhabited average depths ranging from 17.7 ± 18 m (W4) to 32.1 ± 20.4 m (W3), with minimum and maximum depths ranging between 0–95 m (W4) and 0.5–105 m (W3) (Table 8.7). Sharks W1, W3 and W4 experienced autumn and winter tag-measured SSTs from 9.5–17.7 °C: averages ranged from 14.8 ± 1.9 to 16.6 ± 0.4 °C. Average daily temperature minima experienced by these three individuals ranged from 14.7 ± 1.9 to 16.4 ± 0.4 °C, whereas the lower values of sharks W2 and W5 reflect the large depth ranges they traversed while visiting shelf and slope habitats (average daily temperature minima 13.9 and16.1 °C, for W2 and W5 respectively; with estimated thermal minima = 4.7 °C at 783 m for W2).

Sharks W2 and W5 inhabited average depths of 103.5 ± 184.7 m and 22.5 ± 22.3 m, respectively. Depth ranges were 0–917 m (W2) and 0–163 m (W5) (Table 8.7). Reported sea-surface temperatures inhabited by these two individuals ranged from 15.8–20.3 °C. The average reported SST experienced by shark W2 was 17.7 ± 1.1 °C, as it travelled across the GAB to Cape Leeuwin, Western Australia. Shark W5 experienced SSTs ranging from 15.4 to 17.2°C (average = 16.1 ± 0.52 °C) as it travelled north-west from the South Neptune Islands to the mid-continental shelf region the south of Head of Bight.

Table 8.7. Habitat parameters for five tagged white sharks (W1–W5) in autumn and winter 2015 in Spencer Gulf and the GAB. Parameter estimates shown here are measured by the mini-pop-up satellite tags during the deployments.

Parameter and statistic	W1	W2	W3	W4	W5
N depth records	2077	26668	11362	19776	2413
Ave depth (m)	20.7	103.5	32.1	17.8	22.5
SD depth	18.9	184.7	20.4	18.1	22.3
Min depth	0.0	0.0	0.5	0.0	0.0
Max depth	98.0	916.5	105.0	95.0	162.5
N tag-measured SST records	141	191	108	171	32
Ave SST (° C)	14.8	17.7	16.6	15.7	16.1
SD SST	1.9	1.1	0.4	1.0	0.5
Min SST	9.5	15.8	15.9	13.8	15.4
Max SST	17.7	20.3	17.6	17.7	17.2
N water temp minima records (° C)	821	1350	803	1196	241
Ave water temp minima	14.7	13.9	16.4	15.1	16.1
SD water temp minima	1.9	4.8	0.4	1.2	0.5
Min water temp	9.5	4.7	15.2	13.2	15.3
Max water temp	17.6	18.3	17.2	17.4	16.8

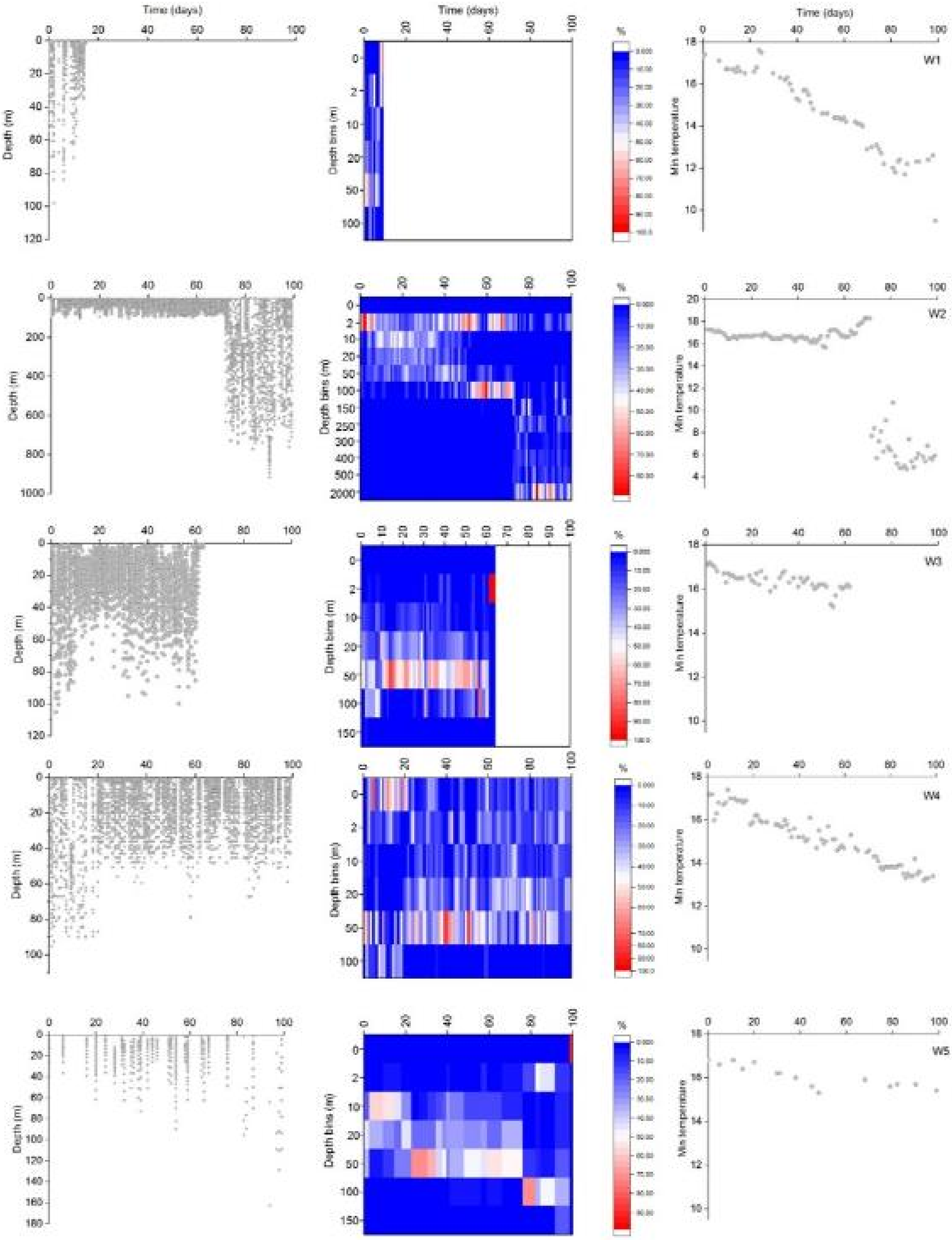


Figure 8.21. Time spent at depth and temperature by white sharks in Spencer Gulf and the GAB.

Bigeye thresher

The bigeye thresher spent ~84% of the tag deployment time below the average tag-estimated mixed layer depth (MLD) of 103.5 ± 25.9 m (MLD range = 43–199 m) (Figure 8.22). Minimum and maximum depths occupied by the bigeye thresher ranged from the surface to 1240 m. Average minimum and maximum daily depths were 13.7 ± 9.0 m and 661.3 ± 152.9 m, respectively (98 records). Average thermal minima experienced by the bigeye thresher was 7.8 ± 1.8° C. Average temperature minima and maxima experienced by the shark in the mixed layer were 20.5 ± 3.4 and 21.7 ± 3.3 °C.

8.4.5 Biological samples

Stomachs were collected from yellowtail kingfish, southern bluefin tuna, shortfin mako and school sharks. Biological samples including tissue biopsies, fin clips and external parasites were collected from a sub-set of the captured and released specimens. The sample set is archived at SARDI, West Beach, South Australia.

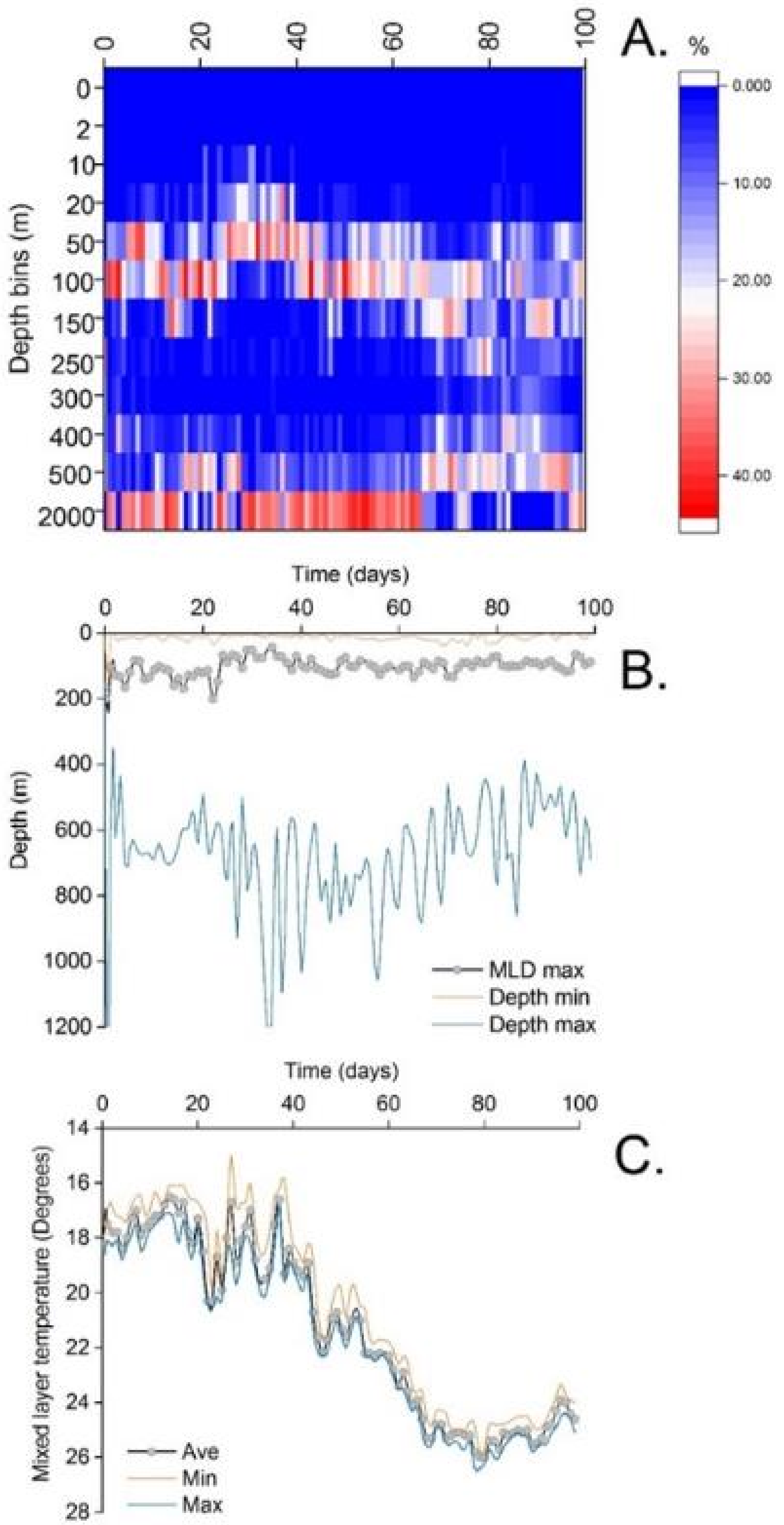


Figure 8.22. A. Time spent at depth by the bigeye thresher. B. Mixed layer, minimum and maximum depth. C. Mixed layer minimum, maximum and average temperature.

8.5 Discussion

A recent review identified a need to understand the distributions, biodiversity, and habitat use of several nationally and internationally listed threatened, endangered and protected pelagic shark species that traverse between the GAB and productive neighbouring oceanic regions (e.g. the northern STF; Rogers *et al.* 2013). Pelagic shark species found in the region, including the longfin mako, shortfin mako, porbeagle and white shark are listed under the Convention on the Conservation of Migratory Species (CMS, Appendix II), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), IUCN Red List of Threatened Species, and *Environmental Protection and Biodiversity Conservation Act* (1999). These species are protected and threatened (Vulnerable) species and/or have a management and conservation status that is pending current national and international assessment processes (e.g. two thresher shark species).

The offshore pelagic survey reported here was one of a series of related components of Theme 4 of the collaborative GAB Research Program that aimed to combine new and existing datasets to identify shared areas of ecological significance (e.g. habitats used by multiple marine predator species). Specifically, this pelagic survey represented the first dedicated effort to assess the biodiversity, species composition, distributions and habitat use of the pelagic shark assemblage in the shelf break, slope and near slope oceanic habitats in the GAB. The first facet that must be acknowledged when interpreting the findings, is the 'snap-shot' nature of the survey relative to the vast spatial scales and complexity of physical and oceanographic processes that occur in these environments. Further work is required to assess the importance of submarine canyon and slope habitats to listed pelagic shark species (e.g. those south-west and south of Kangaroo Island in the Commonwealth Marine Reserve).

8.5.1 Biodiversity and composition

Previous diet studies suggest blue sharks forage on highly productive prey taxa, including the ommastrephid squids (Stevens 1984) that also represent the prey of a range of other sympatric medium to high trophic level predators (Rogers *et al.* 2012; Goldsworthy *et al.* 2013). Blue sharks and shortfin makos were the two most commonly encountered species during the survey, with the highest relative abundances occurring in the eastern study region. The highest relative number and diversity of species encountered during the survey was at the du Couedic Canyon, which is the most significant bathymetric feature in the region, with a large and distinctive scalloped front wall. At du Couedic Canyon (set S1), we observed a large predator aggregation comprising multiple species foraging at the surface directly adjacent to the shelf-break and canyon head wall, including nine species of seabirds, pinnipeds (Australian fur seals), and cetaceans (100s of common dolphins) (see Appendix 8.3). However, as a result of three periods of poor weather, we were unable to conduct the pelagic fish sets and some of the pelagic shark sets in this eastern region of the study area, which reduced the spatial coverage of the survey in some of the key, high relief submarine canyons.

Size and sex information of the sample of blue sharks analysed showed mature-sized individuals comprised of males from 180–250 cm TL, and females from 200–224 cm TL. This provides the first preliminary evidence that slope and oceanic habitats of the Great Australian Bight region represent foraging habitats of reproductively mature blue sharks. However, the total sample size was small. Prior to this survey, there were no published fishery-independent data describing the size range, distribution, and habitat use of blue sharks in the GAB, or elsewhere in the south-east Indian and Southern Oceans. The size and sex composition of the other three pelagic shark species examined during the survey suggested that small juvenile to maturing shortfin mako and mature-sized *Alopias*

species were using the GAB shelf break, slope and oceanic near slope habitats.

The occurrence of the large female bigeye thresher in the continental shelf waters of the GAB, and its subsequent migration through the south-east Indian Ocean to tropical waters off Exmouth, Western Australia was a significant new scientific discovery, given it is predominantly a tropical and subtropical species. Deployment of bio-logging equipment on this individual and the subsequent data collected advanced the knowledge of the distribution of this rare, nocturnal oceanic predator (Last and Stevens 2009). Prior to this survey, there were only three published records of deployment of satellite telemetry equipment on bigeye threshers, being the capture and PAT deployment on one female by fishery observers and the CSIRO in the south-west Pacific Ocean (Stevens *et al*. 2010), and two that were PAT tagged by researchers and fishers in the Gulf of Mexico and off Kona, Hawaii (Weng and Block 2004).

In summary, despite its snap-shot nature, we confirmed previous expectations that offshore shelf-break, slope and adjacent oceanic habitats in the GAB supported similar species compositions of highly migratory shark fauna to the productive ecosystems of the California Current (Southern Californian Bight), where white sharks, shortfin makos, blue sharks, and common threshers form components of the large pelagic predator fauna and upper trophic levels of the ecosystems (Block *et al.* 2011). Further work is required in the shelf slope and offshore submarine canyon habitats to improve both the spatial resolution of the survey, and assessments of pelagic shark biodiversity and species composition. The latter is required as several other species are known to inhabit the area (based on strandings and recreational fisheries catches), e.g. porbeagle, long-fin mako, smooth hammerhead, dusky shark, and bronze whaler. None of those species were encountered in this study.

8.5.2 Spatial and temporal distributions

Key findings of the satellite telemetry deployments included the vast spatial and temporal distribution of blue sharks, and their preference for oceanic and lower slope habitats adjacent to the continental shelf. During previous studies in the region, no pelagic shark species equipped with telemetry equipment had exhibited such strong and protracted preferences for open ocean habitats adjacent to the continental shelf slope. Satellite tracked blue sharks migrated south-wards to oceanic areas between the shelf slope and latitudes aligned with the northern side of the STF region, and oceanic areas in the south-east and tropical north-east Indian Ocean. This northern STF area is also the focus of migrations of several predator species that use pelagic habitats of the GAB, including shortfin makos (Rogers *et al.* 2015a; Rogers and Bailleul 2015), long-nosed fur seals (Page *et al.* 2006), and southern bluefin tuna (Bestley *et al*. 2008). Affinity of predators to, and across the STF during the austral autumn and summer months warrants further investigation, because the region appears to be ecologically significance, but is poorly understood. One blue shark also migrated through the Bonney Upwelling Region and Bass Strait and into oceanic areas of the Tasman Basin. This shark reached a turn-around point at the rising bathymetric gradient ~200 km west of a mid-oceanic ridge, the Belona Saddle, which is located ~950 km from North Island, New Zealand. Our findings were consistent with telemetry and observer data from the north-west Atlantic Ocean, showing that blue sharks were seasonally migratory, and mostly had oceanic ranges interspersed with occasional forays into shelf-break habitats (Campana *et al.* 2011, 2016).

The common thresher and bigeye thresher were encountered at the shelf-break during set S6, although encounters with Alopiidae were infrequent. The bigeye thresher and common thresher were encountered in water depths of 199–265 m to the south of Fowlers Bay. Following

instrumentation with a mini-PAT, the bigeye thresher migrated ~1600 km across south-western Australia during the austral autumn and winter to tropical oceanic waters off Exmouth, Western Australia. During this migration, the shark mostly remained below the typical mixed layer depths, and underwent regular dives to >500 m, suggesting the large-scale movement indicated by the tags final pop-up location had mostly occurred outside the depth ranges characteristic of the shelf break. The common thresher has elongated longitudinal red-muscle that provides metabolic advantages and supports sustained swimming behaviour (Bernal *et al.* 2010), and this may partly explain the dive behaviours we observed. Given its oceanic distribution (Last and Stevens 2009), it is likely the bigeye thresher is encountered by pelagic long-line fleets operating in outer slope and oceanic areas (high seas) of both the Southern and SE Indian Oceans.

During the survey, we extended the knowledge of the spatial and seasonal distributions of sub-adult female shortfin makos in these rarely accessed oceanic and continental shelf slope environments. Shortfin makos were patchily distributed from east to west through the survey area, albeit in comparatively lower abundances than the blue shark. Telemetry-based distribution patterns and areas where shortfin makos were encountered during the survey, were similar to that found during recent studies of habitat use and movements of juveniles in the central and eastern GAB (Rogers *et al.* 2014, 2015a), and analogous to observations in northern hemisphere pelagic ecosystems (Vetter *et al.* 2008; Abascal *et al*. 2011; Block *et al*. 2011). Patterns of spatial distribution of the tagged shortfin mako showed it occupied a range of neritic, shelf break and shelf slope waters with a preference for the outer shelf and break habitats. This individual migrated into oceanic waters of the Indian Ocean as found for juvenile (1.7–2.4 m) conspecifics during the austral winter and spring of 2015 (Rogers *et al.* 2014, 2015a).

For the five white sharks (220–420 cm TL) we instrumented with mini-pop-up satellite tags, the key finding was the high diversity of movement strategies and depth habitats used during autumn and winter 2015. These included three white sharks that remained in the ‘gulf and approach’ habitats, and two that traversed longer distances to the central GAB, and the lower shelf slope area off Cape Leeuwin, Western Australia. Transmitted water temperature data, pop-up locations and depth profiles suggested Spencer Gulf and its approach were important for three white sharks, which was generally consistent with the seasonal patterns of sightings and residency in this region between May and September (Rogers and Huveneers 2016). Tracked white sharks showed an affinity for depths >15 m and water temperatures of 15–17 °C, which are typical of the gulf and inner to central continental shelf regions. However, as found during a recent acoustic telemetry study off Western Australia (McAuley *et al.* 2016), individuals exhibited highly varied spatial distributions and maximal extents as shown via our pop-up tag reporting locations that ranged from the gulf habitats to neritic, near-slope oceanic waters.

Patterns of distribution of the five white sharks were consistent with previous satellite telemetry studies (Bruce *et al*. 2006) and depth ranges, while proximity to shore aligned with spatial patterns of acoustic detections in neritic areas off Western Australia (McAuley *et al.* 2016). Pop-up locations and maximal depths of white sharks W2 and W5 indicated these individuals visited the shelf break and slope during winter during large scale movements to the central GAB and south-east Indian Ocean. This is consistent with previous studies of white sharks and shortfin mako, and in conjunction with depth habitat data collected by the mini-PAT tags, represents further evidence that complex, high relief shelf-break and slope habitats may form migratory paths and/or navigational cues for the Lamnidae and Alopiidae (Bruce *et al.* 2006; Rogers *et al*. 2015a; Rogers and Bailleul 2015).

The timing of the first leg of the survey coincided with the passage of three strong Southern Ocean frontal systems across the GAB. Immediately prior to this period, white sharks had returned to the

Neptune islands following a two-month hiatus (Rogers and Huveneers 2016). In 2015, this return movement was hypothesised to relate to a change-over period between small-medium sized males that dominate sightings and visitations during summer, arrival of medium to large individuals of mixed sexes that visit in autumn and early winter (Bruce and Bradford 2015), and a visit by killer whales in February 2015 (Rogers and Huveneers 2016). We formed the hypothesis that the intrusion of the Leeuwin Current across the shelf from the west may form a migratory cue for white sharks, as the eastward, cross-shelf flow of warm tropical water could provide energetic savings for groups migrating from the Indian Ocean, as well as contain aggregations of suitable pelagic prey taxa. This hypothesis could be investigated when explaining other potential factors that may drive observed movement and residency patterns.

Migration-mediated linkages between the GAB and north-eastern Indian Ocean by three of the four pelagic shark species show the broad importance of shelf-break, slope and adjacent oceanic habitats in the offshore NE Indian Ocean, Bonney Upwelling Region, Tasman Sea, and northern STF. The deep scatter layer (DSL) was prominent on the vessel sonar at the shelf slope during some of the survey sets. Our observations were that this layer of unidentified mesopelagic biota extends vertically as a ~50–80 m thick mass of acoustic back-scatter at depths varying from ~120–400 m. Although, no quantitative data were collected on the DSL during this survey, its presence and prevalence during May 2015 was noteworthy and consistent with previous observations (Hall *et al.* 1981; Rogers *et al.* 2015a).

8.5.3 Identification of key habitats

By correlating remote-sensed environmental variables with surface swimming positions, and measurements collected by the mini-PATs, we were able to summarise the habitat characteristics of four pelagic shark species found in the GAB.

Blue sharks

Most blue sharks exhibited area-restricted search movements in oceanic areas characterised by low sea-surface temperatures, high variability in depth gradients, low variability in sea-surface height and surface thermal gradient. Habitat modelling approaches that manage biases (e.g. those stemming from spatial auto-correlation) should be adopted to explain the suites of factors behind the variability in habitat selectivity we observed in the individual tracks. We also suggest that prey field data continues to be a major gap in explaining the trophic role of this species and why individuals display preferences for particular sets of environmental variables.

Shortfin mako

During some seasons, the offshore pelagic habitats of the GAB and Bonney Upwelling Region support large aggregations of the pelagic squid, *Nototodarus gouldi* (Smith 1983), which are important prey of the shortfin mako (Rogers *et al*. 2012). The tracked shortfin mako inhabited a broad range of outer continental shelf and shelf-break, and to a lesser extent, oceanic areas characterised by median bottom depths of ~200 m (shelf-break isobaths). Notably, this individual exhibited low levels of spatial overlap with bottom depths and areas used by the tracked blue sharks. But it should be noted this comparison stems from a single track. As found for blue sharks, the shortfin mako inhabited areas with shallower mean bottom depths and larger ranges of depth gradients during area-restricted (fidelity) classified movement stages, compared to areas it traversed quickly and directly. The notable exception was during a migration to the Indian Ocean, when it spent most of its time in oceanic habitats. The observed switch in preference from continental shelf

and shelf break to oceanic habitats was consistent with our previous study of juvenile and sub-adult shortfin makos, during which we tracked multiple individuals of both sexes (some over multiple years) with similar seasonal migration routes (Rogers *et al.* 2015a, b; Rogers and Bailleul 2015). One previous study found that the surface gradient environmental parameters (SST, Chl-*a*) associated with oceanographic frontal features, and distance from the shelf slope best explained observed variation in ARS classified satellite positions of tracked shortfin makos (Rogers, 2011).

White sharks

Spatial distribution and habitat data we collected for white sharks using satellite tags showed this iconic species used the GAB continental shelf habitats during medium and large scale autumn and winter migration events, one of which directly traversed the Ceduna sub-basin with the end-point to the SSW of Cape Leeuwin, Western Australia. The otherwise diverse range of habitats used by the tagged white sharks in the GAB was consistent with previous telemetry-based studies in Australian waters (Bruce *et al*. 2006; Sims *et al*. 2011). In these other regions, tracked white sharks were observed to exhibit coastal and island movement and residency phases (Weng *et al*. 2007; Domeier and Nasby Lucas 2008), interspersed with oceanic migrations characterised by regular time spent at depths of 400–700+ m (Nasby Lucas *et al.* 2007). The observed diversity of movement patterns is hypothesised to relate to patterns of distribution and abundance of suitable prey, reproductive cycling and oceanographic cues, but the relative importance of each of these drivers remains unresolved.

Analyses of mini-PAT summary data for the five white sharks reported showed these large bodied endotherms inhabited diverse depth and thermal habitats. The depths ranged from those associated with the predominantly shallow areas in upper Spencer Gulf, to the reefs and gutters of the southern gulf approaches, and the lower shelf slope and oceanic habitats of the GAB and south-east Indian Ocean. White sharks exhibited two movement modes we defined as ‘gulf-approach’ and ‘migratory-shelf’. The prominent offshore preference we observed was consistent with previous movement and behavioural studies in the South-west Region (Bruce *et al.* 2006; McAuley *et al.* 2016). Two specimens that migrated considerable distances during autumn-winter experienced high variability in thermal habitats of 4.7–18.3°C. These movements consisted of episodic surface swimming interspersed with regular deep dives of 600–700 m when migrating, and possibly foraging in offshore shelf slope habitats (max depth = 917 m) off southern WA. This pattern was consistent with findings of a previous study of white sharks during migratory movements in the north-east Pacific Ocean (Weng *et al*. 2007).

Bigeye thresher

The bigeye thresher is a rare deep-water oceanic species, and like the Lamnidae (white sharks and shortfin makos) has specialised physiological features, including regional endothermy and rete meribile that heat the eyes and brain and are thought to allow extensive and rapid vertical migrations in thermally stratified oceanic and slope habitats (Weng and Block 2004). The bigeye thresher tagged during the survey spent ~84% of its time below the estimated mixed layer depth (MLD) of 103.5 ± 25.9 m, which is consistent with findings for bigeye threshers tagged in deep-water oceanic habitats of the eastern Pacific Ocean (Nakano *et al*. 2003) and off Hawaii and in the Gulf of Mexico (Weng and Block 2004). Minimum and maximum depths occupied by the bigeye thresher tagged in our study ranged from the surface to 1096 m, which was considerably deeper than vertical maxima in other studies in the eastern Pacific Ocean (Max = 723 m, n = 2) (Nakano *et al*. 2003),

northern Pacific (Kona, Hawaii) and the Gulf of Mexico (Max = 600–800 m, n = 2) (Weng and Block 2004), and the SW Pacific Ocean (Max = 600 m, temp range = 11.1–21.6° C, n = 1) (Stevens *et al*. 2010). The average minimum and maximum daily depths of the bigeye thresher we tagged in the GAB were 13.7 ± 9.0, and 661.3 ± 152.9 m, respectively, showing this shark undertook brief yet regular forays into the surface and upper mixed layers above the thermocline. Two acoustically tagged bigeye threshers in the eastern tropical Pacific Ocean, WSW of the Galapagos Islands, were found to undertake crepuscular daily 'yo-yo style' movements whilst exploring large portions of the water column (Nakano *et al*. 2003). The bigeye thresher we tagged in the GAB experienced low average thermal minima of 7.8 ± 1.8° C during deep dives off the shelf slope, compared to the relatively warm and stable average temperature minima and maxima in the upper mixed layer (20.5 ± 3.4 and 21.7 ± 3.3° C); further data analyses will assess relationships with crepuscular, diurnal, and nocturnal timing, throughout the entire spatial and temporal extent of the track.

8.5.4 Overlaps with spatially managed areas and petroleum leases

Time-spent-per-area analyses confirmed that areas where blue sharks exhibited highest residency were at and beyond the lower continental shelf slope, and north of the latitudinal band bounding the STF region, south of the GAB. Highest quantities of time spent in oil and gas lease areas by blue sharks ranged between 115–120 days, yet four individuals also spent <30 days inside the leases. By comparison, time spent in the central GAB Marine Reserve by this species ranged between 0 and 38 days. Vertical habitat information suggests blue sharks exhibit fidelity in depth ranges between 100 and 300 m in the GAB (SARDI unpublished data). Whilst some blue sharks and the shortfin mako that were tracked during the survey subsequently migrated to the Indian Ocean, or the Tasman Sea via Bass Strait, these individuals spent minimal time in spatially discrete, oceanic 'patches' during these migrations, when compared to the time they spent to the south of the GAB, thus reinforcing the relative importance of this ecosystem. We speculate that these oceanic patches may be less productive and have lower persistence times than the shelf slope regions where bentho-pelagic habitat complexity is generally higher.

Further assessment of habitat use by the shortfin mako was conducted during Project 4.2 of the GAB Research Program. The areas of highest use by the single shortfin mako that was tracked included the shelf-break and slope adjacent to the Lacepede Shelf, Murray Canyons the south of Kangaroo Island, and the outer continental shelf, and shelf break between the 100 and 300 m isobaths in the central and western GAB. Similar patterns of habitat use were observed in our recent analyses of shortfin makos tagged in western Victoria during summer 2012–13, and state space model-based analyses of ten juveniles tagged in the GAB in 2008–09, which showed important shared habitats included the central and eastern GAB, the Bonney Upwelling, southern WA, western Victoria, western and eastern Bass Strait, and the STF (Rogers *et al*. 2015a, b; Rogers and Bailleul 2015).

8.5.5 Research gaps and next steps

Highly migratory species have international conservation and management profiles, and are valued by community and regional economies of southern Australia and neighbouring Pacific and Indian Ocean regions.

There remains a need to fully understand the biodiversity significance of the region and identify the shared habitats and migration pathways of the listed pelagic and oceanic sharks that inhabit the GAB. Listed species for which significant data gaps remain include the white shark, shortfin mako, two thresher shark species, and the porbeagle.

Gaps also remain in available dietary and foraging data in shelf slope, submarine canyons and near slope oceanic habitats; further information is required on these topics when applying ecosystem modelling approaches to understanding anthropogenic impacts.

8.6 Conclusions

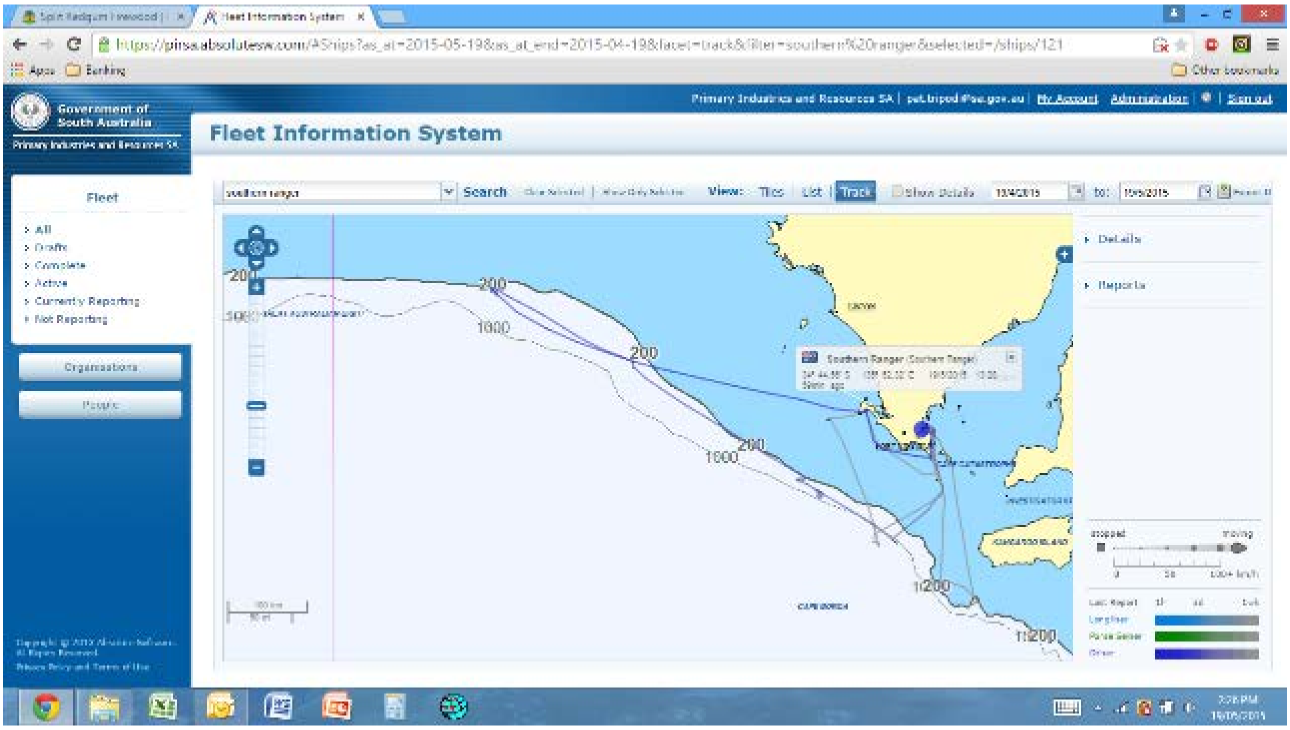
The species we investigated have varying levels of international and national conservation and management significance, and some are listed and/or protected by the *Environmental Protection Biodiversity and Conservation Act* (1999) of the Australian Commonwealth Government. The white shark, shortfin mako, and thresher sharks are globally recognised and listed as threatened (Vulnerable) by the International Union for Conservation of Nature Red-list. They are each listed as highly migratory species under the CMS and threats to the survival of populations occur in areas beyond national jurisdictions.

We combined telemetry and survey methods to update existing information on the distributions, critical habitat use, and migration-mediated connectivity of highly migratory pelagic and oceanic shark species that inhabit the shelf-break, slope and oceanic ecosystems of the GAB and eastern Indian Ocean. Knowledge of pelagic shark distributions and migration paths could be applied in the future to reduce operational interactions between sharks and vessels operating in and beyond the GAB.

8.7 Appendices

Appendix 8.1. Locations, activities, weather conditions and vessel track during the survey.

Day	Date	Location	Wind direction and speed (knots)
1	30 Apr 2015	Port Lincoln (steamed to S1 at mid-night)	N 12–18
2	1 May 2015	S1	NW to W 12–17
3	2 May 2015	South Neptune Island	SW to W 25–30
4	3 May 2015	South Neptune Island to S2	Var-NE 5, W 20–30
5	4 May 2015	Greenly Island and Avoid Bay anchorages	NW to SW 30–60
6	5 May 2015	Avoid Bay anchorage	SW 30
7	6 May 2015	South Neptune Island	SW 20–25
8	7 May 2015	Returned to Port Lincoln	SW 20–25
1	13 May 2015	Port Lincoln to South Neptune Island	S to SW 20–25
2	14 May 2015	S3	S to SW 15
3	15 May 2015	S4 and S5	S to SE 10–15
4	16 May 2015	S6	E 8–12
5	17 May 2015	S7, travelled to Avoid Bay anchorage	NE to N 20-30 then variable to 5-12
6	18 May 2015	Avoid Bay to Port Lincoln	



Appendix 8.2: Seabird bycatch mitigation techniques adopted during the pelagic survey

- Side-setting - the mainline was deployed on the starboard side and the baited hooks and leaders were lowered down the darkened side of the vessel, whilst giving each baited hook sufficient time to sink under the vessel wake.
- Minimal deck-lighting was used during the sets to reduce the chance of seabirds making visual contact with baits.
- Leaders included weighted swivels to increase the sink-rate of baits during the set, and hooks were painted black to reduce the potential to attract birds.
- Constant visual contact was maintained with individual seabirds during the setting processes.
- No bait scraps or wheelhouse food scraps were disposed of from the vessel near set locations. Where possible, scraps were retained in bio-degradable hessian bags for disposal.
- The setting rates were modified or stopped if a seabird was present near the stern of the vessel.
- Deep-bait setting equipment and a tori line was on-board for deployment if seabird density increased during sets.

Appendix 8.3. Observation data. Marine predator species observations at set locations in the Great Australian Bight.

Location	Date	Common name	Species	Estimate (~) or count
S1	1 May 2015	Australian fur seal	*Arctocephalus pusillus*	?
S1	1 May 2015	Common dolphin	*Delphinus delphis*	~500
S1	1 May 2015	Yellownose Albatross	*Thalassarche chlororhynchos*	10
S1	1 May 2015	Shy Albatross	*Thalassarche carteri*	1
S1	1 May 2015	Wandering Albatross	*Diomedea exulans*	1
S1	1 May 2015	Black-browed Albatross	*Thalassarche melanophris*	20
S1	1 May 2015	White faced storm petrel	*Pelagodroma marina*	15
S1	1 May 2015	Wilsons storm petrel	*Oceanites oceanicus*	5
S1	1 May 2015	Southern giant petrel	*Macronectes giganteus*	1
Inside S2	3 May 2015	Yellownose Albatross	*Thalassarche chlororhynchos*	2
Inside S2	3 May 2015	Shy Albatross	*Thalassarche carteri*	2
Inside S2	3 May 2015	Black-browed Albatross	*D. impavidan* = 1, *D. melanophris*	13
Inside S2	3 May 2015	Fleshfoot shearwater	*Puffinus carneipes*	3
Inside S2	3 May 2015	Wilsons storm petrel	*Oceanites oceanicus*	1
Inside S2	3 May 2015	Southern giant petrel	*Macronectes giganteus*	?
S2	3 May 2015	Wandering Albatross	*Diomedea exulans*	2
S2	3 May 2015	Black-browed Albatross	*Thalassarche melanophris*	12
S2	3 May 2015	White faced storm petrel	*Pelagodroma marina*	5
S2	3 May 2015	Wilsons storm petrel	*Oceanites oceanicus*	1
S2	3 May 2015	Yellownose Albatross	*Thalassarche chlororhynchos*	5
S2	3 May 2015	Fleshfoot shearwater	*Puffinus carneipes*	1
S2	3 May 2015	Southern giant petrel	*Macronectes giganteus*	1
S3	14 May 2015	Common dolphin	*Delphinus delphis*	5
S3	14 May 2015	Blackbrow Albatross	*Thalassarche melanophris*	5
S4	14 May 2015	Common dolphin	*Delphinus delphis*	5
S4	14 May 2015	Black-browed Albatross	*Thalassarche melanophris*	10
S4	14 May 2015	Yellownose Albatross	*Thalassarche chlororhynchos*	2
S4	14 May 2015	Shy Albatross	*Thalassarche carteri*	2
S4	14 May 2015	Kerguelen petrel	*Lugensa brevirostris*	1
S4	14 May 2015	Wilsons storm petrel	*Oceanites oceanicus*	5
S5	14 May 2015	Slender-billed prion	*Pachyptila belcheri*	15
S5	15 May 2015	Black-browed Albatross	*Thalassarche melanophris*	10
S5	15 May 2015	Light mantled sooty albatross	*Phoebetria palpebrata*	1
S5	15 May 2015	Kerguelen petrel	*Lugensa brevirostris*	1

S5	15 May 2015	Wilsons storm petrel	*Oceanites oceanicus*	4
S5	15 May 2015	Cape Petrel	*Daption capense*	2
S5	15 May 2015	Giant Petrel spp.	Unid.	1
S7	17 May 2015	Black-browed Albatross	*Thalassarche melanophris*	~400
S7	17 May 2015	Wilsons storm petrel	*Oceanites oceanicus*	2

9. PINNIPED SURVEYS

Status and trends in abundance of pinnipeds in the Great Australian Bight

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9.1 Executive summary

- This project compiled the most comprehensive synthesis of recent and historic surveys of pinniped populations throughout the GAB region, including trends in their abundance.
- The study highlighted that the GAB region is very important for Australia's pinniped biodiversity, with significant populations of all of Australia's three resident mainland species occurring here: Australian sea lion, long-nosed fur seal and Australian fur seal.
- The region is especially important for the Australian sea lion and long-nosed fur seal, with an estimated 93% and 98% of each species' Australian populations occurring here, respectively. Australian fur seal populations are centred on Bass Strait, with only about 18% in the GAB region, however the western extent of the species range has recently expanded into the eastern GAB off South Australia (SA).
- Current estimates for pup production per breeding season and total population size in the GAB region were: Australian sea lion: 2,801 pups, total abundance 10,728; long-nosed fur seal: 24,063 pups, total abundance 114,540; Australian fur seal: 3,291 pups, total abundance 14,811.
- The study identified that while populations of both fur seal species have largely recovered or are in the latter stages of recovery (following early colonial sealing which ended almost 190 years ago), populations of the threatened Australian sea lion are smaller than previously estimated and undergoing a rapid decline.
- Australian sea lion pup abundance in South Australia (SA), which account for 83% of the species, declined by 24% since surveys undertaken 7-11 years earlier (between 2004 and 2008).
- For the entire GAB region (SA and south coast Western Australia), based on the change in Australian sea lion pup abundance between two comparable surveys, the decline in pup numbers was estimated to be -2.8% (sd = 3.2) per year, or -4.1% (sd = 4.8) per breeding season.
- Following IUCN Redlist assessment methods, the estimated change in pup abundance over three generations based on the observed change in pup abundance across the GAB region was -76.4%, meeting the 'Endangered' IUCN Criterion A assessment criteria (>50 and <80% decline over three generations).

- Assessment at the colony level identified that almost 40% of sites assessed in the GAB region meet the 'Critically endangered' criteria (>80% decline over three generations).

9.2 Introduction

There are three pinniped species that breed in coastal areas and islands off the southern Australian mainland, all belong to the Otariidae subfamily which includes the fur seals and sea lions. They are the Australian sea lion *Neophoca cinerea*, and two fur seals, the long-nosed fur seal *Arctocephalus forsteri,* and the Australian fur seal *Arctocephalus pusillus doriferus*. All three species are native to Australia, occur in the Great Australian Bight and occur in sympatry over parts of their range (Kirkwood and Goldsworthy 2013). In addition to these resident species, there are a number of vagrant species that visit southern Australia irregularly, especially the subantarctic fur seal *A. tropicalis* (its nearest breeding colonies are located at subantarctic Macquarie Island and Amsterdam/St Paul Islands in the Southern Ocean); and the southern elephant seal (*Mirounga leonina*). Prior to European arrival in Australia, this species bred on King Island, Bass Strait, but was eliminated by sealers by the early 1800s. There are a number of breeding records in southern Australia, most notably in Tasmania. There are also occasional sightings of leopard seal *Hydrurga leptonyx*, crabeater seal *Lobodon carcinophagus*, Weddell seal *Leptonychotes weddelli*, Ross seal *Ommatophoca rossii* and Antarctic fur seal *A. gazella* in southern Australia, but they are relatively uncommon (Shaughnessy et al. 2012, Kirkwood and Goldsworthy 2013).

The goal of Project 4.1 of the GAB Research Program was to provide the most up to date and detailed assessment of the status, distribution and abundances of key iconic and apex predator species in the GAB region. This section addresses part of objective four of the project, to 'Obtain abundance indices of key pinniped and seabird populations in the GAB', the key outcome explicitly being to provide estimates of pup production and trends in abundance for the three resident species within the GAB region. A brief background to each species is given below.

The Australian sea lion is Australia's least numerous pinniped species, with a breeding distribution limited to South Australia (SA) and Western Australia (WA). All of the SA population and that off the south coast of WA fall within the GAB region. Australian sea lions are unique among pinnipeds, being the only species with a non-annual and temporally asynchronous breeding cycle. It has the longest gestation period of any pinniped, as well as protracted breeding and lactation periods. The evolutionary determinants of this unusual reproductive strategy remain enigmatic. These factors, and the species' small population size distributed over numerous, small breeding sites, make it vulnerable to extinction (Goldsworthy et al. 2009b). The species is listed as Vulnerable under the threatened species category of the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act), and Endangered under the International Union for the Conservation of Nature (IUCN) Redlist (Goldsworthy 2015). Recent population genetic studies indicate little or no interchange of females between breeding sites, even for those separated by short distances (Campbell et al. 2008a, Lowther et al. 2012). The important conservation implication is that each breeding site is effectively a closed population. In light of this, conservation and management measures need to focus at the level of breeding sites.

The major identified threatening process limiting recovery of Australian sea lion populations is incidental bycatch mortality, especially in demersal gillnet fisheries (Goldsworthy et al. 2010b, DSEWPaC 2013). Management for recovery of the species requires the ability to detect changes in the status of populations over time (Goldsworthy et al. 2009a). A population monitoring strategy was developed which identified key and/or representative breeding sites within regions across the range of the species to target trends in pup production (Goldsworthy et al. 2009b). However, a

critical issue is the limited baseline information on the status of Australian sea lion populations across their range. In the past, estimates of the size of Australian sea lion populations have typically been based on the best available survey data for individual breeding sites, often spanning 1-2 decades. An assessment of the size of the Australian sea lion populations in SA in the late-2000s mainly used data obtained between 2004 and 2008, although data for some breeding sites were from as early as 1990 (Shaughnessy et al. 2011). That study estimated Australian sea lion pup abundance in SA to be 3,119.

For this assessment, we report on surveys of pup abundance for all Australian sea lion breeding sites in SA conducted within an 18-month period in 2014 and 2015 (Goldsworthy et al. 2015), and analyse historic time-series data for breeding sites to provide an assessment of trends in abundance. To this we add the best available data on Australian sea lion pup abundances available for breeding sites along the south coast of WA to provide a contemporary assessment of the species' status across the GAB region.

Two species of fur seal breed in the GAB Region, the long-nosed fur seal which is also known as the New Zealand fur seal, and the Australian fur seal. The long-nosed fur seal breeds in southern Australia from New South Wales to WA; it also breeds in New Zealand and its subantarctic islands. Most of the Australian population is in SA, between Kangaroo Island and the southern tip of Eyre Peninsula (Shaughnessy et al. 2014). All of the SA, the south coast WA, and western Bass Strait populations fall within the GAB region. The Australian fur seal breeds primarily on islands in Victoria and Tasmania, particularly in Bass Strait with small populations elsewhere in Tasmania, New South Wales and SA (McIntosh *et al*. 2014). It is a subspecies of the Cape or South African fur seal *A. pusillus pusillus*, with the Australian subspecies occurring as a consequence of late Pleistocene/Holocene (approximately 12,000 years before present) migration events from southern Africa to southern Australia via west-wind drift across the Indian Ocean (Wynen et al. 2001, Deméré et al. 2003). Breeding populations in SA and western Bass Strait fall within the GAB region.

Fur seal populations in southern Australia were heavily exploited by colonial sealers between 1801 and 1830, resulting in major reductions in range and abundance (Kirkwood and Goldsworthy 2013). Ling (1999) estimated that the seal harvest from Kangaroo Island during this period was 99,000, although it is likely that this figure referred to a wider area than Kangaroo Island. Fur seal numbers remained at very low levels for 150 years, after which they slowly began to build up and colonies re-established or new colonies were established across their former range. Legislation protecting seals in Australia was gradually introduced in the various States from 1891 and in Commonwealth waters from 1975 (Kirkwood and Goldsworthy 2013).

Long-term monitoring of abundance of long-nosed fur seal pups at colonies on Kangaroo Island and Neptune Islands has shown considerable increases over the last two decades (Shaughnessy and Goldsworthy 2015, Shaughnessy *et al.* 2014), the only estimate of pup abundance for all colonies in SA from a single breeding season is from 1989-90 (Shaughnessy *et al*. 1994).

In this assessment, we provide a summary of recent production surveys undertaken across all SA breeding colonies for long-nosed and Australian fur seal pups (Shaughnessy et al. 2014, McIntosh et al. 2014). To this we add new survey information on long-nosed fur seal pup production surveys undertaken at Williams Island, and the best available data on pup production for long-nosed and Australian fur seal breeding sites along the south coast of WA (Campbell et al. 2014) and in eastern Bass Strait (McIntosh et al. 2014) to provide a contemporary assessment of the status and trends in abundance of these species across the GAB region.

9.3 Methods

9.3.1 Region of interest

Within this domain, the GAB region extends from Cape Otway (Victoria) in the east, to just west of Albany (WA) in the west. All known breeding sites of the three resident pinniped species inhabiting this region are presented in Figure 9.1.

9.3.2 Australian seal lion

Survey methodology

Timing of surveys

Surveys were conducted between January 2014 and August 2015 across 83 sites in SA (Figure 9.2). Most sites were accessed by helicopter (Robinson, R44 Clipper); those on Kangaroo Island were accessed by vehicle, and boats were used to reach Dangerous Reef, English, Olive and Jones islands.

Direct counts of live and dead pups

Pups were counted by an observer walking through a breeding site (referred to as ground counts), from a cliff-top (in the case of sites at the base of the Bunda Cliffs) or from a helicopter. Live pups were recorded in five categories: black mate-guarded (pups with a mother that was mate-guarded by an adult male, indicative of a pup aged 0-10 days), black (pups considered to be <4 weeks of age), brown (pups approximately 4 - 20 weeks), moulted (pups >20 weeks). We recorded the number of pups that had died since the previous visit. To avoid double counting, dead pups were covered with rocks when they were counted. Where multiple surveys were conducted during a breeding season, the number of dead pups recorded at a particular survey was added to the number(s) recorded at previous survey(s). When the cumulative number of dead pups was added to the number of live pups, it provided an estimate of pup abundance to that date. The breeding season was considered to have ended when no black mate-guarded pups were present and there were few or no black pups.

Mark-recapture and cumulative pup production estimation

Direct counting of pups to estimate their abundance underestimates total pup production, because pups that are hidden from view (sightability bias) or absent from the breeding site (availability bias) at the time of the survey are not included. The influence of the former factor on estimates of pup production can be reduced to some extent by undertaking a mark-recapture procedure. Mark-recapture was used to estimate the number of live pups at Olive, Lilliput and Blefuscu islands, and Dangerous Reef. Pups were tagged with individually numbered plastic tags (Dalton® Size 1 Supertags) applied to the trailing edge of each fore-flipper. During field trips, the total number of tagged, untagged and newly recorded dead pups were recorded on each survey. Re-sights of individual tagged pups were usually undertaken over a minimum of three days to obtain a mark-recapture estimate of live pup numbers. When more than one recapture survey was conducted at a colony during the same breeding season, tagged pups were resighted again to determine the sample of 'marked' individuals in the population available for the next recapture survey. During recapture surveys, the individual identity of tagged pups was determined by reading tag numbers with binoculars. The number of untagged pups and recently dead pups that had not been marked was also recorded. Pups sighted in future surveys (i.e., known to be alive) were included as having been available for re-sighting in previous recapture surveys.

Mark-recapture estimates of the number of live pups ($\widehat{N}$) were calculated with the formula:

$$\hat{N} = \frac{(M+1)(n+1)}{(m+1)} - 1;$$

where M is the number of marked pups available for resighting, n is the number of pups examined in the recapture sample, and m is the number of marked pups in the recapture sample. This is referred to as the Petersen estimate (Seber 1982).

The variance of this estimate, the method used to combine several mark-recaptures estimates of abundance, the variance of that estimate and 95% confidence limits are provided in Goldsworthy et al. (2015).

When multiple mark-recapture surveys are undertaken, the number of pup births between consecutive mark-recapture surveys $\left(\hat{B}_{1-2}\right)$, was estimated as:

$$\hat{B}_{1-2} = \overline{N}_2 - \overline{N}_1 \emptyset_{1-2},$$

where, $\overline{N}_1$ is the Petersen estimate of the number of live pups in the breeding site at survey 1, and $\overline{N}_2$ is the Petersen estimate of the number of live pups at survey 2. The apparent survival of pups between survey 1 and 2 $(\emptyset_{1-2})$ is estimated as the proportion of the marked pups known to be alive in survey 1 (M_1) that were known to be alive in survey 2 $(or\ M_2/M_1)$.

Methods for calculating the variance of this estimate and 95% confidence limits are provided in Goldsworthy et al. (2015).

Trends in abundance

Data from previous surveys

Information on pup counts from past surveys at Australian sea lion breeding sites across SA and WA was derived from published accounts, reports and databases. To simplify analyses, the timing of surveys was summarised into two 6-month blocks: between April and September, designated as whole years (e.g., 2014, 2015), and between October and March, designated as split years (e.g., 2013.5, 2014.5). Survey data were omitted if judged to have been undertaken at inappropriate times (i.e., too early or late relative to the breeding season).

Changes in pup abundance at individual sites between two surveys

For the majority of Australian sea lion breeding sites, few survey data are available. To maximise the number of sites over which a change in pup numbers could be assessed, we estimated the change between two time periods when similar survey methods had been used. Where possible, the earliest comparable survey was compared to the most recent. The rate of change in pup numbers was calculated using linear regression of the natural logarithm of pup numbers against year. The intrinsic rate of change per annum (r) is the slope of the regression line. It can be expressed as a percentage rate of growth (λ) as follows,

$$\lambda = 100(e^r - 1).$$

Changes in growth per breeding season were estimated as $\lambda/1.5$.

Assessment of the Australian sea lion population and breeding sites against IUCN Criterion A was undertaken following the IUCN methods for taxa with widely distributed or multiple populations (IUCN Standards and Petitions Subcommittee 2014). This methodology uses past and present indices of abundance to estimate the percentage change of subpopulations over three generations. Generation time for Australian sea lion has been estimated as 12.4-12.8 years (mean 12.6 years),

hence three generations are equivalent to 38 years (Goldsworthy 2015). As the past and present estimates of pup numbers for different breeding sites are from different years and span different time periods, it is necessary to make projections in order to estimate the change in abundance for each breeding site across the same 3-generation period (1977 to 2015). For each breeding site, rates of change between past and present pup numbers were used to project pup numbers back to 1977 or forward to 2015, assuming a constant exponential rate of change. The overall change in the sum of pup numbers over three generations across all breeding sites was then used to assess Australian sea lion populations in against IUCN Criteria A2 ('Critically endangered' criteria >80% decline over three generations; 'Endangered' criteria >50% and <80% decline over three generations; 'Vulnerable' criteria >30% and <50% decline over three generations; 'Least concern' criteria <30% decline over three generations) (IUCN Standards and Petitions Subcommittee 2014).

Trends in aggregated abundance

Tends in aggregated abundance of Australian sea lion pups across regions in SA were estimated using the method developed by Johnson and Fritz (2014). The Bayesian modelling approach uses Markov Chain Monte Carlo methods and a hierarchical model to augment missing data to infer regional trends of abundance for species with uneven and patchy sampling. Analyses were undertaken using the R package 'agTrend'. An important requirement for the agTrend analyses was to ensure that all time-series data used for each breeding site were obtained using the same survey method. In instances where there had been a methodological change, we applied a correction factor to adjust a count to a mark-recapture estimate, or to adjust a count or a mark-recapture estimate to a cumulative pup production estimate (Goldsworthy et al. 2015a). Because the relationship between these types of estimates varies between sites in relation to a range of intrinsic site factors, especially sightability, site-specific correction factors were developed and applied.

Following agTrend procedures, non-surveyed breeding seasons were designated as zero observations. The specific site-level augmentation model used to estimate missing count data varied in relation to the number of non-zero observations. With >10 non-zero observations, a Generalised Additive Model (GAM) was used; with 6 to 10 non-zero observations, a General Linear Model (GLM) was fitted to the data and with <6 non-zero observations, a GLM with intercept only was fitted (Johnson and Fritz 2014). The upper-bound limit capability in agTrend was set at 1.3 times the maximum observed pup number at a site. The agTrend analyses produce plots of aggregated regional abundance trends, with a line fitted to the median of the posterior predictive counts which are bounded by the 90% highest probability density credible interval. Regional trends in aggregated abundance were estimated for the last 10 years for six regions in SA, and for two regions in WA for which comparable data were available. These regions were based on those identified in Goldsworthy et al. (2007b) using geographic distance analysis among Australian sea lion breeding sites, which identified at least 11 distinct metapopulations or regions, seven in SA (Bunda Cliffs, Nuyts Reef, Nuyts Archipelago, Chain of Bays, south-west Eyre, Spencer Gulf, Kangaroo Island), and four in WA (Twilight Cove, Recherche, South Coast, West Coast: the last includes Jurien Bay and Abrolhos Islands regions) (Goldsworthy et al. 2007b).

9.3.3 Fur seals

Details of survey sites, timing of surveys and methodology used to estimate pup production across breeding colonies in SA are provided in Shaughnessy et al. (2015). Briefly, surveys were undertaken between late January and mid-March in 2014, at the end of the 2013-14 breeding season. Access to

fur seal sites on Kangaroo Island was by vehicle. Neptune and Liguanea islands were accessed using the SARDI *RV Ngerin* and an inflatable dinghy. Islands in southern Spencer Gulf, Investigator Strait, off the west coast of Eyre Peninsula and off Kangaroo Island (North Casuarina and Paisley Island) were accessed using a Robinson R44 helicopter.

Data on the abundance of long-nosed fur seal pups off the south coast of WA were obtained from Campbell et al. (2014), which details results from three surveys conducted in 1989, 1999 and 2014. For Australian fur seals, data from breeding sites in western Bass Strait and SA were obtained from pup production surveys undertaken by Kirkwood et al. (2005, 2010), Shaughnessy et al. (2002, 2010, 2014) and McIntosh et al. (2014).

As with sea lions, fur seal abundance estimates are directed at pups because they form the only age-class that is easily recognisable based on their small size and black natal coat (lanugo). Furthermore, they are all ashore together and remain in the colony (or its vicinity) when disturbed. Mark-resight estimation procedures were used in most large breeding colonies (50+ pups) and direct counting methods were used for smaller breeding colonies (<50 pups). Direct counting was also used for small aggregations of pups on the periphery of breeding colonies.

Trend analyses followed similar methods for sea lions, where the rate of change in pup numbers between two survey periods was calculated using linear regression of the natural logarithm of pup numbers against year. Regional trends in abundance were also calculated using the agTrend procedure. Five regions across SA were used for these analyses: East Kangaroo Island, West Kangaroo Island, Neptune Islands and Liguanea Island, south west Eyre and west Eyre).

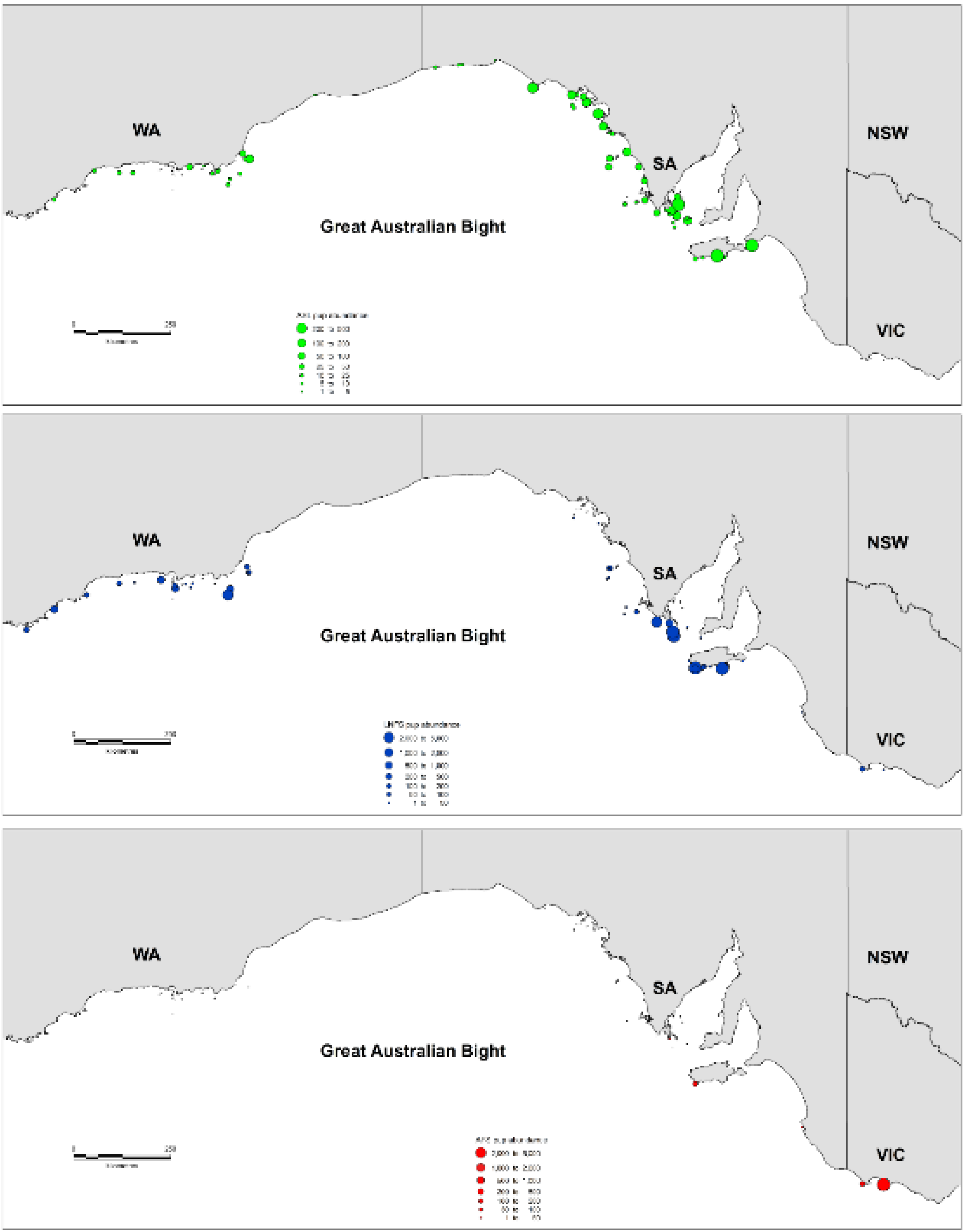


Figure 9.1. Map of the locations and size (based on pup abundance) of all known breeding sites of the three resident pinniped species inhabiting the GAB Region; Australian sea lion (ASL) (top/green), long-nosed fur seal (LNFS)(middle/blue) and Australian fur seal (AFS)(bottom/red).

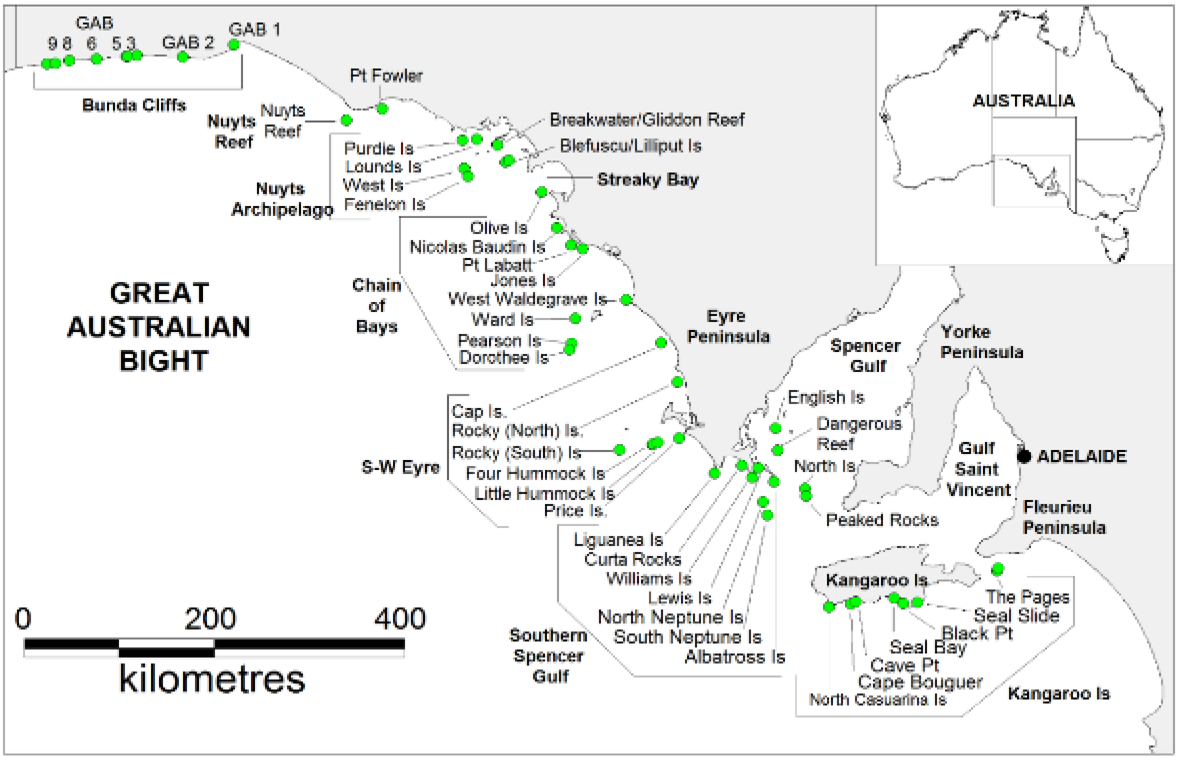


Figure 9.2. Location of Australian sea lion site surveys in SA during 2014 and 2015. The seven regional metapopulations or regions recognised by Goldsworthy et al (2007b) are also indicated.

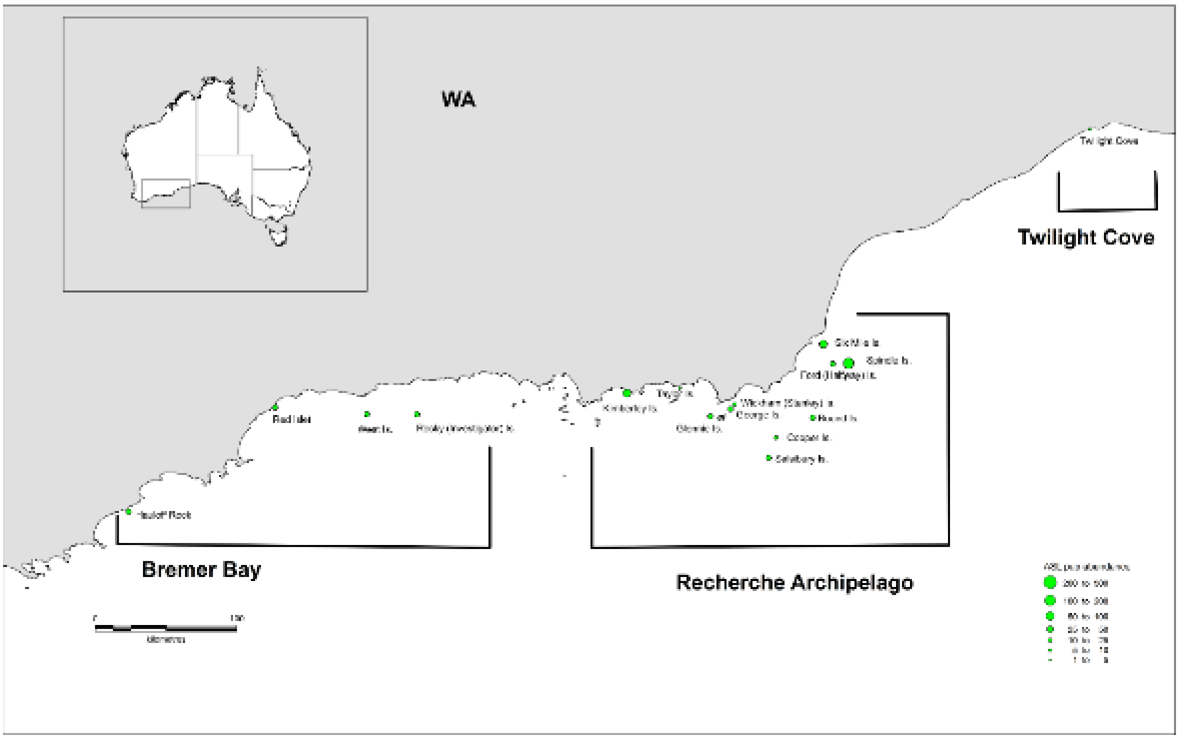


Figure 9.3. Location of Australian sea lion breeding sites off the south coast of WA. The three metapopulations or regions recognised by Goldsworthy et al (2007b) are also indicated.

9.4 Results

9.4.1 Australian sea lions

State-wide census in SA

A total of 233 individual surveys were conducted across 89 sites in SA between January 2014 and August 2015. They are summarised in Figure 9.2 and Table 9.1a, which includes the timing of surveys relative to the estimated span of breeding seasons at individual sites. Pups were recorded at 40 breeding sites, with 2,378 pups observed in total. For seven sites surveyed at inappropriate times (outside of peak breeding), the estimate from the most recent reliable survey was substituted (Table 9.1). With these adjustments, the total estimate of Australian sea lion pup abundance in SA is 2,500. The number of breeding sites was 42, mean pup production was 60 (sd = 105.7) and median 23. Five sites produced more than 100 pups (Nuyts Reef, Olive Island, Dangerous Reef, Seal Bay and The Pages Islands) and accounted for 58% (1,440) of the estimated pup abundance in SA. Five new breeding sites were discovered: Cap (31 pups), Rocky (South) (11 pups) and Little Hummock islands (4 pups) in the south-west Eyre region (identified as breeding sites in 2011), and Curta Rocks (7 pups) and Williams Island (5 pups) in the Spencer Gulf region (identified as breeding sites in 2014).

Estimates of pup abundance south-coast WA

Data on the estimated pup abundance for breeding sites on the south-coast of WA, the timing of surveys and estimated span of breeding seasons is presented in Table 9.1b. The location of breeding sites is presented in Figure 9.3. For a number of sites (Twlilight Cove, Spindle and Ford Island) there is no contemporary data on pup abundance or timing of breeding (Table 9.1b). Pup abundance data were available for 16 breeding sites for the period between 1990 and 2016, and provide an estimate of 301 pups, with a mean of 19 (sd=13.7) pups per site, and median of 16. The two largest breeding sites are Spindle (53 pups) and Six Mile (40 pups) islands; they have not been surveyed during the breeding season for 26 and 16 years, respectively. Six sites where breeding has not been observed for >25 years (Twin Peaks, Little, Poison Creek, Kermadec (Wedge), McKenzie and Middle Doubtful islands) and where there are no recent observations to suggest that breeding still occurs were omitted from the analysis.

Trends in pup abundance

Changes in pup abundance at individual sites between two surveys

The estimated change in pup abundance between two time periods where similar survey methods were used could be calculated for 28 (67%) of the 42 extant SA breeding sites surveyed. These accounted for 89% (2,219) of the current SA pup abundance. For the south-coast of WA, equivalent data were available for 8 (50%) of 16 extant breeding sites. These accounted for 52% (158), of the estimated pup abundance for the region. The change in pup numbers over time by site for the seven Australian sea lion regions of SA and two Australian sea lion regions off the south-coast of WA are summarised in Table 9.2.

The period over which changes in pup abundance were recorded ranged from 6 to 45 years (mean = 15.6, sd = 8.9). For the entire GAB region (SA and south coast WA), the estimated annual rates of change in pup numbers averaged -2.8% (sd = 3.2), and the change per breeding season averaged -4.1% (sd = 4.8). For SA populations, there were decreases in pup counts for 23 (82%) sites and

increases for 5 (18%) sites, and for south-coast WA populations, decreases in pup counts were observed for all 8 sites (Table 9.3). For SA populations, the estimated annual rates of change in pup numbers at individual sites ranged from -10.1% to 3.9% (Table 9.2) and averaged -2.9% (sd = 3.6), and the change per breeding season ranged from -15.1% to 5.9%, with average -4.4% (sd = 5.3). Regional declines were greatest for Nuyts Archipelago (-4.6%/year or -6.9%/breeding season), and lowest for the Kangaroo Island region (-1.0%/year or -1.4%/breeding season) (Table 9.3).

For south-coast WA populations, the estimated annual rates of change in pup numbers at individual sites ranged from -5.1% to -0.8% (Table 9.2) and averaged -2.1% (sd = 1.4%), and the change per breeding season ranged from -7.6% to -1.3%, with average -3.2% (sd = 2.1%). Regional declines were similar for the Recherche Archipelago (-2.1%/year or -3.1%/breeding season) and Bremer Bay regions (-2.3%/year or -3.4%/breeding season) (Table 9.3).

The overall estimated change in pup abundance over three generations assuming a constant exponential rate of change for the Australian sea lion population in the GAB region was -76.4%; for the SA and south-coast WA populations it was -77.2% and -51.2%, respectively (Table 9.3). Following the IUCN Criterion A assessment the GAB, SA and south-coast WA Australian sea lion populations all meet the ‘Endangered’ criteria (>50 and <80% decline over three generations). Individual assessment of the 36 GAB region breeding sites (subpopulations) under IUCN Criterion A2 are presented in Table 9.2. These analyses indicate that 36% (14) meet the ‘Critically endangered’ criteria (>80% over three generations); 13% (5) meet the ‘Endangered’ criteria, 21% (8) meet the ‘Vulnerable’ criteria (>30% and <50% decline over three generations) and 31% (12) meet the ‘Least concern’ criteria (<30% decline over three generations).

Individual assessment of the 28 SA breeding sites under IUCN Criterion A identified that 46% (13) meet ‘Critically endangered’ criteria; 11% (3) meet the ‘Endangered’ criteria, 11% (3) meet the ‘Vulnerable’ criteria and 32% (9) meet the ‘Least concern’ criteria. Individual assessment of the 8 south-coast WA breeding sites under IUCN Criterion A identified that 13% (1) meet ‘Critically endangered’ criteria; 25% (2) meet the ‘Endangered’ criteria, 50% (4) meet the ‘Vulnerable’ criteria and 13% (1) meet the ‘Least concern’ criteria.

Regional trends in aggregated abundance

Estimates from trend analyses of aggregated regional abundance over the last ten years are available for six Australian sea lion regions across SA (only a single estimate was available for the seventh region, Nuyts Reef), and for the two south-coast WA regions. Results indicate that aggregated pup abundance across most regions declined (Table 9.4, Figure 9.4). For SA, trends in aggregated regional abundances showed the greatest rate of decline in the western regions of the Nuyts Archipelago (-3.3%/year, or -5.0%/breeding season) and Bunda Cliffs (-2.9%/year, or -4.3%/breeding season), intermediate for the Chain of Bays (-1.5%/year, or -2.2%/breeding season) and SW-Eyre regions (-1.3%/year, or -1.9%/breeding season), and were lowest for the Spencer Gulf (-1.0%/year, or -1.4%/breeding season) and Kangaroo Island regions (-0.4%/year, or -0.6%/breeding season, Table 9.4). These results were similar to those from analyses of the change in pup numbers over two surveys.

For the two south-coast WA regions, results from analyses of the aggregated pup abundances showed no apparent trend for the Recherche Archipelago region (0.2%/year, or 0.2% per breeding

season), and a small decline for the Bremer Bay region (-0.1%/year, or -0.2 per breeding season) (Table 9.4, Figure 9.4) It should be noted that most regional assessment had large lower and upper 90% highest probability density credible intervals for the posterior predictive counts. With the exception of the Nuyts Archipelago region, these bounds encompassed both negative and positive growth (Table 9.4, Figure 9.4).

Both methods for estimating trends in pup abundance identified colonies or regions where pup abundance had declined. There was a positive relationship between the results of the two methods, with the mean regional change between two surveys at individual sites producing higher rates of decline compared to trends in aggregated regional pup abundances (Tables 9.2 and 9.3, Figure 9.5). This results is not surprising given that the former method calculates change in mean abundances over a variable time period (6-45 years) for individual breeding sites, while the latter method is calculated over a fixed period (10 years) and presents the median of the posterior predictive counts of aggregated (pooled) pup abundances at the regional level.

Table 9.1. Summary of the timing of Australian sea lion surveys and breeding seasons at 52 sites in South Australia (a) between January 2014 and August 2015, and at 16 sites off the south coast of Western Australia (b). Timing of previous surveys and estimated breeding seasons back to November 2012 are also indicated. The estimated duration of the breeding season at each site is indicated by blue shading. The number of pups recorded and estimated for each site is presented. Some estimates are based on previous surveys as indicated (with source). The type of survey method used is indicated (C = cliff-top count, G = ground count, A= helicopter survey of breeding status, M = mark-recapture and cumulative pup production method).

a) South Australia

	2012		2013												2014												2015								Pups	Pups		
Site	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	Surveyed	Estimated	Year	Source
The Pages Islands																				G															313	478	2010	Goldsworthy et al. 2016
Seal Slide (Kangaroo Is.)						G			G		G						G				G					G	G				G				8	8	2015	Goldsworthy et al. 2015
Black Point (Kangaroo Is.)																																			-	1	2002	Shaughnessy et al. 2009
Seal Bay (Kangaroo Is.)					G	G	G	G	G	G	G	G	G	G	G	G	G								G	G	G	G	G	G	G	G	G	G	239	239	2013	Goldsworthy et al. 2016
Cave Point (Kangaroo Is.)															G																				0	0	2014	Goldsworthy et al. 2015
Cape Bouguer (Kangaroo Is.)															G		G																		9	9	2014	Goldsworthy et al. 2015
North Casuarina Is. (Kangaroo Is.)																G																			11	11	2014	Goldsworthy et al. 2015
Peaked Rocks																	A																		17	58	2011	Goldsworthy et al. 2012
North Islet																	GA				A														32	21	2011	Goldsworthy et al. 2012
Dangerous Reef																	A		G	GM	GM			GM											485	485	2014	Goldsworthy et al. 2015
English Is.																	A				G														64	34	2011	Goldsworthy et al. 2012
Albatross Is.																	G				G														95	69	2011	Goldsworthy et al. 2012
South Neptune Islands																G					G														7	7	2014	Goldsworthy et al. 2015
North Neptune Islands																G					G														9	9	2014	Goldsworthy et al. 2015
Lewis Is.				G	G																G		G												82	82	2014	Goldsworthy et al. 2015
Williams Is.																	AG				G		G												5	5	2014	Goldsworthy et al. 2015
Curta Rocks				A												A							G												7	7	2014	Goldsworthy et al. 2015
Liguanea Is.																G					G					G					GA				25	25	2015	Goldsworthy et al. 2015
Price Is.																	A						G			G									32	32	2014	Goldsworthy et al. 2015
Little Hummock Is.																	G				G		G												4	4	2014	Goldsworthy et al. 2015
Four Hummocks Is.																	G				GA		GA			G									6	6	2014	Goldsworthy et al. 2015
Rocky (South) Is.																	G				G		G												11	11	2014	Goldsworthy et al. 2015
Rocky (North) Is.				G												G					G		G												35	35	2014	Goldsworthy et al. 2015
Cap Island																G					A		G												31	31	2014	Goldsworthy et al. 2015
West Waldegrave Is.										G						G					G		A			A				G					89	89	2015	Goldsworthy et al. 2015
Jones Is.								G																	G										19	19	2014	Goldsworthy et al. 2015
Point Labatt								C													A				C	C									0	2	2013	Goldsworthy et al. 2014
Dorothee Is										G						A																			0	0	2013	Goldsworthy et al. 2014
Pearson Is.										G						G										G				G					30	30	2015	Goldsworthy et al. 2015
Ward Is.										G						G														G					44	44	2015	Goldsworthy et al. 2015
Nicolas Baudin Is.				A				GM								G					A		A			G									63	63	2014	Goldsworthy et al. 2015
Olive Is.				A				GM	GM							G					G		G		GM	GM									133	133	2014	Goldsworthy et al. 2015
Lilliput				A						G	GM	GM									G		A			A		GM		GM					72	72	2015	Goldsworthy et al. 2015

	2012		2013												2014												2015								Pups	Pups		
Site	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**Surveyed**	**Estimated**	**Year**	**Source**
Blefuscu				A						G	GM	GM									G		A			A		GM		GM					97	97	2015	Goldsworthy et al. 2015
Gliddon Reef																										A		A							0	0	2015	Goldsworthy et al. 2015
Breakwater Is.																										A		G							27	27	2015	Goldsworthy et al. 2015
Lounds Is.																					G									G					20	20	2015	Goldsworthy et al. 2015
Fenelon Is.																	G													G	A				19	19	2015	Goldsworthy et al. 2015
West Is.														G												G				G	A				20	20	2015	Goldsworthy et al. 2015
Purdie Is.																					G									G					67	67	2015	Goldsworthy et al. 2015
Pt Fowler (Camel-Foot Bay)																															A				0	0	2015	Goldsworthy et al. 2015
Nuyts Reef (x3)											GA			GA			G					G				G		A			G				105	105	2015	Goldsworthy et al. 2015
Bunda B1																																			0	0	2014	Goldsworthy et al. 2015
Bunda 02 (B1.1)			C		C															C				C											3	3	2014	Goldsworthy et al. 2015
Bunda 04 (B2)	C		C		C															C				C											0	0	2014	Goldsworthy et al. 2015
Bunda 06 (B3)	C		C		C															C				C											9	9	2014	Goldsworthy et al. 2015
Bunda 08 (B4)	C		C		C															C				C											0	0	2014	Goldsworthy et al. 2015
Bunda 09 (B5)	C		C		C															C				C											7	7	2014	Goldsworthy et al. 2015
Bunda 12 (B6)	C		C		C															C				C											0	0	2013	Goldsworthy et al. 2015
Bunda 18 (B7)	C		C		C															C				C											0	0	2014	Goldsworthy et al. 2015
Bunda 19 (B8)	C		C		C															C				C											7	7	2014	Goldsworthy et al. 2015
Bunda 22 (B9)	C		C		C															C				C											0	0	2014	Goldsworthy et al. 2015
																															Total				**2,358**	**2,500**		

b) Western Australia

	2013		2014												2015												2016												Pups	Pups		
Site	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Surveyed**	**Estimated**	**Year**	**Source**
Twilight Cove	A																				**No recent data on breeding schedule**																			4	1996	Dennis & Shaughnessy 1999
Spindle Is.	A																				**No recent data on breeding schedule**																			53	1990	Gales 1990; et al. 1994
Ford (Halfway) Is.																					**No recent data on breeding schedule**																			24	1990	Gales 1990; et al. 1994
Six Mile Is.	G																																							40	2000	DPAW database
Round Is.	G																																						13	13	2013	Goldsworthy unpub. data
Salsibury Is.	A				G																																		10	10	2014	DPAW database
Wickham (Stanley) Is.	A				G																																		5	5	2014	DPAW database
George Is.	G																																						10	10	2013	Goldsworthy unpub. data
Glennie Is.	A																																							21	1999	DPAW database
Taylor Is. 3	G																																						4	4	2013	Goldsworthy unpub. data
Kimberley Is.	G				G																																		32	32	2014	DPAW database
Cooper Is.	G				G																																		8	8	2014	DPAW database
Rocky (Investigator) Is.	G																																							16	2007	DPAW database
West Is.	A																																							24	2007	DPAW database
Red Islet	G	G		G																																	G		16	16	2016	DPAW database
Hauloff Rock	G		G																																	V	G		21	21	2016	DPAW database
																																						Total	**119**	**301**		

Table 9.2. Estimates of trends in Australian sea lion abundance across SA and the south coast WA, based on changes in pup abundance over two comparable surveys. For each colony, the mean percentage rate of change (λ) is given per year and per breeding season (1.5 years). Estimated changes in pup abundance across 3 generations (38 years) are also provided; they assume a constant exponential rate of change, following IUCN guidelines to assess species under Criterion A (CR=critically endangered; EN=endangered; VU=vulnerable; LC=least concern).

Breeding site	State	Region	Year 1	Year 2	Interval	Pup No. Yr 1	Pup No. Yr 2	λ/yr	λ/season	3-gen change	Criterion A2	Source Year 1	Source Year 2
The Pages	SA	Kangaroo Island	1989.5	2009.5	20	522	478	-0.44	-0.66	-15%	LC	Shaughnessy et al. 2013	Shaughnessy et al. 2013
Seal Slide (Kangaroo Is.)	SA	Kangaroo Island	2003	2014.5	11.5	9	8	-1.02	-1.53	-32%	VU	Shaughnessy et al. 2009	Goldsworthy et al. 2015
Seal Bay (Kangaroo Is.)	SA	Kangaroo Island	1985.5	2014.5	29	359	239	-1.39	-2.09	-41%	VU	Shaughnessy et al. 2006	Goldsworthy et al. 2015
North Is.	SA	Spencer Gulf	2005	2011	6	28	21	-4.68	-7.02	-84%	CR	Shaughnessy et al. 2011	Goldsworthy et al. 2012
Dangerous Reef	SA	Spencer Gulf	1999	2014.5	15.5	425	408	-0.26	-0.39	-9%	LC	Goldsworthy et al. 2007	Goldsworthy et al. 2015
English Is.	SA	Spencer Gulf	2005	2011	6	27	34	3.92	5.88	327%	LC	Shaughnessy et al. 2011	Goldsworthy et al. 2012
South Neptune, Main	SA	Spencer Gulf	1969.5	2014	44.5	10	4	-2.04	-3.06	-54%	EN	I. Stirling in lit in Shaughnessy et al. 2011	Goldsworthy et al. 2015
North Neptune, East	SA	Spencer Gulf	2005	2014	9	14	9	-4.79	-7.19	-84%	CR	Shaughnessy et al. 2011	Goldsworthy et al. 2015
Lewis Island	SA	Spencer Gulf	2007	2014	7	149	82	-8.18	-12.27	-96%	CR	Goldsworthy et al. 2008	Goldsworthy et al. 2015
Liguanea Is.	SA	Spencer Gulf	2004.5	2015	10.5	43	25	-5.03	-7.55	-86%	CR	Shaughnessy et al. 2011	Goldsworthy et al. 2015
Price Is.	SA	SW-Eyre	1995.5	2014.5	19	25	32	1.31	1.96	63%	LC	Shaughnessy et al. 2005	Goldsworthy et al. 2015
Four Hummocks Is.	SA	SW-Eyre	1995.5	2014	18.5	11	6	-3.22	-4.83	-71%	EN	Shaughnessy et al. 2005	Goldsworthy et al. 2015
West Waldegrave Is.	SA	Chain of Bays	2003	2015	12	157	89	-4.62	-6.93	-83%	CR	Shaughnessy et al. 2005	Goldsworthy et al. 2015
Jones Is.	SA	Chain of Bays	2004.5	2014.5	10	15	19	2.39	3.59	144%	LC	Goldsworthy et al. 2008	Goldsworthy et al. 2015
Pearson Is.	SA	Chain of Bays	2005	2015	10	35	30	-1.53	-2.29	-44%	VU	K. Peters & B. Page, in Goldsworthy et al. (2009b)	Goldsworthy et al. 2015
Ward Is.	SA	Chain of Bays	2006	2015	9	45	44	-0.25	-0.37	-9%	LC	D. Armstrong, in Robinson et al. (2008)	Goldsworthy et al. 2015
Nicolas Baudin Is.	SA	Chain of Bays	2006	2014.5	8.5	98	63	-5.07	-7.60	-86%	CR	Shaughnessy 2008	Goldsworthy et al. 2015
Olive Is.	SA	Chain of Bays	2006	2014.5	8.5	192	133	-4.23	-6.34	-80%	CR	Goldsworthy et al. 2007	Goldsworthy et al. 2015
Lilliput	SA	Nuyts Archipelago	2007.5	2015	7.5	70	72	0.38	0.56	15%	LC	Goldsworthy et al. 2009	Goldsworthy et al. 2015
Blefuscu	SA	Nuyts Archipelago	2007.5	2015	7.5	98	97	-0.14	-0.20	-5%	LC	Goldsworthy et al. 2009	Goldsworthy et al. 2015
Breakwater/Gliddon Reef	SA	Nuyts Archipelago	2005	2015	10	24	27	1.18	1.78	56%	LC	Shaughnessy et al. 2011	Goldsworthy et al. 2015
Lounds Is.	SA	Nuyts Archipelago	2008	2015	7	34	20	-7.30	-10.95	-94%	CR	Goldsworthy et al. 2010	Goldsworthy et al. 2015
Fenelon Is.	SA	Nuyts Archipelago	2008	2015	7	40	19	-10.09	-15.13	-98%	CR	Shaughnessy et al. 2011	Goldsworthy et al. 2015
West Is.	SA	Nuyts Archipelago	2005	2015	10	56	20	-9.78	-14.68	-98%	CR	Shaughnessy et al. 2011	Goldsworthy et al. 2015
Purdie Is.	SA	Nuyts Archipelago	2005	2015	10	132	67	-6.56	-9.83	-92%	CR	Shaughnessy et al. 2011	Goldsworthy et al. 2015
Bunda 06 (B3)	SA	Bunda Cliffs	1995	2014	19	13	9	-1.92	-2.88	-52%	EN	Dennis and Shaughnessy (1996)	Goldsworthy et al. 2015
Bunda 09 (B5)	SA	Bunda Cliffs	1995	2014	19	18	7	-4.85	-7.27	-85%	CR	Dennis and Shaughnessy (1996)	Goldsworthy et al. 2015
Bunda 19 (B8)	SA	Bunda Cliffs	1995	2014	19	16	7	-4.26	-6.39	-81%	CR	Dennis and Shaughnessy (1996)	Goldsworthy et al. 2015
Six Mile Is.	WA	Recherche Archipelago	1991	1999.5	8.5	43	40	-0.85	-1.27	-28%	LC	Gales et al (1994)	DPAW database
Round Is.	WA	Recherche Archipelago	1990	2013.5	23.5	20	13	-1.82	-2.72	-50%	VU	Gales et al (1994)	Goldsworthy unpublished
Salsibury Is.	WA	Recherche Archipelago	1990	2013.5	23.5	14	10	-1.42	-2.13	-42%	VU	Gales et al (1994)	DPAW database
Wickham (Stanley) Is.	WA	Recherche Archipelago	1989	2013.5	24.5	18	5	-5.09	-7.64	-86%	CR	Gales et al (1994)	DPAW database
Glennie Is.	WA	Recherche Archipelago	1991.5	1998	6.5	24	21	-2.03	-3.05	-54%	EN	Gales et al (1994)	DPAW database
Kimberley Is.	WA	Recherche Archipelago	1991.5	2013.5	22	42	32	-1.23	-1.84	-37%	VU	Gales et al (1994)	DPAW database
Red Islet	WA	Bremer Bay	1998	2016.5	18.5	30	16	-3.34	-5.01	-72%	EN	Gales et al (1994)	DPAW database
Hauloff Rock	WA	Bremer Bay	1989	2016.5	27.5	29	21	-1.17	-1.75	-36%	VU	Gales 1990	DPAW database

Table 9.3. Summary of estimates of trends in Australian sea lion abundance across seven regions in SA and two regions off the south coast of WA, based on changes in pup abundance between two surveys estimated for individual breeding sites and summarised for the nine regions. The number of breeding sites per region and the number with useable time series are indicated, along with the number that have decreased or increased. The mean percentage rate of change (λ) per year of breeding sites within each region is presented, along with the mean of the mean regional rates of change (in parentheses). Estimated changes in pup abundance within regions (for sites with time series data, see Table 9.2) across 3-generations (38 years) are also provided (following IUCN guidelines to assess species under Criterion A), as is the mean of 3-generation change across the 28 assessed sites in SA and the 8 assessed sites of the south coast of WA (in bold).

Region	No. breeding sites	No. with time series	No. decreased	No. increased	Pup abundance	λ/yr (%)	Change in 3-gen (%)
Kangaroo Island (SA)	6	3	3	0	746	-0.95	-26%
Spencer Gulf (SA)	11	7	6	1	802	-3.01	-79%
SW-Eyre (SA)	6	2	1	1	119	-0.96	-4%
Chain of Bays (SA)	7	6	5	1	380	-2.22	-79%
Nuyts Archipelago (SA)	7	7	5	2	322	-4.61	-91%
Nuyts Reef (SA)	1	0	-	-	105	-	-
Bunda Cliffs (SA)	4	3	3	0	26	-3.67	-77%
Twilight Cove (WA)	1	0	-	-	4	-	-
Recherche Archipelago (WA)	11	6	6	0	224	-2.07	-47%
Bremer Bay (WA)	4	2	2	0	77	-2.25	-59%
Total SA	**42**	**28**	**23 (82%)**	**5 (18%)**	**2500**	**-2.94 (-2.57)**	**-77.2%**
Total south coast WA	**16**	**8**	**8 (100%)**	**0 (0%)**	**301**	**-2.12 (-2.16)**	**-51.2%**
Total GAB	**58**	**36**	**31 (86%)**	**5 (14%)**	**2801**	**-2.76 (-2.47)**	**-76.4%**

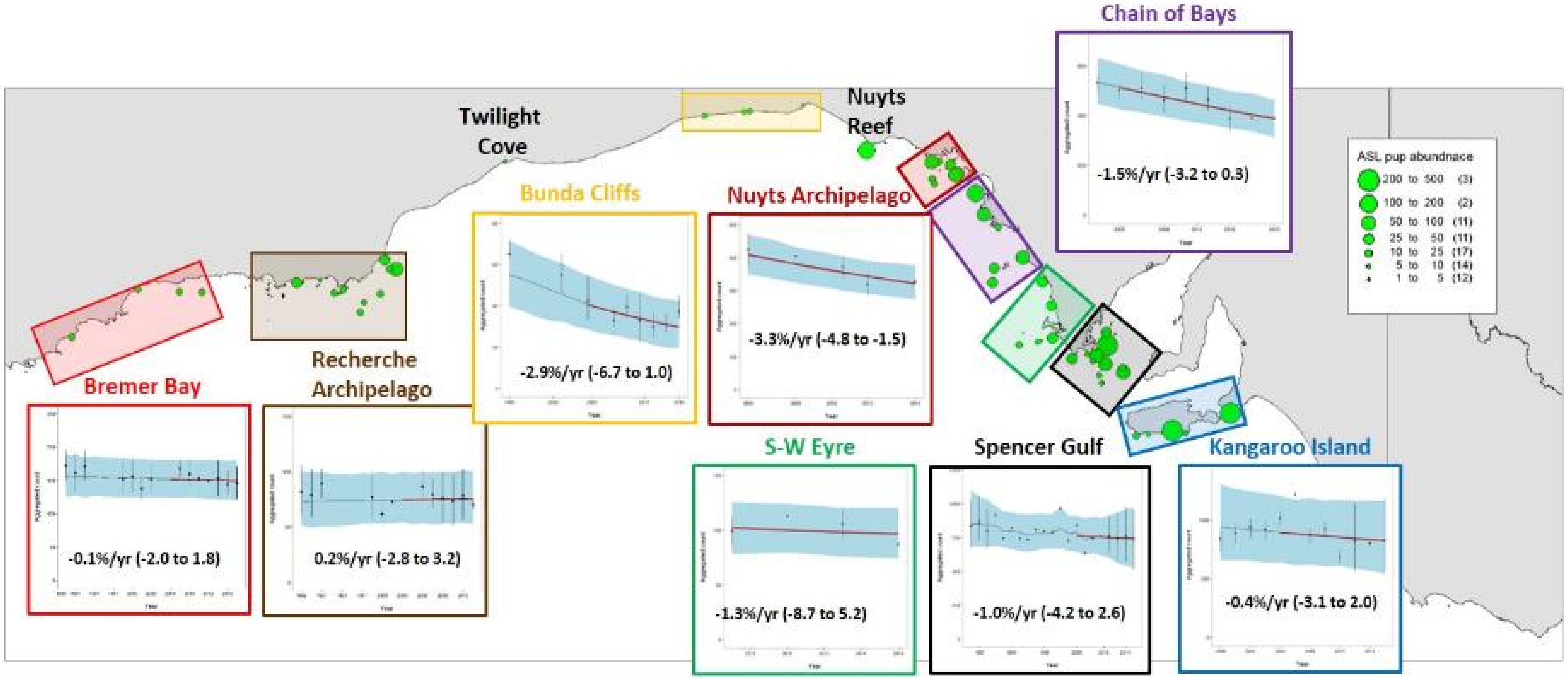


Figure 9.4. Predicted distribution of aggregated abundance and trend for eight Australian sea lion regions in the GAB Region. The blue envelope represents the 90% highest probability density credible interval of the posterior predictive counts. Points and error bars represent the observed counts with augmented missing values; the red lines are the fitted least-squares predictive trend over the last decade and the black lines are the median of the posterior predictive counts over the entire time interval. Trend estimates are given for the posterior median percentage rate of growth by year, and (in brackets) the lower and upper 90% highest probability density credible intervals (CI).

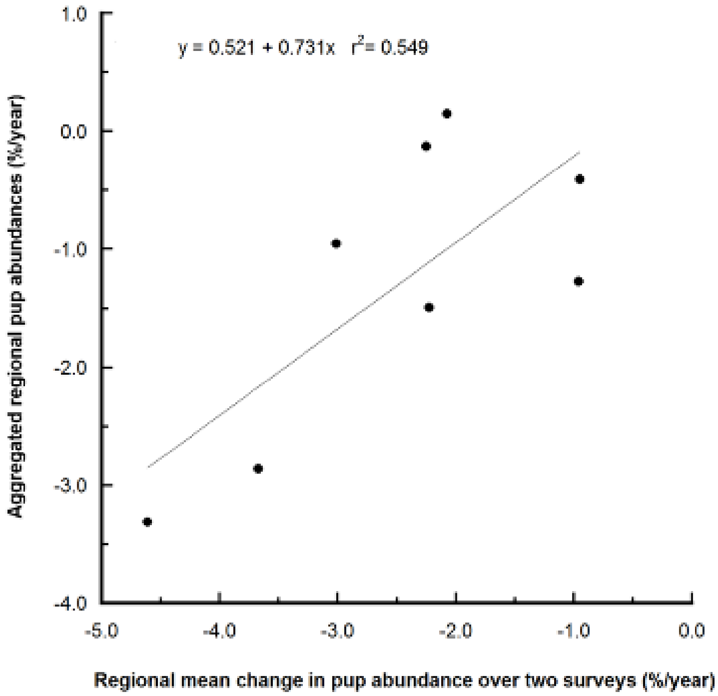


Figure 9.5. Relationship between results of the two methods use to estimate the growth rates in pup abundance in eight Australian sea lion regions in the GAB; the mean regional change between two surveys at individual sites (x-axis) and trends in aggregated regional pup abundances (y-axis).

Table 9.4. Estimated trends of aggregated abundance for Australian sea lion pups in six regions off SA and two regions off the south coast of WA. Time intervals for the SA regions are 2005 to 2015 and for the south-coast WA they are between 2003 and 2013 for the Recherche Archipelago and between 2006 and 2016 for Bremer Bay. Trend estimates are given for the posterior median, and lower and upper 90% highest probability density credible intervals (CI) of λ by year, and by breeding season (1.5 years).

Region	**λ yr^{-1}**			**λ breeding season^{-1}**		
	Median	**Lower CI**	**Upper CI**	**Median**	**Lower CI**	**Upper CI**
Kangaroo Island (SA) (3 sites)	-0.41	-3.11	2.00	-0.62	-4.67	3.00
Spencer Gulf (SA) (6 sites)	-0.95	-4.42	2.57	-1.43	-6.63	3.86
SW-Eyre (SA) (5 sites)	-1.27	-8.66	5.23	-1.91	-12.99	7.84
Chain of Bays (SA) (7 sites)	-1.49	-3.24	0.30	-2.24	-4.86	0.45
Nuyts Archipelago (SA) (7 sites)	-3.31	-4.82	-1.53	-4.96	-7.23	-2.29
Bunda Cliffs (SA) (10 sites)	-2.86	-6.65	0.98	-4.29	-9.98	1.47
Recherche (WA) (6 sites)	0.15	-2.83	3.19	0.23	-4.25	4.78
Bremer Bay (WA) (4 sites)	-0.13	-1.96	1.78	-0.19	-2.94	2.67

9.4.2 Fur seals

Distribution of long-nosed fur seals in the GAB

Long-nosed fur seals are distributed throughout the GAB region. In SA, a survey of most breeding colonies was undertaken in the 2013/14 summer; to this was added data from some other colonies not visited then (Shaughnessy et al. 2014; Table 9.5). More recent data from Williams Island in 2015/16 have also been included Table 9.5. long-nosed fur seals have been recorded from Baudin Rocks in the south-east to Nuyts Reef in the north-west. Previously, small numbers of non-breeding long-nosed fur seals were recorded further west, at the base of the Bunda Cliffs (Dennis and Shaughnessy 1996), but those sites were not included in surveys undertaken in 2013/14 (Shaughnessy et al. 2014). During the 2013/14 and 2015/16 (Williams Island) surveys a total of 34 breeding sites, distributed from Baudin Rocks to Fenelon Island were identified in SA (Tables 9.5, Shaughnessy et al. 2014). In WA, surveys undertaken in 2010/11 identified 17 breeding sites between Daw Island in the eastern Recherche Archipelago, and Cape Naturaliste (Bunker Bay) (Campbell et al. 2014). Four of these breeding sites, accounting for 173 pups, occur west of the GAB region (Stanley, Chatham, and Flinders Islands, and Bunker Bay) and are not considered (Campbell et al. 2014). Details of the remaining twelve sites within the GAB region of WA are presented in Table 9.5. In western Bass Strait, surveys undertaken in 2013/14 identified two breeding sites at Cape Bridgewater and Lady Julia Percy Island (McIntosh et al. 2014) (Table 9.5).

Estimates abundance and trends of long-nosed fur seals

The most recent long-nosed fur seal breeding site surveyed was Williams Island in southern Spencer Gulf on 1 February 2016. Based on the mark-recapture method, the Petersen estimate was 339 (95% CL 325 – 354), including 9 dead pups. This is an improvement on a previous estimate from the initial survey of this site on 14 March 2014 of 182 pups, based on a ground count (Shaughnessy et al. 2014). Adding this number to previous SA-wide surveys gives an overall estimate of pup abundance for SA of 20,588 (Tables 9.5).

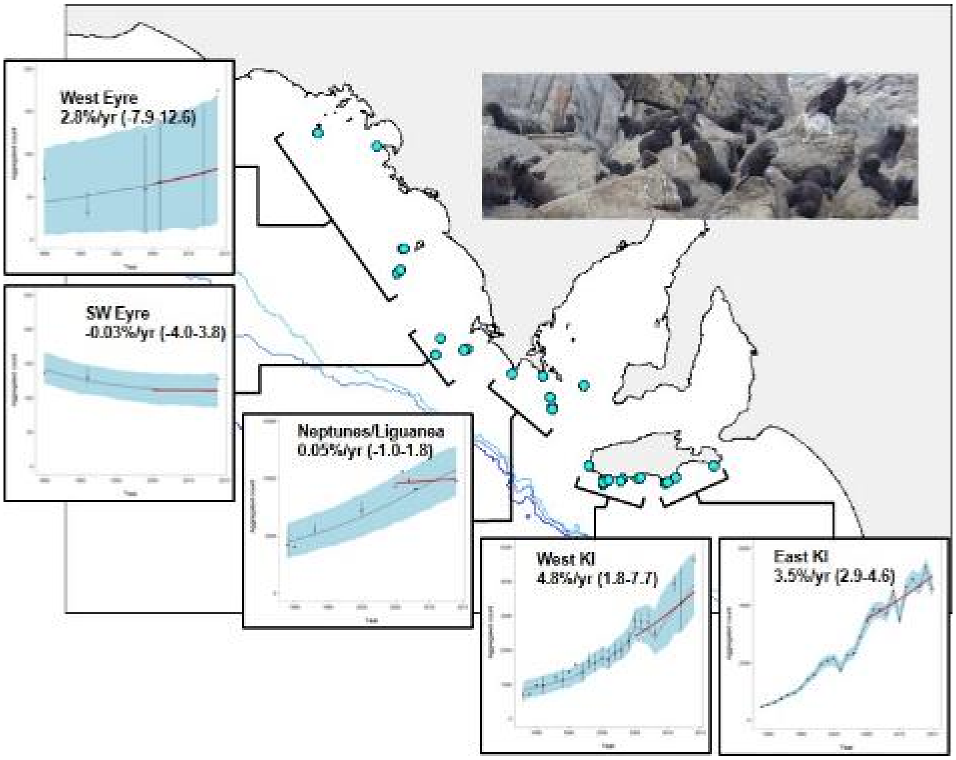
For the south coast of WA within the GAB region, the overall estimate of pup abundance based on surveys undertaken in the 2010/11 season was 3,349, and for western Bass Strait (Victorian) breeding sites, the estimate of pup abundance was 126 (Table 9.5). This gives an overall estimate of pup abundance for the GAB region of 24,063 (Table 9.5).

The estimate of pup production for long-nosed fur seal pups in SA from this survey (20,588) is 3.7 times greater than the previous estimate from a survey in the 1989-90 breeding season of 5,636 pups (Shaughnessy *et al*. 1994). It also exceeds the estimate of 11,119 pups in SA that can be computed from the compilation by Goldsworthy *et al*. (2003) of available data between 1989 and 2001, and that of 17,622 pups by Goldsworthy and Page (2007). The increase from 1989-90 to 2013-14 has been at an average exponential rate of r = 0.054, equivalent to 5.5% per year. This rate of increase is likely to be inflated, because pup production estimates for the Neptune and Liguanea Islands in 1989-90 were obtained using a mixture of direct counts and mark-resight procedures, and therefore likely under-estimated the number of pups produced on those islands then (Shaughnessy *et al*. 1994).

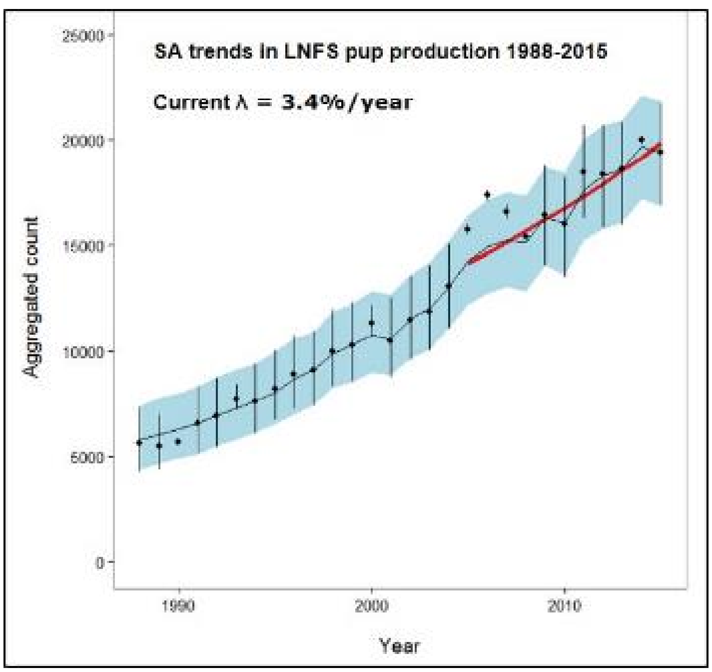
Regional trend analyses of aggregated regional pup abundance for five regions across SA indicate that pup abundance across most regions has increased strongly over a 10-year period between 2005 and 2015 (Table 9.6). The greatest growth has occurred on Kangaroo Island, while growth has been much lower (West Eyre), or close to stable for Neptunes/Liguanea and SW Eyre (Figure 9.4 and Table 9.6).

However, the overall trend in pup abundance between 2005 and 2015 shows a positive median growth rate of 3.4% per year (Figure 9.5 and Table 9.6).

For most south coast WA and western Bass Strait long-nosed fur seal colonies, only two or three surveys have been undertaken, with too few data points available to undertake analyses comparable to those made for the SA data. For the south coast of WA, Gales et al. (2000) reported that pup production had more than doubled between 1989 and 1999, and grew at 10% per annum. However, over the 12 years between 1999 and 2011, growth rates had declined to ~1% per year (Campbell et al. 2014). Campbell et al. (2014) noted that some breeding sites showed large annual declines of 6–7% in pup production over the 12 years while other sites had increased by 6–9% per annum. For western Bass Strait, McIntosh et al. (2014) noted that between the 2009 and 2014 surveys, long-nosed fur seal pup abundance had increased from 40 to 102 at Cape Bridgewater and from 15 to 24 at Lady Julia Percy Island.



a)



b)

Figure 9.5. Predicted distribution of aggregated abundance and trend for five long-nosed fur seal regions in SA (a), and for the entire SA population (b). The blue envelope represents the 90% highest probability density credible interval of the posterior predictive counts. Points and error bars represent the observed counts with augmented missing values; the red lines are the fitted least-squares predictive trend over the last decade and the black lines are the median of the posterior predictive counts over the entire time interval. Trend estimates are given for the posterior median, and lower and upper 90% highest probability density credible intervals (CI) of percentage rate of growth by year.

Table 9.5. Summary of estimated pup production for known long-nosed fur seal breeding sites in the GAB region of SA, WA and western Bass Strait (Vic).

Breeding site	State	No. pups	95% CL	Method of estimation	Date	Source
Baudin Rocks	SA	2		Count	13-May-08	Shaughnessy et al. 2014
Cape Hart	SA	8		Count	18-Mar-14	Shaughnessy et al. 2014
Cape Linois	SA	64		Count	27-Jan-14	Shaughnessy et al. 2014
Berris Pt	SA	1344	1325-1362	MR	Jan-14	Shaughnessy et al. 2014
Cape Gantheaume	SA	3925	3878-3973	MR	Jan-14	Shaughnessy et al. 2014
Cape Kersaint East	SA	10		Count	27-Jan-14	Shaughnessy et al. 2014
Cape Kersaint West	SA	28		Count	19-Feb-14	Shaughnessy et al. 2014
Xenolith Point	SA	1		Count	8-Feb-06	Shaughnessy et al. 2014
Cave Point	SA	58		Count	23-Jan-14	Shaughnessy et al. 2014
Horseshoe Bay	SA	3		Count	8-Feb-06	Shaughnessy et al. 2014
Cape Bouguer	SA	71		Count	20-Mar-14	Shaughnessy et al. 2014
East of Remarkable Rocl	SA	6		Count	25-Feb-14	Shaughnessy et al. 2014
Cape du Couedic	SA	4348	4281-4415	MR & Count	Jan-14, Jan-98	Shaughnessy et al. 2014
North Casuarina Is.	SA	245	234 – 255	MR	30-Jan-14	Shaughnessy et al. 2014
Paisley Is.	SA	22		Count	29-Jan-14	Shaughnessy et al. 2014
Althorpe Is.	SA	5		Count	2006-07 summer	Shaughnessy et al. 2014
North Islet	SA	7		Count	14-Mar-14	Shaughnessy et al. 2014
Williams Island	SA	339	325 – 354	MR & Count	1-Feb-16	This report
South Neptune Islands	SA	3210	3162-3258	MR & Count	Feb-14	Shaughnessy et al. 2014
North Neptune Islands	SA	4669	4605-4733	MR & Count	Feb-14	Shaughnessy et al. 2014
Liguanea Is.	SA	1832	1797 - 1867	MR & Count	Feb-14	Shaughnessy et al. 2014
Rocky (South) Is.	SA	19		Count	13-Mar-14	Shaughnessy et al. 2014
Little Hummock Is.	SA	27		Count	13-Mar-14	Shaughnessy et al. 2014
Four Hummocks (South)	SA	16		Count	13-Mar-14	Shaughnessy et al. 2014
Four Hummocks (Middle	SA	47		Count	13-Mar-14	Shaughnessy et al. 2014
Four Hummocks (North)	SA	68		Count	13-Mar-14	Shaughnessy et al. 2014
Greenly Is.	SA	13		Count	13-Mar-14	Shaughnessy et al. 2014
Dorothee Is.	SA	2		Count	12-Feb-14	Shaughnessy et al. 2014
Veteran Isles (south)	SA	1		Count	11-Feb-14	Shaughnessy et al. 2014
Pearson Is (North, north	SA	39		Count	11-Feb-14	Shaughnessy et al. 2014
Ward Is.	SA	127		Count	11-Feb-14	Shaughnessy et al. 2014
South Ward Is.	SA	24		Count	11-Feb-14	Shaughnessy et al. 2014
Olive Is.	SA	5		Count	11-Feb-14	Shaughnessy et al. 2014
Fenelon Is.	SA	3		Count	19-Mar-14	Shaughnessy et al. 2014
Daw (Christmas) Is.	WA	125		Count	Feb-11	Campbell et al. 2014
New Year Is.	WA	45		Count	Feb-11	Campbell et al. 2014
Cranny Is.	WA	120		Count	Feb-11	Campbell et al. 2014
Cooper Is.	WA	306		Count	Feb-11	Campbell et al. 2014
Salisbury Is.	WA	1251		Count	Feb-11	Campbell et al. 2014
Beaumont Is.	WA	39		Count	Feb-11	Campbell et al. 2014
Draper Is.	WA	39		Count	Feb-11	Campbell et al. 2014
Finger Is.	WA	37		Count	Feb-11	Campbell et al. 2014
Libke Is.	WA	340		Count	Feb-11	Campbell et al. 2014
Hood Is.	WA	175		Count	Feb-11	Campbell et al. 2014
Seal Rock	WA	276		Count	Feb-11	Campbell et al. 2014
Rocky (Investigator) Is.	WA	47		Count	Feb-11	Campbell et al. 2014
West Is.	WA	57		Count	Feb-11	Campbell et al. 2014
Doubtful Is.	WA	71		Count	Feb-11	Campbell et al. 2014
Hauloff Rock	WA	285		Count	Feb-11	Campbell et al. 2014
Eclipse Is.	WA	136		Count	Feb-11	Campbell et al. 2014
Lady Julia Percy Is.	Vic	24	22 - 26	MR	14-Jan-14	McIntosh et al. 2014
Cape Bridgewater	Vic	102	98 - 108	MR	11-Jan-14	McIntosh et al. 2014
Total pups for SA		**20,588**	**20,469– 20,707**			
Total pups for WA		**3,349**				
Total pups for western Bass Strait (		**126**	**117– 135**			
Total pups for GAB		**24,063**	**24,117– 24,355**			

Table 9.6. Estimated trends of aggregated abundance for long-nosed fur seal pups in five regions off SA between 2005 and 2015. Trend estimates are given for the posterior median, and lower and upper 90% highest probability density credible intervals (CI) of percentage change by year.

	Median growth %/yr (±90% CI)
Site	2005-2015
East Kangaroo Is	3.5 (2.9-4.6)
West Kangaroo Is	4.8 (1.8-7.7)
Neptunes/Liguanea	0.5 (-1.0-1.8)
SW Eyre	-0.03 (-4.0-3.8)
Western Eyre	2.8 (-7.9-12.6)
South Australia	3.4 (2.0-4.7)

Distribution of Australian fur seals in the GAB

The Australian fur seal is endemic to south-eastern Australian waters and is found from the coast of New South Wales (NSW), Tasmania to Victoria, and across to SA with the centre of their distribution in Bass Strait (Kirkwood et al. 2010). They have not been recorded in WA. There are 21 known breeding sites that include nine established colonies in Bass Strait; Lady Julia Percy Island, Seal Rocks, The Skerries, and Kanowna Island in Victoria; Judgment Rocks, Moriarty Rocks, Reid Rocks, West Moncoeur Island, and Tenth Island in Tasmania; eight colonies that have established in the past 10 to 15 years: Rag Island and Cape Bridgewater (Victoria), Wright and Double Rocks (Tasmania), Bull and Sloop rocks (Tasmania), Montague Island (NSW) and North Casuarina Island (SA); and there are three haul-outs, with accessional pupping at Iles des Phoques (Tasmania), Williams Island and Baudin Rocks (SA) (Kirkwood et al. 2010, Shaughnessy et al. 2010, McIntosh et al. 2014, Shaughnessy et al. 2014) (Figure 9.1). The range of the species is expanding, with the new colonies in NSW and SA all establishing in the past 10 years. The historical range of the species prior to colonial sealing (pre-1800s) is unknown. In the GAB region, there are five known breeding sites for the species, Lady Julia Percy Island and Cape Bridgewater in western Bass Strait (Victoria), and North Casuarina Island (off Kangaroo Island), Williams Island and Baudin Rocks (SA). There is a further breeding site in western Bass Strait at Reid Rocks, south-east of King Island, but it lies outside of the GAB ecosystem modelling domain, and is not including in this assessment.

Estimates abundance and trends of Australian fur seals

In SA, Australian fur seals were first observed to be breeding at North Casuarina Island in 2006/07, when 11 pups were observed (Shaughnessy et al. 2010). A total of 29 pups were estimated there using mark-recapture methods in 2007/08, and 74 and 76 pups were estimated using the same methodology in 2011/12 and 2013/14, respectively (Shaughnessy et al. 2010, Shaughnessy and Goldsworthy 2012, Shaughnessy et al. 2014). In 2013/14, Australian fur seal pups were recorded at two other localities in SA, six at Baudin Rocks, and two at Williams Island (Shaughnessy et al. 2014), giving a total SA pup abundance estimate of 84 for SA in 2013/14 (Table 9.7). Surveys undertaken of the western Bass Strait breeding sites in 2013/14 estimated 2,659 Australian fur seal pups at Lady Julia Percy Island and 120 at Cape Bridgewater (Table 9.7) (McIntosh et al. 2014), giving a total western Bass Strait pup abundance

estimate of 2,779 in 2013/14. The total estimated pup abundance for the GAB region for 2013/14 was 2,863 (Table 9.7).

There is limited data to base trend analysis on Australian fur seals in SA. However, analyses of trends in aggregated regional (SA) pup abundance suggest the SA population is increasing by 18.7% per year, noting the broad credible limits in median growth are large (range 9.5 – 27.2) (Figure 9.6). There have been three surveys of Australian fur seals at Lady Julia Percy Island and Cape Bridgewater in 2002/03, 2007/08 and 2013/14 (Kirkwood et al. 2005, Kirkwood et al. 2010, McIntosh et al. 2014). For Lady Julia Percy Island, estimates of 5,899, 5,574 and 2,659 pups, respectively, were obtained, suggesting that pup production has more than halved over the 11-year period, by ~-7.0% per year. In contrast, those at Cape Bridgewater estimated 7, 7, and 120 pups, respectively, indicating that pup production in this establishing breeding site has increased more than 16-fold over the 11-year period by ~29.5% per year.

Table 9.7. Estimated abundance of Australian fur seal pups in the GAB Region in the 2013/14 breeding season.

Breeding site	State	No. pups	Method of estimation	Date	Source
North Casuarina Is	SA	76	MR	30-Jan-14	Shaughnessy et al. 2014b
Williams Is	SA	2	Count	14-Mar-14	Shaughnessy et al. 2014b
Baudin Rocks	SA	6	Count	2014	Shaughnessy et al. 2014b
Lady Julia Percy	Vic	2,659	MR & Count	10-Jan-14	McIntosh et al. 2014
Cape Bridgewater	Vic	120	Count	11-Jan-14	McIntosh et al. 2014
Total pups for SA		**84**			
Total pups for eastern Bass Strait (Vic)		**2,779**			
Total pups for GAB		**2,863**			

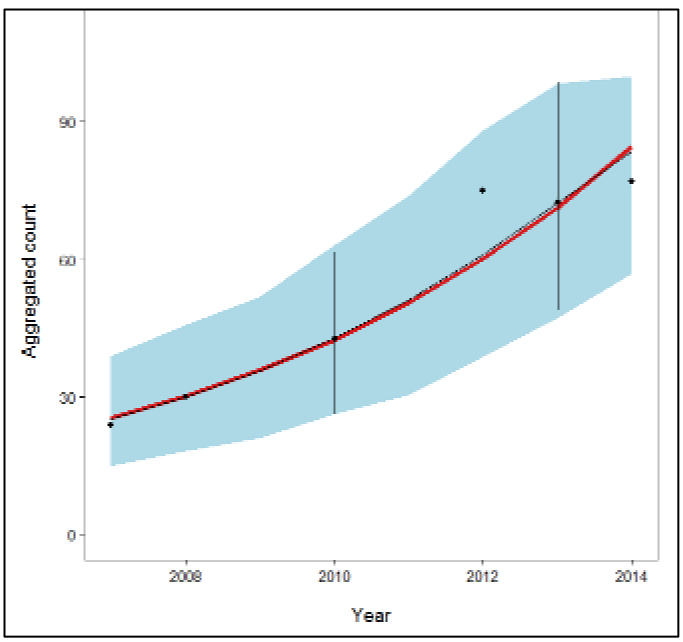


Figure 9.6. Predicted distribution of aggregated pup abundance and trend for the Australian fur seal population in SA. The blue envelope represents the 90% highest probability density credible interval of the posterior predictive counts. Points and error bars represent the observed counts with augmented missing values; the red line is the fitted least-squares predictive trend and the black line are the median of the posterior predictive counts over the entire time interval.

9.5 Discussion

9.5.1 Australian sea lion

Population status

This report provides the most comprehensive assessment of the status and trends in abundance of the Australian sea lion populations in the GAB region. For the SA population, these surveys are the first time most breeding sites have been surveyed within an 18-month period, the approximate span of one breeding cycle.

Before this study, the most comprehensive survey in SA was based on data collected primarily between 2004 and 2008, with data for some breeding sites from as early as 1990 (Shaughnessy et al. 2011). That survey estimated Australian sea lion pup abundance in SA to be 3,119, which is 619 greater than the result from the present survey (2,500), conducted 6 to 11 years later. However, the former survey did not include five recently discovered breeding sites, for which the combined pup abundance in the current survey was 58. In addition, recent results suggest that surveys undertaken at three of the sites by Shaughnessy et al. (2011) (at Nuyts Reef, and Rocky (North) and North Casuarina islands) were undertaken either too early or outside the breeding season, and potentially underestimated pup abundance by 117 pups. Most of this difference is attributed to Nuyts Reef, a group of remote offshore islets previously only accessed by vessel. Surveys of the middle and western islets in March 1990 and April 2004 recorded 3 and 12 pups, respectively (Gales et al. 1994, Shaughnessy et al. 2005), while a survey by helicopter at the end of the breeding season in May 2015 recorded 69 and 36 pups at the middle and western islets, respectively, giving a difference of 90 pups between surveys.

To make meaningful comparisons between surveys across SA in the two periods, it is necessary to exclude the newly discovered breeding sites and inadequately surveyed sites identified above, as well as to adjust counts of pups at sites along the Bunda Cliffs used by Shaughnessy et al. (2011). With these alterations, the pup abundance estimate for the 2004 to 2008 surveys reduces to 2,902 pups for 32 sites. For these same sites, the total pup abundance in the 2014-2015 surveys was 2,195, 24.4% fewer (707 pups) than reported by Shaughnessy et al. (2011). Most of this difference is attributed to reductions in observed pup numbers at The Pages Islands, Dangerous Reef and Lewis, West Waldegrave, Nicolas Baudin, Olive Purdie, West, Fenelon and Lounds islands. Ten sites previously recognised as breeding sites or haul-out sites with occasional pupping were not recorded to have pups in this recent survey: Bunda 22 (previously designated B9), Bunda 18 (B7), Bunda 12 (B6), Bunda 8 (B4), Bunda 4 (B2), Bunda 1, Pt Fowler (Camel Foot Bay), Gliddon Reef, Dorothee Island, and Cave Point on Kangaroo Island. The status of Black Point, Kangaroo Island remains uncertain.

The compilation of data available for the south coast of WA suggests there are at least 16 extant breeding sites and a pup abundance of 301, although there is large uncertainty about this figure. Furthermore, the status of many breeding sites is doubtful, some of which have not been surveyed during a breeding season for more than 25 years and a number that have only ever been surveyed once (Gales et al. 1994). In surveys undertaken between 1989 and 1992, Gales et al. (1990) counted 364 pups for the south coast of WA. Goldsworthy et al. (2009) assessed pup numbers to be 338 in 2009, based on a compilation of available data, much of which had not changed since the surveys of Gales et al. (1994). The total Australian sea lion pup abundance can be estimated to be 509 in WA (south coast 301; west coast 208) and 2,500 in SA, leading to a pup abundance estimate for the species of 3,009. Based on this assessment, around 93% of the species is restricted to the GAB region.

Shaughnessy et al. (2011) estimated the total size of the Australian sea lion population in SA to be 12,726, based on multiplying pup numbers by 4.08 to estimate total population size. That multiplier was developed by Goldsworthy and Page (2007) and based on a generic otariid life-table developed by Goldsworthy et al. (2003), adjusted for a 1.5 year breeding interval and female longevity of 25 years. From a more recent Australian sea lion life-table that utilised survival estimates from the Seal Bay population adjusted to achieve a stable population structure, a multiplier of pup numbers to total population size of 3.83 was derived by Goldsworthy et al. (2010b). With this multiplier and the current assessment of Australian sea lion pup numbers, the size of the Australian sea lion population in SA is 9,652, and for the south-coast WA population it is 1,153, providing a total abundance estimate for the GAB region and the species of 10,728. This may be an over-estimate because the multiplier assumes a stable population. As the Australian sea lion population is in decline, a lower multiplier would be more appropriate (Harwood and Prime 1978).

Trends in abundance

This study is the first to provide quantitative estimates of the status and trends in abundance of Australian sea lion populations across their entire SA range. We also provide an assessment of data available for south coast WA Australian sea lion populations that fall within the GAB region. The two methods used to examine trends (change in pup abundance between two surveys, and regional trends on aggregated abundances) produced similar results with respect to the status and trends in pup abundance across Australian sea lion regions. The key finding of the study is that pup numbers at most breeding sites and in all regions have declined between survey periods. For the entire GAB region (SA and south coast WA), based on the change in pup abundance between two comparable surveys, the decline in pup numbers was estimated to be -2.8% (sd = 3.2) per year, or -4.1% (sd = 4.8) per breeding season. South coast WA regional declines were similar for the Recherche Archipelago and Bremer Bay regions, but declines varied more across SA being greatest greatest in the Nuyts Archipelago and lowest in the Kangaroo Island region.

Following IUCN Redlist assessment methods, the estimated change in pup abundance over three generations based on the observed change in pup abundance across the GAB region was -76.4%, meeting the 'Endangered' IUCN Criterion A assessment criteria (>50% and <80% decline over three generations). This is consistent with the recent IUCN Redlist assessment for the species (Goldsworthy 2015), but is higher than the current 'Vulnerable' status under the Australian Government's EPBC Act (DSEWPaC 2013). Almost 40% of sites assessed in the GAB region meet the 'Critically endangered' criteria (>80% decline over three generations).

9.5.2 Fur seals

Abundance and trends of long-nosed fur seals

This assessment has identified that long-nosed fur seals are an abundant marine predator distributed throughout the GAB region with an overall annual pup abundance estimated to be 24,063. This indicates that around 97% of the total national pup abundance for the species occurs within the GAB region, based on a total estimated pup abundance in Australia of 24,821, with 758 pups (~3%) occurring outside of the GAB region (an additional 186 pups in Victoria, 399 in Tasmania, 36 off NSW and 173 west of the GAB region in south-west WA, McIntosh et al. 2014, Campbell et al. 2014). Within the GAB region, there

are two major population centres; a larger one in the eastern GAB centred on Kangaroo Island and the lower Eyre Peninsula which accounts for ~83% of the national population or 86% of the GAB region, and a smaller one in the western GAB centred on the Recherche Archipelago which accounts for 13% of the national population or 14% of the GAB region. Using a pup production to total population abundance multiplier of 4.760 developed by Goldsworthy and Page (2007) based on a life table for the species, this leads to a total estimate of abundance of long-nosed fur seals in the GAB of 114,540 (97,999 in SA; 15,941 in WA and 600 in western Bass Strait).

In SA, there has been about a 3.7-fold increase in pup production between 1989/90 and 2013/14 breeding seasons, equivalent to an annual growth rate of around 5.5% per year (Shaughnessy *et al*. 2014). With pup production peaking at the Neptune and Liguanea islands in the mid-2000s, growth rates declined to around 3.4% per year between 2005 and 2015. Pup production at a number of major breeding sites has stabilised and appears to have reached carrying capacity (Shaughnessy *et al*. 2014). A similar conclusion has been reached for populations off the south coast of WA (Campbell *et al.* 2014). The stabilisation of some populations is likely related to density dependent factors relating to space, with most of the available suitable breeding substrate now filled (Shaughnessy *et al*. 2014). The strong growth in long-nosed fur seal populations over the last 30+ years has been attributed to recovery of the population from overharvesting by early Europeans from the early 19th century, which has been aided by protection of the species, especially since the mid-1970s (Kirkwood and Goldsworthy 2014, Shaughnessy *et al*. 2014).

Abundance and trends of Australian fur seals

This assessment has identified that Australian fur seals are restricted to the eastern margins of the GAB region, with the bulk of the population restricted to the Bass Strait and the adjacent continental shelves of Victoria and Tasmania. The largest population in the GAB region is at Lady Julia Percy Island in western Bass Strait. The species has recently colonised SA, and there is a small but growing breeding population at North Casuarina Island off Kangaroo Island, in addition to several sites where pups were first observed over the last five years. Recent surveys suggest that the total annual pup abundance in the GAB region is 2,863, with most (97%) in western Bass Strait. Total population estimates of Australian fur seals have included a 15% pup mortality adjustment to account for pups that have died prior to surveys, which was then multiplied by 4.5 to estimate total abundance (Kirkwood et al. 2010). Application of these adjustments and multiplication factors to the above data produces a total pup production estimate of 3,291 and a total population abundance estimate of 14,811 in the GAB region. In the national census of Australian fur seals undertaken in 2013/14, McIntosh et al. (2014) estimated the total pup abundance to be 15,063, suggesting that the GAB region accounts for about 18% of the species' population size.

Although the small emerging population in SA appears to be growing rapidly (Shaughnessy et al. 2014), the status of the main population centre in Bass Strait is unclear. The population at Lady Julia Percy Island was once the largest fur seal colony in Australia, producing 5,899 pups in the 2002/03 breeding season. By 2013/14, pup production had more than halved to 2,659 pups, suggesting ~7% decline per year over the 11-year period between the two surveys (McIntosh et al. 2014). There have been three national surveys of pup production for the species undertaken at approximately five-yearly intervals since 2002–03. One undertaken in 2002–03 estimated a pup production of 19,820, another undertaken

in 2007–08 estimated a pup production of 21,881, and the most recent survey undertaken in 2013–14 estimated a pup production of 15,063 (Kirkwood et al. 2005, Kirkwood et al. 2010, McIntosh et al. 2014). The rate of increase in pup production between 2002–03 and 2007/08 was estimated to be 0.3% per year, reducing to -6.0% between the 2007/08 and 2013/14 (McIntosh et al. 2014). It is not clear if the apparent decline between the 2007/08 and 2013/14 surveys is real or due to a poor pupping season in 2013/14, as there is no colony that is monitored on an annual basis (McIntosh et al. 2014). Based on the 2007/08 surveys, Kirkwood et al. (2010) estimated the total Australian fur seal population to be 120,000 individuals (Kirkwood et al. 2010).

9.5.3 Conclusions

The study has highlighted that the GAB region is very important for Australia's pinniped biodiversity, with populations of all three species occurring here. The region is especially important for the Australian sea lion, with an estimated 93% of the species population, and for the long-nosed fur seal containing an estimated 98% of its Australian populations. The population status of both species contrasts markedly, with Australian sea lion populations in low abundance and declining across their range, while long-nosed fur seal populations have undergone a major recovery and growth over the last 30+ years. Australian fur seal populations are centred on Bass Strait, with only about 18% in the GAB region, however the western extent of the species range has recently expanded into SA. For all species, there is a marked geographic skew in their population distributions, with the eastern GAB region containing more than 80% of the Australian sea lion and long-nosed fur seal populations, and Bass Strait containing more than 80% of the Australian fur seal population.

Populations of both fur seal species have largely recovered or are in the latter stages of recovery, while those of the Australian sea lion are in decline. For pinnipeds in the GAB region therefore, the key issue is the status of Australian sea lion populations. This study has identified that the total Australian sea lion population in the GAB region is much smaller than previously estimated, and is presently undergoing a rapid decline. A number of potential factors have been identified that may be contributing to this decline. These include deaths caused by fisheries bycatch and interactions with marine debris; habitat degradation and interactions with aquaculture operations; human disturbance to colonies; deliberate killings; disease; pollution and oil spills; prey depletion and climate change (DSEWPaC 2013). Data on the importance of these factors and their cumulative impacts is limited, with the exception of fisheries bycatch mortality (Goldsworthy and Page 2007, Campbell 2008, Campbell et al. 2008b, Goldsworthy et al. 2010). The impact of bycatch mortality in the demersal gillnet fishery for sharks off SA on Australian sea lion populations was estimated by Goldsworthy et al. (2010). This study identified that bycatch mortality of Australian sea lion in the Gillnet, Hook and Trap (GHAT) Fishery was unsustainable over much of the species range, has impacted the recovery of the species and has likely resulted in recent declines observed in some colonies. Between 2010 and 2012, the Australian Fisheries Management Authority (AFMA) introduced a range of management measures into the GHAT Fishery off SA to mitigate bycatch of Australian sea lion, including spatial closures, electronic monitoring and bycatch trigger limits. Logbook data on Australian sea lion interactions reported since 2012 suggest these measures have reduced Australian sea lion bycatch in that fishery, with ten mortalities reported between 2013 and 2016. Although these measures have reduced the incidence of bycatch mortality, the extent to which they have reduced population declines is unknown. Bycatch of Australian sea lion pups and juveniles in

rock lobster pots has been largely mitigated through the introduction of pot-spikes in the rock lobster fisheries off WA (Campbell et al. 2008b) and SA.

9.5.1 Key Knowledge Gaps

Although this study marks an important step for assessing the status and trends in Australian sea lion populations in SA, equivalent baseline data for most south coast WA populations is absent. Furthermore, despite the species Threatened status under the EPBC Act, there is no ongoing, coordinated population monitoring program for the species. Ensuring that a sufficient and effective abundance and distribution monitoring is in place to adequately understand population size and trends at representative sites across the range of the Australian sea lion is a key priority of the species Recovery Plan (DSEWPaC 2013). The only site within the GAB region currently monitored regularly (each breeding season) is the Seal Bay population on Kangaroo Island. The absence of basic population monitoring programs remains a critical gap and need for this rapidly declining species. They are needed to i) assess the effectiveness and adequacy of bycatch mitigation measures, ii) the extent to which present declines in Australian sea lion populations can be explained by legacy (historic) bycatch in gillnet fishery and the time-frame for populations to recover if they are; and iii) identify if there are other factors that may be contributing to the lack of recovery in the species.

9.6 Acknowledgements.

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10. SEABIRD SURVEYS

Status and trends in abundance of seabirds in the Great Australian Bight

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10.1 Executive summary

- Key knowledge gaps for seabirds in the Great Australian Bight (GAB) region include baseline information on breeding distribution, status and trends in abundance. The objectives of this study were to obtain baseline or updated abundance data for three seabird species, with different movement and foraging ecology, at key breeding colonies in the GAB.
- Aerial surveys were undertaken at ten islands during the crested tern breeding season (November-February), based on available information regarding the location of breeding colonies in the eastern GAB. These were Nuyts Reef, Lounds Island, St Peter Island, Pigface Island, Rocky North Island, The Brothers, Donington Rock, Liguanea Island, and North and South Neptune Islands.
- Nesting crested terns were recorded at six of the ten surveyed islands: Nuyts Reef, Lounds Island, The Brothers and Donington Rock in December 2015, and at North and South Neptune Islands in February 2016. The number of nesting pairs of crested terns calculated from aerial photographs was 1,438 at Nuyts Reef, 3,119 at Lounds Island, and 428 and 408 at South and North Neptune Islands, respectively. Crested terns were present at Liguanea in February 2016, but the resolution of photographs was not sufficient to determine if breeding was underway. No crested terns were recorded at Pigface, Rocky North Island or St. Peters Island during surveys in December 2015.
- Surveys of little penguins were undertaken at two breeding colonies in the eastern GAB, Pearson Island and Olive Island.
- Surveys for flesh-footed shearwaters were undertaken at the two known breeding colonies for this species in South Australia; Smith Island and Lewis Island in Spencer Gulf.
- A range of survey methods were used to estimate breeding abundance of little penguins. A full burrow count was undertaken at Olive Island in 2013 and 2014. Results suggest a decline of ~80% in the total number of breeding individuals since the only other survey was conducted at the colony in 2006. At Pearson Island, transects, census plots and a full burrow count of a

discrete area were used to estimate the breeding abundance of little penguins. Comparison of results with those from 2004 was complicated by difference in survey methods. However, based on a 31% decline in burrow density recorded in a similar area in 2004 and 2013, there may have been a decline in the number of breeding individuals of ~66%.

- Given the apparent decline in little penguin numbers at both Pearson and Olive islands, there is a need for future systematic surveys to determine the status and ongoing population trends at these colonies.
- The current study estimated 928 and 5785 breeding pairs of flesh-footed shearwaters in February 2016 at Lewis and Smith islands, respectively. There remains a need to determine if the species breeds at other locations in South Australia, as reports of breeding on Williams Island in the lower Spencer Gulf have yet to be verified. As declines in flesh-footed shearwater populations have been recorded across their range, there is a need to determine the status of the South Australian breeding colonies, their foraging movements and genetic relatedness. This is particularly important given that the breeding colonies at Lewis and Smith islands could represent a closed subpopulation based on their geographic isolation from other colonies in Australasia.
- While the current study provided new or updated estimates at key breeding sites of three species in the GAB, it also highlights the paucity of baseline data for most species and breeding sites and the need to conduct multiple surveys and/or to further develop survey techniques to improve the accuracy of abundance estimates.
- Robust estimates of breeding abundance and distribution of seabird species are required in order to assess trends in populations and identify and manage anthropogenic drivers of population changes and be able to separate these from underlying responses to natural variability in the marine environment.

10.2 Introduction

Continental shelf, inshore coastal waters and embayments of the Great Australian Bight (GAB) form important foraging habitats for a diverse array of seabirds with breeding colonies on inshore and offshore islands. Seventeen seabird species have been recorded to breed in the area of the GAB (Copley 1996; Ross *et al.* 1996, Appendix 10.1). These species include representatives from penguins (Spheniscidae), terns (Sternidae), storm petrels (Hydrobatidae), diving petrel (Pelecanoididae), gannets (Sulidae), shags and cormorants (Phalacrocoracidae) and the marine raptors (Accipitridae). Copley (1996) estimated that between 1.4 and 1.5 million pairs of seabirds breed in South Australia. However, this estimate is based on data that has generally not been updated since the late 1960s to 1990s. For many colonies, no abundance estimates exist; rather, the presence of breeding individuals was recorded and their occurrence was listed as common, numerous or abundant (Copley 1996). Therefore, there are very few recent estimates of population sizes for most seabird species in the GAB, and many sites that have been identified as breeding colonies remain unsurveyed.

Seabirds play an important role within marine ecosystems as predators that occupy the upper trophic level in marine food webs and through their contribution to ecosystem nutrient cycling (Maron *et al.* 2006; Ellis *et al.* 2006). As seabirds are generally long-lived and have low reproductive output, their populations are sensitive to changes in environmental processes and the impacts of anthropogenic

activities (Croxall *et al.* 1990; McLeay *et al.* 2009b; Piatt *et al.* 2007; McLeay *et al.* 2009b; Furness and Greenwood 2013). Large declines in global seabird populations in recent decades have been reported (Paleczny *et al.* 2015), with bycatch, competition with fisheries, pollution, habitat degradation and disturbance identified as key threats to the conservation status of seabird populations (Croxall *et al.* 2012). A number of studies have demonstrated several links between seabirds and marine ecosystem health (Montevecchi and Myers 1996; Piatt *et al.* 2007). Changes in reproductive success, chick condition and survival of a number of seabird species have been shown to reflect changes in prey availability that may occur as a result of environmental processes such as die offs, or prey depletion due to fisheries (e.g., Furness and Tasker 2000, Weimerskirch *et al.* 2001, Frederiksen *et al.* 2008, McLeay *et al.* 2009a, 2009b). This is because breeding seabirds are central place foragers that must return to the breeding colony to provision their chick until it is fledged and therefore will be sensitive to changes in prey abundances within their foraging range (Burke and Montevecchi, 2009). Seabird species most sensitive to changes in local prey availability will be those with restricted diets and relatively small foraging ranges.

10.3 Background and need

Given the limited data available for seabird species that breed in the GAB, the project focused on collecting data for three distinct guilds of seabirds with different foraging ecologies. These were a surface forager (crested tern *Sterna bergii*), a non-flying, diving forager (little penguin *Eudyptula minor*) and a large-scale migratory species (flesh-footed shearwater *Puffinus carneipes*).

Crested terns

Breeding colonies of crested tern have been described for 28 locations in the GAB, with the majority (22) in South Australia (Copley 1996; McLeay *et al.* 2009a, 2010; Appendix 10.1, 10.2). Crested terns breed annually between October and March, and lay a single egg that is incubated for approximately 28 days. Both parents then provision the chick for up to two months, predominantly with small pelagic fish such as sardine and anchovy, providing a single prey item from each foraging trip (McLeay *et al.* 2009a). During the breeding season, foraging adults tagged at Troubridge Island, Gulf St Vincent, showed restricted foraging ranges within 40km of the colony and in waters generally less than 20m deep (McLeay *et al.* 2010). Reductions in recruitment and chick growth at Troubridge Island have been linked to decreases in prey availability associated with disease-related mortality events which killed ~70% of the biomass of sardine stock in southern Australia in 1995 and 1998 (McLeay *et al.* 2009a). Due to the high proportion of sardine in the diet of the species, the restricted foraging range during breeding and chick provisioning, and the large overlap in foraging area with the South Australian sardine fishery, crested terns have been identified as potential ecological indicators for this fishery (McLeay *et al.* 2009b; Goldsworthy *et al.* 2011).

A key knowledge gap noted by Copley (1996) was accurate data on the abundance and location of breeding colonies of crested terns off the west coast of Eyre Peninsula. Additional colonies identified since the review by Copley (1996) are Lilliput Island, Rocky North Island, Liguanea Island, Baudin Rocks and Daly Head Island (Shaughnessy 2007; Goldsworthy and Page 2010; L. SARDI unpublished data). Currently there is limited information on the abundance of the species in the GAB region, and ongoing monitoring and abundance estimates are only available from the breeding colony at Troubridge Island in Gulf St Vincent, South Australia (SARDI unpublished data).

Little penguin

Little penguins are resident in the GAB region and their presence has been recorded at 135 locations between the Recherche Archipelago in Western Australia and the South Australian – Victorian border. (Appendix 10.1 and 10.2). Little penguins are generally faithful to their natal colony (Marchant and Higgins 1990) although movement between colonies has been observed (Wiebkin 2007). Little penguins are central place foragers and will generally forage close (<20 km) to the colony during the breeding season (Bool *et al.* 2007, Wiebkin 2012), although longer foraging trips of up to 86 km from the colony have been recorded during the guard phase (Wiebkin 2012). In contrast to crested terns, little penguins are multiple-prey loaders and able to consume a number of prey items on a foraging trip before returning to provision their young. Little penguins are generalist predators that feed on small pelagic fish and cephalopods. Australian anchovy (*Engraulis australis*) was recorded as the main prey item in the diet of individuals from eight colonies in South Australia (Wiebkin 2012), and at least 12 other prey species have been recorded in their diet (Bool *et al.* 2007, Goldsworthy *et al.* 2011).

Little penguins breed in South Australia between April and November and produce two eggs per clutch which both adults take turns to incubate for a period of approximately five weeks. Once hatched, one adult remains with the chick for two weeks, termed the guard phase. After this both adults forage and provision the chick until it is fledged at between seven to nine weeks of age. In South Australia, the species has been observed to breed twice a year at some locations (Johnson and Wiebkin 2008). The number of chicks that successfully fledge is likely to reflect food availability and foraging success during the breeding season (Boyd *et al.* 2006).

Approximately 100 colonies have been recorded in South Australia where the little penguin is listed as common under the South Australian *National Parks and Wildlife Act 1972* (SA NPWS Act). The largest breeding colony in South Australia, at Pearson Island off western Eyre Peninsula, was estimated to have 6,000 breeding pairs (12,000 breeding individuals) in 2006 (Wiebkin 2011). Some colonies in the Gulf St Vincent region of South Australia have undergone major declines in abundance in recent decades (Wiebkin 2011; Colombelli-Negrel and Kleindorfer 2014; Colombelli-Negrel 2015), while others appear to be stable (Department of Environment, Water and Natural Resources 2016). Factors that have been suggested as causes for these declines include predation, disturbance and habitat loss (Wiebkin 2011). For the majority of colonies (69) in South Australia, there are currently no abundance or trend data available to assess the status of little penguins (Department of Environment, Water and Natural Resources 2016), and no abundance estimates have been made at offshore colonies in the GAB since 2006. Therefore, there is a need to monitor abundance and population trends for little penguin breeding colonies on offshore islands across the GAB to determine if the declines observed in Gulf St Vincent are localised or reflect a broader scale decline of little penguins in across the bioregion.

Flesh-footed shearwater

The flesh-footed shearwater is a small procellariform that undertakes trans-equatorial migrations between non-breeding foraging grounds and breeding colonies. The breeding range extends from St Paul Island in the Indian Ocean, across offshore islands of Western Australia and South Australia, Lord Howe Island in the Tasman Sea, and islands off the North Island of New Zealand. The flesh-footed shearwater is highlighted as one of the most poorly studied seabird species in the world (Croxall *et al.*

2012), with limited or no available data on survival rates and breeding success for almost all known breeding locations. The species is listed as vulnerable under the New South Wales *Threatened Species Conservation Act 1995* and the Western Australian *Wildlife Conservation Act 1950*, and as rare under the *South Australian National Parks and Wildlife Act 1972*.

Ongoing flesh-footed shearwater declines have been recorded for the breeding population at Lord Howe Island since the late 1970s; causes of these declines have been attributed to fisheries bycatch, habitat loss and road kill (Priddel *et al.* 2006; Reid *et al.* 2012, Reid *et al.* 2013). These declines led to the species being nominated for assessment for listing under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in 2013. A recent survey of colonies in Western Australia undertaken between 2011 and 2014 estimated that the population was 18,300-35,900 pairs (Lavers 2015), compared to 100,000–310,000 pairs estimated in 1993 (Burbidge *et al.* 1996). The assessment noted these data but judged that information on population trends of flesh-footed shearwaters from 40 known colonies in Western Australia were insufficient at that time to determine if they were declining. Therefore, the species was not eligible for listing under the EPBC Act (1999). There is also evidence of declines in population size at some colonies in New Zealand (Waugh *et al.* 2013, Barbraud *et al.* 2014). The only known breeding colonies of flesh-footed shearwaters in South Australia are on Lewis Island and Smith Island in southern Spencer Gulf (Goldsworthy *et al.* 2013). These islands are located more than 1,000 km east of the nearest breeding colony in Western Australia, and over 2,000 km west of the only east coast Australian breeding colony at Lord Howe Island.

Flesh-footed shearwaters breed from September to May and produce a single egg that both adults take turns incubating for a period of ~50–60 days, after which the chick is provisioned by both adults until it is fledged at ~100 days old (Priddel *et al.* 2006, Powell *et al.* 2007). During incubation and chick provisioning, a number of shearwater species have been shown to undertake a foraging strategy in which adults alternate between short and long foraging trips. (Schultz and Klomp 2000, Magalhães *et al.* 2008, Thalmann *et al.* 2009, Einoder *et al.* 2011, Berlincournt and Arnould 2015). Shearwaters are able to switch between these strategies as overfeeding of chicks after short trips leads to chick obesity which means they can withstand prolonged intervals between feeding when adults undertake longer foraging trips (Schultz and Klomp 2000). This strategy efficiently transfers energy to chicks whilst allowing adults to maintain required body condition. Movement data collected during the breeding season from shearwater species in Australasia show that short foraging trips tend to be undertaken in neritic waters whilst longer trips target areas of enhanced productivity such as sub-Antarctic oceanic fronts (Thalmann *et al.* 2009, Einoder *et al.* 2011, Berlincournt and Arnould 2015).

Preliminary abundance estimates of flesh-footed shearwaters at the two confirmed colonies in South Australia (Lewis and Smith islands) produced a combined estimated breeding abundance of ~3,300 pairs (Goldsworthy *et al.* 2013, Lavers *et al.* 2015). In light of recorded declines in abundance of the species at locations across its Australasian range (Priddel *et al.* 2006; Reid *et al.* 2012, Reid *et al.* 2013, Waugh *et al.* 2013, Lavers *et al.* 2015) and only preliminary data for the species in South Australia, further information is required to determine the number of breeding colonies in South Australia, and develop monitoring programs to establish baseline abundance estimates and to assess population trends.

10.4 Objectives

Key knowledge gaps for seabirds in the GAB region include baseline information on distribution, status and trends in abundance in the GAB region. The objectives of this study were to obtain baseline or updated abundance data for three seabird species at key breeding colonies in the GAB. The three species chosen have different movement and foraging ecology.

10.5 Methods

Crested Terns

Data collection and analysis

Ten islands were surveyed during the crested tern breeding season (November-February), based on available information regarding the location of breeding colonies in the GAB (Copley 1996; Goldsworthy and Page 2010, McLeay unpublished data) (Figure 10.1). Aerial photographs of colonies were taken from a helicopter at Nuyts Reef, Lounds Island, St Peter Island (all on 7 December 2015), Pigface Island, Rocky North Island, The Brothers (8 December 2015), Donington Rock (9 December 2015 and 3 February 2016), Liguanea Island, and North and South Neptune islands (3 February 2016) (Figure 10.1).

Aerial photographs were used to count the number of nesting crested terns observed at each island. A tern was classified as nesting if it was sitting firmly on the ground in proximity to large clusters of other nesting individuals. Standing birds were classified as nesting if either an egg or chick was visible in the photograph. Two crested terns with their wings outreached towards one another (courtship behaviour) were classified as a breeding pair. These surveys did not involve the handling or tagging of seabirds.

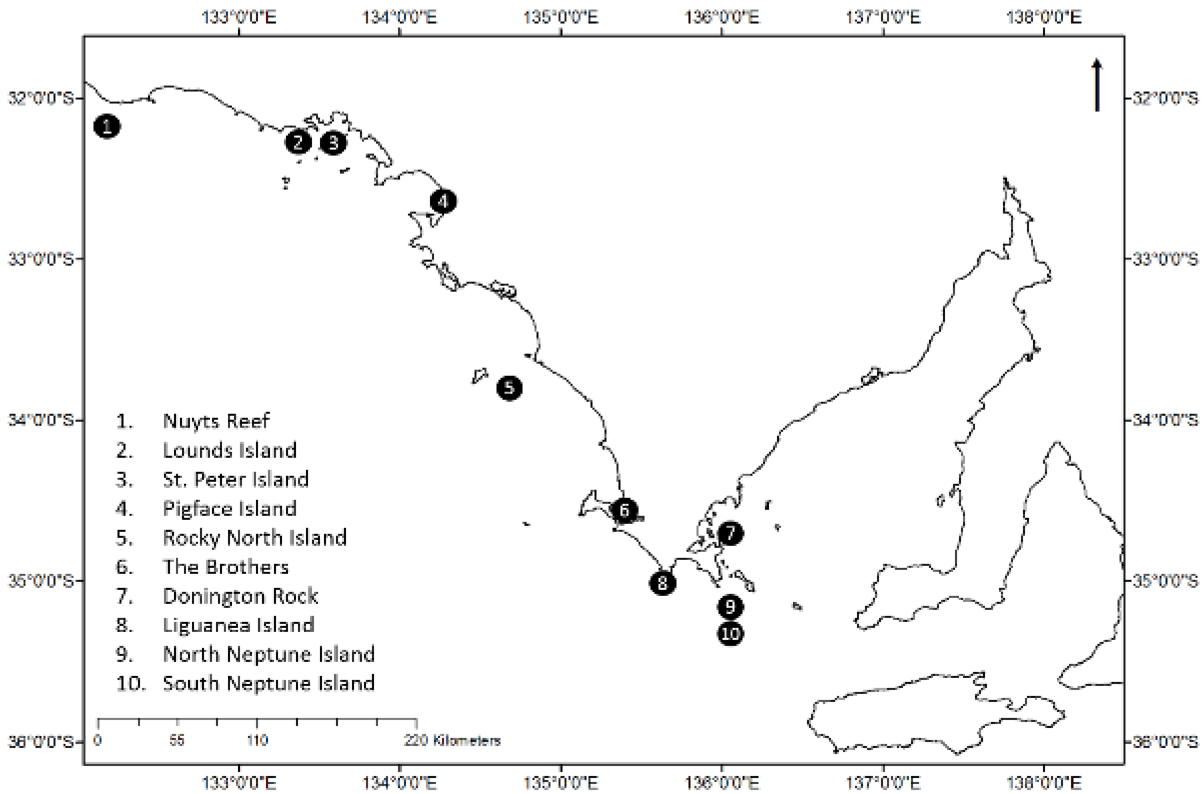

Figure 10.1. Location of crested tern breeding colonies in South Australia surveyed in December 2015 and / or February 2016.

Little Penguin

Surveys of little penguins were undertaken at two breeding colonies in the eastern GAB: Pearson Island and Olive Island. Methods of data collection and analyses are described separately for each colony. For estimates of burrowing seabirds, each active burrow represents two breeding individuals. These surveys did not involve the handling or tagging of seabirds.

Pearson Island

Pearson Island is predominantly granite with some areas of calcrete limited to two main lobes of the island with a total length of ~3.3 km that are connected by a narrow hummock in the middle. A survey of little penguin burrows was undertaken on 24–25 August 2013 on the southern lobe of Pearson Island which is ~1 km in length, 0.4 km wide and rises to 115 m above sea level at its highest point (Robinson *et al.* 1996). Two survey methods were used to estimate the number of breeding individuals; a full burrow count of the flat area of habitat on the northern end of the survey area (Section A), and a line transect survey of the steep slopes on the southern end of the survey area (Section B) (Figure 10.2). All burrows

were inspected and classified as active or inactive, and where burrow contents could be determined, the presence of adults and or chicks, and/or eggs was recorded. Burrows were classified as active by the presence of penguins or eggs, or through clear signs of recent activity such as feathers, faeces or footprints. All data were recorded in the field using the Fulcrum™ app.

Transects were spaced ~100 m apart and their length was determined by the presence of available penguin habitat. Each transect was 2 m in width, and ran perpendicular to the coastline in Section B (Figure 10.2). For each transect, the amount of unavailable burrow habitat (e.g. bare rock) was recorded. Circular plots were sampled at random locations between transect lines and a full count of little penguin burrows was conducted for each plot. The radius of circular plots was 7 m, following Sutherland and Dann (2012).

Burrow density was calculated for each transect by dividing the number of active burrows by the total surface area of that transect after areas of bare rock were excluded. The mean density of active burrows was used to estimate the total number of active burrows for Section B by extrapolation to estimated available burrow habitat. An estimate of total burrow density for Section B was also calculated using the same method and the mean density of active burrows recorded from circular plots.

Burrow densities estimated from the current survey were compared to densities recorded in Section B in 2004 (Wiebkin unpublished data). These densities were recorded from five quadrats, each measuring 50 x 50 m. The average burrow density recorded in 2004 was also extrapolated to the estimated area of available penguin nesting habitat in Section B to allow comparison between the two surveys.

Figure 10.2. Map of Pearson Island showing area of potential penguin habitat on the southern lobe of the Island (left). Zoomed image (right) shows the area where a full burrow count was undertaken (Section A) and location of surveyed line transects (Section B).

Olive Island

Olive Island is located ~ 6 km west of Cape Bauer near Streaky Bay, Eyre Peninsula, and is ~0.5 km in length by 0.3 km wide. The island has a granite base and perimeter, with a calcrete cap in the centre. A full burrow count was undertaken on 20 August 2013 and on 28 September 2014. The location of each burrow was recorded, and the burrow classified as active or inactive. Active burrows were determined by the presence of penguins, or through signs of recent activity such as feathers, faeces or footprints. Information on the presence of adults, chicks and eggs were noted and all data were recorded in the field using the Fulcrum™ app. The number of active burrows and burrow contents were compared to results of a full burrow survey at the site in 2006 (Weibkin unpublished data).

Flesh-footed shearwaters

Smith and Lewis islands are located ~2.5 km apart in Thorny Passage, in SW Spencer Gulf, and represent the only known breeding sites for flesh-footed shearwaters in South Australia (Goldsworthy *et al.* 2013, Lavers 2015). Methods of data collection and analyses are described separately for each colony. These surveys did not involve the handling or tagging of seabirds.

Lewis Island

Lewis Island is approximately 0.5 km in length and 0.3 km wide with a peaked summit rising to 39 m on its southern end (Robinson *et al.* 1996). Observations of flesh-footed shearwater activity during prior fieldwork on Lewis Island indicated that the calcrete cliff and slope areas of the eastern and southern perimeter of the island were an area with a high density of active burrows (SARDI unpublished data) (Figure 10.3). A full burrow survey of this habitat was conducted on 3 February 2016 and the total number of active burrows recorded (Figure 10.4a). Three transects were also surveyed on the top of the island in an area where shearwater burrows were present. Each transect was 10 m in width and ranged from 60-80 m in length (Figure 10.4a). Given the length of burrows, it was not possible to determine burrow contents.

Figure 10.3. Example of nesting habitat of flesh-footed shearwaters on Lewis Island, South Australia.

Smith Island

Smith Island is flat and covered with sandy surface soil. It is ~ 0.7 km in length and 0.3 km wide. Line transect burrow counts were undertaken of the top of Smith Island on 2 February 2016. Transects were 10 m wide and spaced ~80–100 m apart (Figure 10.4b). Transect length was determined by the area of available burrow habitat between the eastern and western coastline of the island. The total number of active burrows along transects was counted. Active burrows were determined by the presence of footprints, feathers or faeces. Given the length of burrows, it was not possible to determine burrow contents.

Burrow density was calculated for each transect by dividing the number of active burrows per transect area and extrapolating this to the estimated area of burrow habitat. The total number of active burrows was also estimated using a stratified extrapolation approach where the average burrow density of two neighbouring transects was extrapolated to the unsurveyed area between them.

Figure 10.4a. Map of Lewis Island, Thorny Passage, South Australia. Blue shading indicates areas where a full burrow count was undertaken. Pink lines indicate survey transect lines. Surveyed strip width of transects was 10 m. Data plotted on Google Earth.

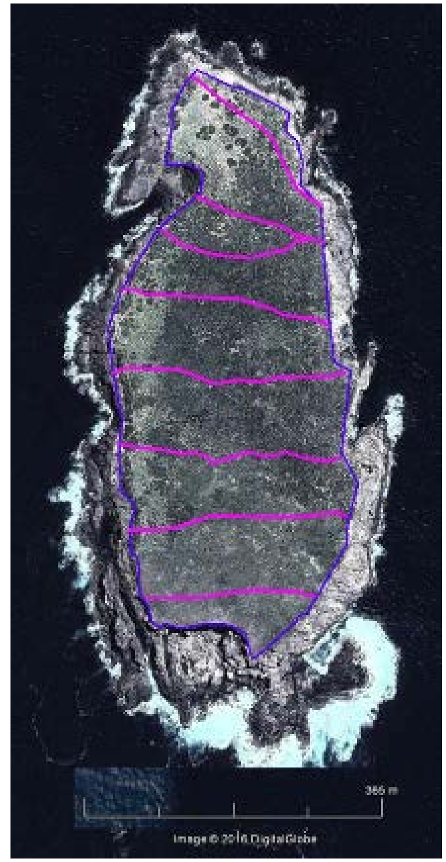

Figure 10.4b. Map of Smith Island, Thorny Passage, South Australia. Pink lines indicate survey transect lines. Surveyed strip width of transects was 10 m. The purple line indicates the extent of potential nesting habitat for flesh-footed shearwaters. Data plotted on Google Earth.

10.6 Results

10.6.1 Crested Terns

Ten islands were surveyed for nesting by crested terns between December 2015 and February 2016. Nesting of crested terns was recorded at six of them: Nuyts Reef, Lounds Island, The Brothers and Donington Rock in December 2015, and at North and South Neptune islands in February 2016. The number of nesting pairs of crested terns calculated from aerial photographs was 1,438 at Nuyts Reef, 3,119 at Lounds Island, and 428 and 408 at South and North Neptune Islands, respectively. Examples of aerial photos used to count nesting adults are provided in Figures 10.5 and 10.6.

Aerial photos of The Brothers Island taken on 8 December 2015 indicated that a small number of crested terns were nesting, but the low densities suggest that it was late in the breeding season, and the photographic resolution was not high enough to count nesting birds. Opportunistic photographs taken at Donington Rock on 9 December 2015 showed evidence of several hundred nesting terns, but the resolution of the photograph was not high enough to estimate the number of nesting pairs. Breeding had finished at Donington Rock when the island was resurveyed in February 2016. Crested terns were present at Liguanea Island when surveyed in February 2016, but it was not possible to determine if breeding was underway due to the low resolution of the photographs.

No crested terns were recorded at Pigface, Rocky North Island or St. Peters Island during surveys in December 2015.

Figure 10.5. Nesting crested terns on Nuyts Reef on 7 December 2015.

Figure 10.6. Nesting crested terns on Lounds Island on 7 December 2015.

10.6.2 Little penguins

Pearson Island

During the complete survey of Section A of the southern lobe of Pearson Island, 69 active burrows were recorded, producing an estimate of 138 breeding individuals.

For section B, 11 transects ranging in length from 83–251 m resulted in a total area surveyed of 3,846 m^2. The average proportion of solid rock in the surveyed area was 0.28, which varied between transects (0.14–0.40). Once areas of solid rock were removed, the estimated total area surveyed by transect was 2,762 m^2. In total, 36 active burrows were counted, with an average density of 0.012 m^{-2} (range 0 - 0.03 m^{-2}). The number of active burrows varied greatly both within and between transects, with many sections (~30m) having no burrows, either active or inactive, recorded. Applying the average density to the estimated total available penguin habitat in Section B (64,481 m^2), produces an estimate of 795 active burrows and 1,590 breeding pairs.

A total of 17 circular plots were surveyed, encompassing a total areas surveyed of 2,542 m^2. Each circular plot had a survey area of 154 m^2, with the exception of one plot which had an area of 79 m^2. In total, 23 active burrows were counted, with an average density of 0.01 m^{-2} (range 0.00 – 0.04 m^{-2}), producing an estimate of 614 active burrows and 1,228 breeding individuals, for the estimated area of penguin habitat in Section B. Therefore, the total estimate of breeding individuals for the surveyed areas of Section A and B are 1,366 to 1,728 breeding individuals.

It was not possible to determine the contents of 27% (34) of the 128 active burrows examined in Sections A and B. Of the remaining burrows, 45% (57) were empty and 29% (37) were occupied. Of these 73% (27) had an adult present, 16% (6) had a chick present and 11% (4) had an egg. For burrows occupied by an adult, it was not always possible to determine if an egg was also present.

In July 2004, a total of 492 active burrows were recorded from five 50 x 50 m quadrats surveyed on Pearson Island, producing an average density of 0.04 m^{-2} (Wiebkin unpublished data). Adults and/or chicks and/or eggs were present in 27 % (132) of active burrows, and 73% (364) were empty.

The exact locations of quadrats used in 2004 are unknown, but their general position in relation to transects undertaken in the current study was provided (Wiebkin pers. comm.). Table 10.1 presents the density of active burrows recorded in 2004 by Wiebkin (unpublished data), with the density recorded for sections of transects estimated to be those in closest proximity to the quadrat locations. The average density of active burrows from the quadrat surveys in 2004 was 0.04 m^{-2} compared to 0.027 m^{-2} for the corresponding sections of the transects (Figure 10.7), representing a 31% reduction in active burrow density between the two surveys. The range of burrow densities recorded by Wiebkin from five quadrats were also larger than from corresponding areas of transect recorded in 2013.

Applying the 2004 density of 0.4m^{-2} to the area estimated as penguin habitat in Section B results in a total estimate of 5,030 penguins for Section B. This is compared to 1,730 individuals for the same area if the average density of corresponding transect sections in 2013 was applied, which is equivalent to a 66% reduction in the number of breeding individuals. To estimate that there were 12,000 breeding individuals as per Weibkin (2011), the average density in 2013 of 0.04 active burrows m^{-2} would need to apply to an area of 150,000 m^2. Applying the average active burrow of 0.027 m^{-2} density to the same area provides an estimate of 8,100 breeding individuals.

Table 10.1. Densities of little penguins recorded at Pearson Island in 2004 from quadrat surveys and in 2013 from equivalent areas using transects.

2004 survey (250 m^2 quadrat) (Wiebkin unpublished data)		**Current Study in 2013**		
Quadrat number	Density m^{-2}	Corresponding portion of transect line	Area of transect section	Density m-^{2}
1	0.054	T5M1-T5M3	150 m^2	0.020
2	0.025	T10M5-T10M3	131 m^2	0.023
3	0.061	T6M3-T6M6	212 m^2	0.024
4	0.024	T11M1-T11M2	98 m^2	0.031
5	0.035	T8M6-T8M4	108 m^2	0.037
Average density m^{-2}	0.04			0.027

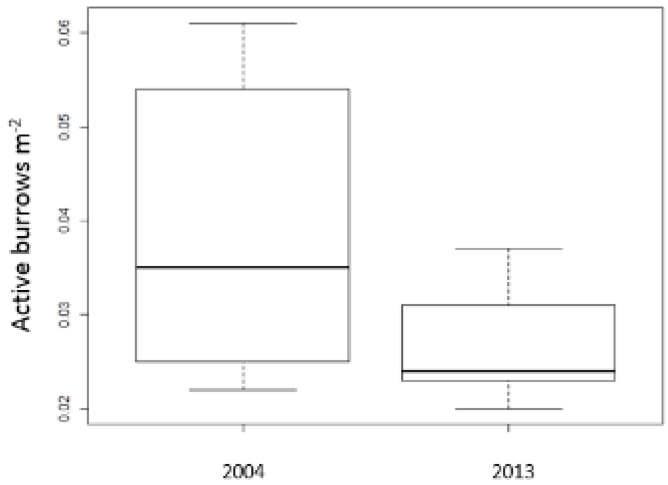

Figure 10.7. Density of active burrows (m^{-2}) of little penguins recorded from five locations on Pearson Island in 2004, and from similar areas in 2013. Dark line indicates the median, lower and upper boundaries of the box represent the 25th and 75th percentile, respectively, and upper and lower whiskers indicate the maximum and minimum values.

Olive Island

In total, 244 active burrows were counted on Olive Island in August 2013, producing an estimate of 488 breeding individuals. The burrow contents were determined for 52% (126) of active burrows, of which 59% (74) were empty, 37% (46) had adults present, 2% had chicks and 2% had eggs. Of the three chicks recorded, two were dead. In September 2014, a total of 90 active burrows were counted, producing an estimate of 180 breeding individuals. The burrow contents were determined for 82% (76) of active burrows, of which 51% (39) were empty, 45% (34) had adults present and 4% (3) had eggs with no adults present. Eight of the burrows with adults present also had an egg present. There was a marked difference in the number of active burrows counted in 2013 (244) and 2014 (91). Based on the timing of different breeding activities recorded from little penguin colonies in Gulf St Vincent (Figure 10.8), part of the difference is likely due to the timing of the surveys relative to the breeding season. The survey in September 2014 is likely to have been at the beginning of the second clutch, given no chicks were recorded.

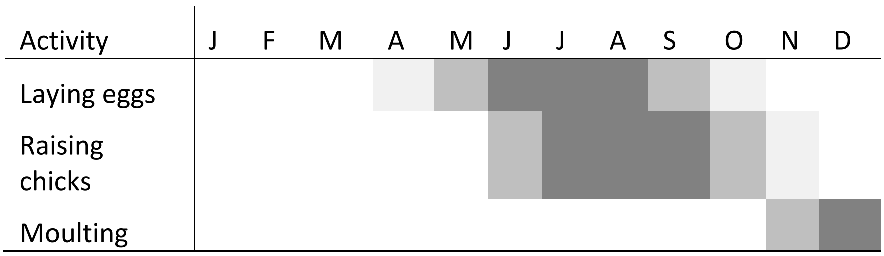

Figure 10.8. Timing of life history stages of little penguins during the breeding season at colonies in Gulf St Vincent. Darker shading indicates peak in breeding activity. Source: Wiebkin (2011).

In July 2006, a full burrow count was undertaken at Olive Island, and 1,145 active burrows were recorded providing an estimate of 2,290 breeding individuals (Weibkin, 2011). Less than half (43%)

of the active burrows were occupied, of which 22% had at least one adult present, 43% had at least one adult with an egg and 35% had at least one chick present.

Results of the surveys undertaken in the current study at both Pearson and Olive Islands have produced estimates of little penguin breeding abundance between 66% and 80% lower than the most recent abundance estimates for these two colonies (Figure 10.9).

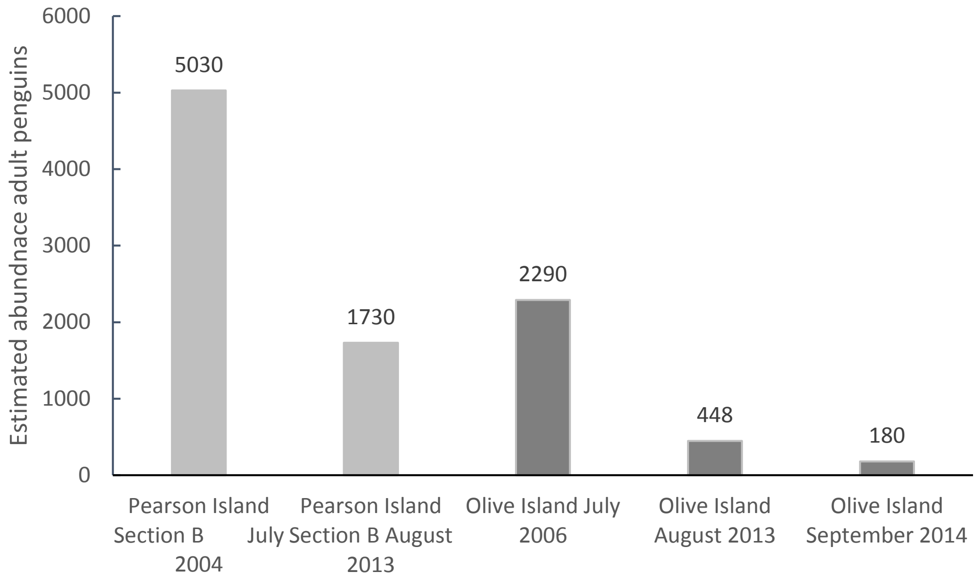

Figure 10.9. Comparison of estimates of total numbers of breeding adult little penguins for Pearson Island (Section B) and Olive Island from two separate surveys. Data collected in 2004 and 2006 are from Wiebkin (2011).

10.6.3 Flesh-footed shearwaters

Lewis Island

The occurrence of breeding flesh-footed shearwaters on Lewis Island was confirmed from photographs of chicks encountered during the survey. A total of 928 active burrows was counted along the coastal calcrete area of the island providing an estimate of 1,856 breeding individuals. For the small area surveyed with transects on the top of the island, the density of active burrows was 0.026 burrows m^{-2} (0.014 - 0.035 m^{-2}). Burrow density recorded from transects was not extrapolated to the area of potential burrowing habitat on top of the island because a previous survey of that part of the island recorded short-tailed shearwaters breeding sympatrically with flesh-footed shearwaters (Goldsworthy *et al.* 2013). To date, no short-tailed shearwaters have been observed nesting in the calcrete cliff area of the island where the full burrow count was undertaken (Mackay pers obs.).

Smith Island

The occurrence of breeding flesh-footed shearwaters on Smith Island was confirmed from photographs of chicks encountered during the survey. Eight transects were surveyed covering a total area of 18,060 m^2, and 821 active burrows were counted. This leads to an estimate of the density of active burrows of 0.039 m^{-2}. The total area of available burrowing habitat on Smith Island (excluding the rocky perimeter) was estimated at 148,329 m^2. Applying the mean active burrow density (0.039 m^{-2}) to the area estimated to be suitable for burrowing produced an estimate of 5785 active burrows and 11,570 breeding individuals. However, burrow densities from transects ranged from 0.03 to

0.098 m^{-2}, with lower densities recorded on the most northern and southern transects (0.010 m^{-2} and 0.003 m^{-2}, respectively) and higher densities recorded across the middle of the island (0.05 - 0.064 m^{-2}). To account for this gradient in burrow density when estimating the total number of active burrows, the mean burrow density of two adjacent transects was applied to the unsurveyed area between them. This leads to an estimate of the total number of burrows and of breeding individuals for all available habitat of 6,057 and 12,114, respectively. Although flesh-footed shearwaters were encountered on the island, burrows were not examined and it is possible that short-tailed shearwaters could also nest there.

10.7 Discussion

10.7.1 Crested Terns

Nesting crested terns were recorded at six of the ten surveyed islands: Nuyts Reef, Lounds Island, The Brothers, Donington Rock, and North and South Neptune islands. The largest breeding colony was recorded at Lounds Island (3,119 breeding pairs), then Nuyts Reef (1,438 breeding pairs) and then North and South Neptune islands (836 pairs combined). Breeding was recorded at Donington Rock in December 2015, but it was not possible to estimate the number of breeding pairs due to the low resolution of the photographs. Breeding had finished when the island was surveyed again in February 2016. Crested terns were present at Liguanea Island when surveyed in February 2016, but it was not possible to determine if breeding was underway due to low resolution photographs. Crested terns have previously been recorded breeding at Liguanea during February (SARDI unpublished data). The aerial surveys and photography enabled the presence or absence of terns at locations to be assessed rapidly.

Crested terns were not recorded breeding at two sites where they have previously been recorded, Pigface and Rocky North islands (SARDI unpublished data; Goldsworthy and Page 2010). It is possible that the timing of the aerial surveys did not match the breeding season at these locations. Although the timing of breeding within a colony is highly synchronous, the timing of breeding is asynchronous between colonies (Dunlop 1985). This means that multiple surveys are required to obtain an accurate count of total nesting birds at a colony. In addition, the number of nesting pairs varies during the breeding season and therefore multiple surveys are required within a season to ensure abundance is estimated during the time of peak nesting. While the minimum estimate of 428 breeding pairs at South Neptune from the current study was much lower than the most recent estimate of 2,000 to 3,000 breeding pairs in January 1993 (Copley 1996), it is not possible to determine when in the breeding season the current survey was conducted.

With the notable exception of the Troubridge Island breeding colony, most sites recorded in Copley (1996) have not been surveyed since the late 1960s to early 1990s. Since then, additional crested tern breeding sites have been identified at Lilliput Island (Shaughnessy 2007, Goldsworthy and Page 2010). Further surveys are required in order to determine if crested terns are still breeding at Pigface and Rocky North islands. Crested terns are known to move breeding colony locations and this is thought to be in response to localised prey abundance (Dunlop, 1985, Crawford *et al.* 2002). Surveys are also required to determine if breeding still occurs at other locations listed in the GAB region (Copley 1996) and understand the current distribution and breeding abundance of crested terns in the GAB. Crested terns are a key indicator species of ecological system functioning (Macleay *et al.* 2009), and future abundance and demographics at colonies across the range would provide information that could be used to monitor both population trends and ecosystem health.

10.7.2 Little Penguins

Little penguins have been recorded breeding on up to 40 islands within the GAB region, but over recent decades, populations at colonies across Gulf St Vincent and Investigator Strait have undergone substantial declines (Bool *et al.* 2007, Wiebkin 2011, Natural Resources Kangaroo Island 2013, Colombelli-Négrel 2015). On Granite Island for example, the penguin population has gone from 1,548 individuals in 2001 to 32 in 2014 (Wiebkin 2011; Colombelli-Négrel and Kleindorfer 2015). Similarly, across a number of sub colonies on Kangaroo Island, little penguin numbers declined by 41% between 2012 and 2013 (Natural Resources Kangaroo Island 2013). More recently, three key breeding colonies on Kangaroo Island, at Antechamber Bay, Emu Bay and Kingscote have undergone an 84% decline between 2011 and 2015 (Colombelli-Négrel 2015). The reasons for these declines are not fully understood (Wiebkin 2011; Colombelli-Négrel and Kleindorfer 2014, Colombelli-Négrel 2015, Copley 1996). In contrast, the colony at Troubridge Island in Gulf St Vincent appears to be stable (Wiebkin 2010, Colombelli-Négrel 2015). Trends in the abundance of little penguins from offshore islands in the GAB have been identified as key knowledge gaps, and could potentially provide critical context to determine if recorded penguin declines in Gulf St Vincent and Investigator Strait are localised or are occurring at a broader regional scale (Wiebkin 2011, Colombelli-Négrel 2015).

Pearson Island off the western Eyre Peninsula is reported as being the largest little penguin colony in the GAB region, with 12,000 breeding individuals estimated in 2004 (Wiebkin 2011). The burrow survey of little penguins in this study was the first undertaken on Pearson Island since 2004, and indicated that there has likely been a decline in the abundance of breeding individuals at the colony. However, it is difficult to determine the scale of this decline as there are a number of factors that confound direct comparison of the two surveys. These are differences in survey methods, timing of surveys within the breeding season and differences in areas of the island surveyed.

Applying the recorded density of active burrows in sampled areas (transect or circular plot) to the total area of available habitat is a commonly used method to estimate the total number of active burrows in seabird colonies. However, there are a number of factors that can lead to variability in estimates between years. These include variability in nest density across a colony, variability in occupancy rate during different stages of the breeding season, correct identification of active burrows and the assumption that each active burrow represents a breeding pair. Data collected in 2013 showed that the number of active burrows varied greatly both within and among transects, with many sections (~30 m) having no burrows recorded, either active or inactive. This suggests that some sections of transects likely extended outside potential penguin nesting habitat. Similarly, no burrows, active or inactive, were recorded in more than a third of circular plots.

The timing of breeding at little penguin colonies can vary between years (Nisbet and Dann 2009). The breeding season of little penguins in those colonies that have been sampled in the eastern GAB in South Australia has been shown to be prolonged and asynchronous both within and between colonies, and pairs may raise a second clutch within a breeding season (Johnston and Wiebkin 2008). This may be as a result of the year-round availability of anchovy in South Australia, which was the most frequently consumed prey in the diet of penguins sampled from eight colonies in the eastern GAB (Weibkin 2011). Movements of little penguins from colonies in Gulf St Vincent, Spencer Gulf and western Eyre peninsula were within 20–60 km of their colonies during the chick raising period (Bool *et al.* 2007, Goldsworthy *et al.* 2011, Wiebkin 2012). Asynchronous breeding can result in high variability in occupancy rates of penguins in burrows within a colony and, depending on when a burrow sampling survey is undertaken, this can lead to large underestimates of population size (Sutherland and Dann 2012). More accurate estimates of population size can be obtained by

undertaking repeat surveys at reference sites during the breeding season which can then be used to estimate occupancy rates across the season (Sutherland and Dann 2012). It was outside the scope of the current project to undertake multiple within-season surveys. The majority (74%) of active burrows recorded in 2004 were empty. In 2013, it was not possible to determine the contents of 27%, but of the ones in which contents could be determined, 45% were empty. Of those burrows that were occupied the majority (73%) had an adult present, 16% had a chick present and 11% had an egg. For burrows occupied by an adult, it was not always possible to determine if an egg was also present.

The current study also undertook full burrow count surveys of the Olive Island breeding colony in 2013 and 2014. This colony had last been surveyed in July 2006 when 1,145 active burrows were recorded, providing an estimate of 2,290 breeding individuals (Weibkin 2011). Estimates of little penguin abundance in the two surveys of the current study differed markedly: 488 breeding individuals in August 2013, and 182 breeding individuals in September 2014. Both estimates were much lower than the estimate made in 2006 (Weibkin 2011). The difference in estimated number of breeding individuals between August 2013 and September 2014 is most likely due to a difference in the timing of surveys relative to the stage of the breeding season. Sutherland and Dann (2012) noted that asynchronous breeding in little penguins can lead to high variability in the attendance rates of individuals that will then affect estimates of population size. The presence of chicks near fledging during the August 2013 survey compared to a higher number of adults recorded on eggs during the September 2014 survey may indicate that August/September represents the transition between the first and second clutch within the breeding season, and that neither survey was undertaken during the peak of breeding. Consequently, both recent surveys may have only recorded a portion of the total breeding population. The high proportion of active burrows where contents could not be determined makes it difficult to fully assess which part of the breeding season the surveys were undertaken in 2013 and 2014.

It is difficult to draw absolute conclusions on trends in little penguins at Pearson and Olive islands from previous surveys to those undertaken in 2013 and 2014, due to differences in survey methodology and the timing of surveys within the breeding season. However, given surveys at Olive Island in 2006, 2013 and 2014 all undertook full burrow counts, the results of the most recent surveys suggest a decline of 80% in the total number of breeding individuals. For Pearson Island, comparison of burrow density collected using different methods is difficult, but based on the decline in burrow density recorded in a similar area in 2004 and 2013, there may have been a decline in the number of breeding individuals of 66%. Given the apparent decline in little penguin numbers at both Pearson and Olive Island, there is a need for future systematic surveys to determine the status and ongoing population trends at these colonies.

Results of the current study, particularly with regards to uncertainties in comparing estimates with historical data, highlight the importance of ongoing monitoring of little penguin colonies at offshore islands within the GAB. In particular, there is a need to conduct ongoing standardised surveys of key breeding colonies to assess if these populations are in decline and if so, to identify potential drivers of these declines. Ongoing monitoring is also needed to determine if penguin declines recorded in Gulf St Vincent colonies are occurring at larger regional scales. As offshore islands like Pearson and Olive Island are not exposed to key terrestrial pressures from predation (Bool *et al.* 2007), habitat destruction or urbanisation (Wiebkin 2011), which have been implicated in declines in Gulf St Vincent colonies, they would provide the opportunity to assess other factors that may be impacting on penguin populations. Little penguins have been recorded in the diet of fur seals, but the relative occurrence has been found to vary between males and females (Page *et al.* 2005) and fur seal

colonies (Reinhold 2015). The influence of recovering marine predators on little penguin declines in South Australia is poorly understood. Predation pressure from recovering populations of long-nosed fur seals (*Arctocephalus fosteri*) at the Neptune islands and Kangaroo Islands has been implicated in the declines of little penguin populations in Gulf St Vincent and Investigator Strait (Bool *et al.* 2007). South Australia's largest long-nosed fur seal breeding colony, Cape Gantheaume, on Kangaroo Island has increased by a factor of 10.7 since the late 1980s (Goldsworthy and Shaughnessy 2016). Predation pressure by fur seals is a less plausible reason for the potential declines identified in this study at Pearson Island and Olive Island, as the long-nosed fur seal populations off western Eyre Peninsula are very small, with ten colonies producing approximately 400 pups annually (Shaughnessy *et al.* 2015). Understanding whether little penguin declines are occurring on key breeding islands within the GAB, with limited exposure to anthropogenic influences and stable seal populations, would help assess the role of these threats and inform long-term conservation strategies.

10.7.3 Flesh-footed Shearwaters

There are five broad regional breeding subpopulations of flesh-footed shearwaters: St Paul Island in the southern Indian Ocean, south-west Western Australia (Cape Leeuwin to Recherche Archipelago), South Australia, Lord Howe Island, and the North Island of New Zealand. The South Australian population is the least studied, and potentially the smallest. To date, that population is known to breed on two small islands in Spencer Gulf, Smith and Lewis Islands.

The current study estimated 928 and 5785 breeding pairs of flesh-footed shearwaters in February 2016 at Lewis and Smith islands, respectively. These estimates are substantially higher than previous estimates of ~300 and ~3,000 breeding pairs by Goldsworthy *et al.* (2013), or 211 ± 121 and 1,613 ± 924 breeding pairs by Lavers (2015). The higher estimates from the current survey are likely a result of differences in timing of the two surveys, and in survey and estimation methods. First, previous surveys were conducted in November 2011 which is likely very early in the breeding season based on data collected from colonies in Western Australia (Powell *et al.* 2007). Second, the current surveys counted active burrows, while the previous surveys counted all burrows and then applied an occupancy rate estimated from a colony in Western Australia to calculate the number of breeding pairs (Lavers 2015).

For Lewis Island, the main difference in estimates is likely to result from the different methodology used and difference in area surveyed. The current survey undertook a full count of active burrows in an area of calcrete cliffs which ring the south and south east of the island, and produced an estimate of 928 breeding pairs from this habitat. This area was previously identified as an area of high occupancy by breeding flesh-footed shearwaters (SARDI unpublished data). The mean burrow density was 0.026 m^{-2} (0.014 – 0.035 per m^{-2}), compared to a mean density of 0.009 ± 0.021 burrows m^{-2} reported by Lavers (2015) for 45 transects of the entire island. Lavers (2015) extrapolated to 64,000 m^{-2} of habitat identified as suitable for burrowing that excluded the rocky perimeter and then applied the mean burrow occupancy rate recorded at two islands in Western Australia to estimate a total population estimate of 211 ± 121 breeding pairs (Lavers 2015). Although the estimate from the current study is higher than the previous estimate, the estimate of total number of breeding individuals at Lewis Island from the current study may be an underestimate, as no account was made of the potential burrow habitat on the top of the island. This is because short-tailed shearwaters have been recorded to breed there sympatrically with flesh-footed shearwaters (Goldsworthy *et al.* 2013), and it was not possible to inspect burrow contents during the current survey. In contrast, all adults and / or chicks examined in the area of the calcrete cliffs during this

and two previous surveys were confirmed to be flesh-footed shearwaters (SARDI unpublished data). Further work is required to determine the extent and / or overlap of flesh-footed and short-tailed shearwater habitat on the top of Lewis Island.

For Smith Island, the estimate of breeding pairs was almost five times higher than recorded there in November 2011 (Goldsworthy *et al.* 2013, Lavers 2015). The mean burrow density reported by Lavers (2015) from 40 transects undertaken on the island in November 2011 was 0.033 ± 0.034 m^{-2}. This density was then applied to an estimated 134,000m^2 ha of suitable burrowing habitat and provided an estimate of 4362 ± 712 burrows. The mean burrow occupancy rate recorded at two islands in Western Australia was then applied to this estimate of total burrows and resulted in an estimate of 1,613 ± 924 breeding pairs (Lavers 2015). The current survey recorded a similar mean density of *active* burrows but estimated a slightly higher area of burrow habitat (148,329 m^2), producing an estimate of 5,785 to 6,057 active shearwater burrows. As noted by Lavers (2015), it was not possible to determine if all burrows belonged to flesh-footed shearwaters, or if some were short-tailed shearwater burrows. However, flesh-footed shearwater breeding was confirmed during the February 2016 survey by species identification of chicks.

Significant declines have been recorded for the flesh-footed shearwater population breeding at Lord Howe Island, with an estimated 19% decline in the number of active burrows from 1978 to 2002 (Priddel *et al.* 2006) and a further 8.5% between 2002 and 2009 (Reid *et al.* 2013). There is also evidence of declines in the population size of the species at some colonies in New Zealand and Western Australia (Waugh *et al.* 2013, Barbraud *et al.* 2014, Lavers 2015). Initial drivers of the decline recorded at Lord Howe Island were identified as loss of burrow habitat due to urbanisation (Priddel *et al.* 2006), and bycatch mortality in the Eastern Tuna and Billfish Fishery (ETBF) longline fishery in the Tasman sea. More recently, road kill on the island has been identified as a substantial source of current mortality (Reid *et al.* 2012). Flesh-footed shearwater chicks have also been shown to have ingested substantial amounts of plastics, but the impact of plastic ingestion on fledgling survival rates is unknown (Hutton *et al.* 2008). However, significantly reduced body mass was recorded in fledglings with increased plastic loads (Lavers *et al.* 2014).

Bycatch of flesh-footed shearwaters in their foraging range during the breeding season has been recorded for all Australasian colonies (Baker and Wise 2005, Abraham and Thompson 2011, Baker and Hamilton 2016). Given declines observed at Lord Howe Island, and at colonies in New Zealand and Western Australia, there is a need to determine the status of the South Australian breeding colonies, their foraging movements and genetic relatedness. This is particularly important given that the breeding colonies at Lewis and Smith islands could represent a closed subpopulation based on their geographic isolation from other colonies in Australasia. There is some indication that during the breeding season of the eastern populations from Lord Howe Island and three colonies in New Zealand each have a discreet foraging area (Thalmann *et al.* 2009, Rayner *et al.* 2011, Reid *et al.* 2011, Waugh *et al.* 2016). It is important to know the foraging overlap of individuals from South Australian colonies with State and Commonwealth fisheries to assess potential risk of bycatch. Shearwaters, not always identified to species, have been recorded as bycatch in longline, gillnet and purse seine operations (Knight and Vainickis 2011, AMFA 2016, Baker and Hamilton 2016). The impact of fisheries bycatch on flesh-footed shearwaters during their non-breeding distribution is unknown. Flesh-footed shearwaters tracked from Lord Howe Island migrated to the north-west Pacific Ocean to areas where they overlapped with longline fisheries, indicating the potential for bycatch risk to also impact at this time (Reid *et al.* 2013).

An understanding of the non-breeding distribution of individuals from the South Australian colonies is also required in order to identify potential drivers of population trends. It has been proposed that

there may be a migratory divide in the non-breeding distribution of flesh-footed shearwaters between colonies from eastern Australia and Western Australia. Flesh-footed shearwaters tagged at Lord Howe Island and in New Zealand have been shown to migrate to the North Pacific Ocean (Rayner *et al.* 2011, Reid *et al.* 2013). Information on the non-breeding distribution of flesh-footed shearwaters from Western Australian colonies is limited, but three individuals were tracked migrating north-westward towards the central Indian Ocean (Powell 2009). Movement patterns of flesh-footed shearwaters tracked from Lewis Island in South Australia showed a non-breeding distribution in the Bay of Bengal and Arabian Sea (SARDI *in prep*).

While the current study provided further estimates of breeding abundance for flesh-footed shearwaters at Lewis and Smith Islands, there remains a need to determine if the species breeds at any other locations in South Australia. Although a survey of the northern part of Hopkins Island did not detect breeding flesh-footed shearwaters, reports of breeding on Williams Island in the lower Spencer Gulf have yet to be verified (Goldsworthy *et al.* 2013). Given the proximity of Williams, and a number of other islands in the lower Spencer Gulf, to Lewis and Smith Island, there is potential for a number of other breeding colonies to occur.

10.7.4 Key Issues and Knowledge Gaps

The surveys undertaken in the project provide new and/or updated minimum estimates of breeding pairs for four crested tern colonies, two little penguin colonies and two flesh-footed shearwater colonies in the eastern GAB. Estimates of breeding population size are required in order to assess trends in populations, to identify and manage anthropogenic drivers of population changes and to enable these to be separated from underlying population fluctuations as a result of natural variability in the marine environment. While the current project generated new data for these colonies, there remains a paucity of information on population status or trends for most seabird species in the GAB region. Key knowledge gaps remain relating to timing of breeding, breeding success and foraging dynamics of most seabird species in the GAB region, and how these link to ecosystem health, fisheries and pelagic productivity.

Seabird bycatch has been recorded in both State and Commonwealth fisheries that operate in the GAB region (Knight and Vainickis 2011, AMFA 2016, Baker and Hamilton 2016). Interactions between seabirds and Commonwealth longline fisheries are managed through the Seabird Threat Abatement Plan (Commonwealth of Australia 2014), and seabird management plans for the Commonwealth GAB Trawl and South East Trawl sectors, and for the Southern and Eastern Scalefish and Shark Fishery. In the Western Australian South Coast Purse Seine Fishery, a code of practice was established in 2006 to reduce interactions with flesh-footed shearwaters (SeaNet 2008). Little penguin bycatch has been recorded in gillnets in Tasmania (Stevenson and Woehler 2007), and while a handful of records have been reported in South Australia, there is little information on interactions between this species and fisheries in the GAB region (Department of Environment, Water and Natural Resources 2016).

The impacts of pollution on seabirds can be immediate or chronic. Immediate impacts include entanglement in marine debris and direct mortality from oil spills. Chronic impacts of oil spills include the effects of ingested hydrocarbons on survival rate (Troisi *et al.* 2016). Plastic pollution is now ubiquitous in the marine environment (Cózar *et al.* 2014), and can impact marine wildlife through either entanglement or ingestion. Ingestion of plastics by seabirds has been recorded for a wide range of species and there are concerns about the population level impacts plastic ingestion may have (Wilcox *et al.* 2015). Ingestion of large items of plastic can result in death due to

obstruction or perforation of the digestive system (Hutton *et al.* 2008). Ingestion of small particles raise concern with respect to bioaccumulation of toxins as organic pollutants in the marine environment become concentrated in plastic fragments, and in micro plastics which are ingested up the food chain (Cózar *et al.* 2014). High levels of plastic ingestion by flesh-footed shearwaters have been recorded in fledglings from the Lord Howe Island colony, with poorer body condition in fledglings correlated with higher levels of plastic ingestion (Lavers *et al.* 2014). Habitat degradation, habitat loss and disturbance at breeding colonies can all impact reproductive success in seabirds (Priddel *et al.* 2006, Stevenson and Woehler 2007).

10.8 Conclusion

Further research is required to determine the breeding distribution and population size of seabird species in the GAB. In particular, for species that are known to be declining in some parts of their range, e.g. the little penguin and flesh-footed shearwater, more robust estimates of population size are required to ensure trends in abundance can be detected with future monitoring. For both species, estimates of population size at breeding colonies through accurate recording of burrow contents are required and multiple surveys within a breeding season should be undertaken. For crested terns, given the asynchrony in the timing of breeding between colonies, multiple surveys within a breeding season are required. Undertaking multiple surveys would also enable the breeding distribution of the species in the eastern GAB to be confirmed. Potential pressures of concern for seabirds that breed in the GAB region include fisheries bycatch, competition with fisheries, pollution and disturbance. Improved data on breeding abundance and distribution, and population trends of seabirds in the GAB will allow management agencies and regulators to better identify, assess and mitigate potential risks.

10.9 Appendices

Appendix 10.1. Summary of seabird breeding colonies in the GAB region. Data presented are summarised from Copley (1996) and Burbidge *et al.* (1996) with the exception of Crested Tern, Little Penguin and Flesh-Footed Shearwater species where abundances have been updated and references for these are given. Note the number of Fairy Tern colonies is a synthesis of Copley (1996) and the Department of Environment and Natural Resources 2012 status report of Fairy Terns in South Australia
(* represents the five Fairy Tern colonies previously recorded at Kangaroo Island by Copley (1996) that no longer exist).

No. Breeding Colonies by Region					
Region	**Cape Otway (VIC) to Encounter Bay (SA)**	**Kangaroo Island (SA)**	**Gulf St. Vincent and Spencer Gulf (SA)**	**Cape Catastrophe (SA) to WA border**	**Recherche Archipelgo to Bremer Bay (WA)**
Little Penguin	19	26	37	23	30
Flesh-footed Shearwater			**2**		25
Short-tailed Shearwater	1	1		33	5
Wedge-tailed Shearwater					2
White-faced Storm-Petrel		1	17	12	8
Great Winged-Petrel					11
Red-tailed Tropicbird			1		
Black-faced Cormorant	2	1	8-9	1+	3
Pied Cormorant	4-5	1	10-13		
Kelp Gull			1		
Pacific Gull	1	5	18	10+	15
Little Tern	1		1-2		
Bridled Tern	1				2
Crested Tern	9	5	19	2+	3
Caspian Tern	6-10	1-2	10-13	7+	9
Sooty Tern		1			
Fairy Tern	16	*	14	10	3

Appendix 10.2. Known breeding colonies and population estimates of crested terns in the Great Australian Bight region.

Breeding Colony	**Current estimate**	**Last**	**Source**	**Previous estimate**
Cape Otway (Vic) -Encounter Bay (SA)				
Baudin Rocks		1982	Copley (1996)	500 eggs
Penguin Island		1986	Copley (1996)	500 pairs
Halfway Island		1985-86	Copley (1996)	3865 nestlings banded
Stonywell Island		1983-84	Copley (1996)	2676 nestlings banded
West Island		1995	Copley (1996)	1500 pairs 1991-92 (Copley 1996)
Cattle Island	presence only	pre 1996	Copley (1996)	breed on the site
Cow Island	presence only	pre 1996	Copley (1996)	
Long (Bull) Island	presence only	pre 1996	Copley (1996)	
Wild Dog Island	presence only	pre 1996	Copley (1996)	
Kangaroo Island		**Last**	**Source**	**Comments**
North Islet, Casuarina Islands		1989	Copley (1996)	50-100 pairs
North Page Island		1993	Copley (1996)	100-1500 nests
Paisley Islet	presence only	1980	Copley (1996)	
South Islet, Casuarina Islets	presence only	1990's	Copley (1996)	
South Page Island	presence only	1993	Copley (1996)	

Appendix 10.2 (cont.). Known breeding colonies and population estimates of crested terns in the Great Australian Bight region.

Breeding Colony	Current estimate	Last	Source	Previous estimate
Gulf St. Vincent and Spencer Gulf				
Bird Island		1975	Copley (1996)	800 nestlings banded 1974-75
Brothers Islands	presence only	2015	This study	
Daly Head Island		1982	Copley (1996)	400 nests
Donnington Rock	several hundred	2015	This study	
Goose Island		1975-76	Copley (1996)	700 nestlings banded
Kirkby Island		1970-71	Copley (1996)	6 nestling banded 1971 - 380 nestlings banded 1966-67
Lighthouse Island		1982	Copley (1996)	500 breeding
Lipson Island		1986-87	Copley (1996)	790 nestlings banded
Lounds Island	3199	2015	This study	
Louth Bay		1982	Copley (1996)	40 breeding
North Neptune Island	408	2016	This study	630 nestlings banded 1966-67 (Copley 1996)
Nuyts Reef	1438	2015	This study	
Outer Harbour, Adelaide		1987	Copley (1996)	32 adults + 20 downy chicks
Rocky Island		1981	Copley (1996)	10 nests
Seal Island		1982	Copley (1996)	80 adults nesting
Seal Rocks	presence only	1981	Copley (1996)	
South Neptune Islands	428	2016	This study	2000-3000 pairs 1993 (Copley 1996)
Troubridge Island		1989	Copley (1996)	2500 pairs - note 2300 nestlings banded 1992-93
Ward Spit, Pt. Germein		1982-83	Copley (1996)	113 nestlings banded
Western Islets		1982	Copley (1996)	3000 nests
Winceby Island	presence only	1979-80	Copley (1996)	large breeding colony

Appendix 10.2 (cont.). Known breeding colonies and population estimates of crested terns in the Great Australian Bight region.

Breeding Colony	Current estimate (breeding pairs)	Last surveyed	Source	Previous estimate
Cape Catastrophe to WA border				
Brothers Island		2015	This study	650 nestlings banded 172-73 and 40 nestlings banded 1984-85 (Copley 1996)
Recherche Archipelago to Bremer				
Red Island		1992	Copley	5000-6000
Rocky Island	presence only	pre 1996	Copley	
Round Island		1990	Copley	1000-10000

Appendix 10.3. Known breeding colonies and population estimates of little penguins in the Great Australian Bight region.

Breeding Colony	Population estimate	Last	Source	Comments
Cape Otway (VIC) to Encounter Bay(SA)				
6km NW Cape Martin	presence only	1982	Copley (1996)	
Baudin Rocks	<60	2006	Wiebkin (2011)	200-600 in 1960-1992 (Copley 1996)
Cape Banks	16	2015	DEWNR 2016	Present in 1983 Atlas of
Cowrie Island	presence only	2016	DEWNR 2016	
Dog Island	presence only	1971	Robinson et al. (1996)	
Granite island	22	2015	Colombelli-Négrel (2016)	approx. 100-1000 in 1962-1992 (Copley 1996)
Griffiths Island	presence only		Andre Chiaradia pers comm	
Lady Julia Percy Island	4000	1981	Harris and Norman (1981)	
Lawrence Rocks	presence only		Andre Chiaradia pers comm	
Merri Island	presence only		Andre Chiaradia pers comm	
Middle Island	presence only	2015	Bourchier 2015	beach arrival counts
Penguin Island	19	2015	DEWNR 2016	present in 1970s (Parker et al. 1979)
Port Campbell	presence only		Andre Chiaradia pers comm	
Port MacDonnell	10	2016	DEWNR 2016	60 in 1970 (Cox 1978;
Portland Harbour	presence only		Andre Chiaradia pers comm	
Pullen Island	presence only	2016	DEWNR 2016	Breeding colony present in 1983 (Robinson et al. 1996)
Seal Island	presence only	2016	DEWNR 2016	Presence recorded in Atlas of Living Australia database 2002
West Island	0	2015	Colombelli-Négrel and Kleindorfer (2014), DEWNR 2016	4000 in 1992 (Copley 1996)
Wright Island	0	2013	Colombelli-Négrel and Kleindorfer (2014), DEWNR 2016	200+ in 1992 (Copley 1996)

Appendix 10.3 (cont.). Known breeding colonies and population estimates of little penguins in the Great Australian Bight region.

Breeding Colony	Population	Last	Source	Comments
Kangaroo Island (SA)				
American River	presence only	1970's	Parker et al. (1979)	
Antechamber Bay	10	2015	Colombelli-Negrel 2016	178 recorded
Beatrice Island	presence only	1918	White (1918)	
Breakneck river	presence only	1970's	Parker et al. (1979)	
Browns Beach	32	2008	Wiebkin	
Busby Islet	none	2014	C. Baxter unpubl. Data (2011-13)	40 recorded 1989 Copley(1996)
Cape Cassini	12	2013	KI NRM penguin census unpubl. data (2011-13)	116 recorded 2008 Wiebkin (2011)
Cape Gantheaume	none	2004	B. Page unpubl. data (2016)	100 1992 Copley (1996)
Cape Willoughby	116	2008	Wiebkin (2011)	presence in 1970 (Parker et. al 1979)
Cape Younghusband	presence only	1989	Copley 1996	
Emu Bay	102	2013	KI NRM penguin census unpubl. data (2011-13)	298 recorded in 2008 (Wiebkin 2011)
Harvey's Return	none	2006	Wiebkin (2011)	Present in 1970's (Parker et. al 1979)
Kingscote	128	2014	Kinloch et al. KINRM unpubl. Data (2006-2014)	
Maupertuis Bay	presence only	1970's	Parker et al. (1979)	
Nobby Islet	presence only	1982	Robinson et al. 1996	
North Page Island	presence only	1967	Copley 1996	
Pelorous Islet	presence only	1982	Robinson et al. (1996)	
Penneshaw	112	2013	KI NRM penguin census unpubl. data (2011-13)	365 recorded in 2008 (C. Gibbson unpubl. Data 2008)
Ravine des Cassoars	none	2006	Wiebkin 2011	presence in 1970's (Parker et al.
Rocky River	presence only	1970's	Parker et al. (1979)	
Seal Bay	none	2010	T. Souter	
Snellings Beach	4	2013	KI NRM penguin census unpubl. data (2011-13)	16 recorded 2008 (Wiebkin 2011)
South Page Island	10	2009	Wiebkin 2011	approx. 200-400 in 1984-1992
Stokes Bay	8	2013	KI NRM penguin census unpubl. data (2011-13)	60 in 2008 (Wiebkin 2011)
Vivonne Bay	68	2013	KI NRM penguin census unpubl. data (2011-13)	200 recorded 1989 (Copley 1996)
Western River Cove	0	2013	KI NRM penguin census unpubl. data (2011-13)	16 recorded 2008 (Wiebkin 2011)

Appendix 10.3 (cont.): Known breeding colonies and population estimates of little penguins in the Great Australian Bight region.

Breeding Colony	Population estimate	Last surveyed	Source	Comments
Gulf St. Vincent and Spencer Gulf (SA)				
Albatross Island	presence only	1982	Robinson et al. 1996	
Althorpe Island	84	2013	Colombelli-Negrel and Kleindorfer 2014	132 recorded in 2004 (Velzeboer and Shepherd 2004)
Blythe Island	presence only	1979	Robinson et al. 1996	
Boston Island	100	1982	Robinson et al. 1997	
Boucaut Island	presence only	1979	Robinson et. al. (1996)	
Curta Rocks - North	Large colony	1982	Robinson et. al. (1996); Copley	
Curta Rocks - South	Breeding colony	1982	Robinson et. al. (1996); Copley	
Dalby Island	presence only	1979	Robinson et. al. (1996)	
Duffield Island	Breeding Colony	1979	Robinson et al. (1996)	
English Island	0	2011	B. Page unpubl. data (2016)	Breeding colony present in 1980 (Robinson et al. 1996)
Franklin Islands (E and W)	2000	2004	Wiebkin (2011)	2000+ in 1986 Copley (1996)
Goose Island	20	2005	Wiebkin (2011)	Breeding colony present in 1981 (Robinson et al. 1996)
Green Island	Breeding colony present	1981	Copley (1996)	
Hareby Island	500	2008	Wiebkin (2011)	Presence in 1979 (Robinson et al. 1996)
Kirkby Island	Breeding Colony Present	1979	Robinson et al. (1996)	
Langton Island	Breeding Colony Present	1979	Robinson et al. (1996)	
Lewis Island	100	2006	Wiebkin (2011)	Breeding colony present in 1982 (Robinson et al. 1996)
Lipson Island	52	2011	DES (2011)	approx. 40-80 in 1965-1987 (Copley 1996)
Lusby Island	presence only	1979	Robinson et al. (1996)	
Marum Island	presence only	1979	Robinson et al. (1996)	
Middle Island	Breeding colony present	1982	Robinson et al. (1996)	
North Islet	none	2005	Breeding in 2005 (Goldsworthy and	

Owen Island	Breeding colony present	1982	Robinson et al. (1996)	
Partney Island	Breeding Colony Present	1979	Robinson et al. (1996)	
Rabbit Island, Pt Lincoln	Breeding colony present	1976	Robinson et al. (1996)	
Reevesby Island	1857	2009	Wiebkin (2011)	several 100 pairs in 1979-1980 (Robinson et al. 1996; Copley 1996)
Roxby Island	Breeding Colony Present	1979	Robinson et al. (1996)	
Royston Island	Breeding colony present	1982	Robinson et al. (1996); Copley (1996)	
Seal Island, Althorpe group	Breeding colony present	1982	Robinson et al. (1996)	
Sibsey Island	10	2004	Wiebkin (2011)	Breeding Colony Present in 1979 (Robinson et al. 1996)
Smith Island	presence only	1982	Copley (1996)	
Spilsby Island	100	2011	Wiebkin (2011)	few thousand in 2000-2005 (Wiebkin 2012)
Stickney Island	presence only	1979	Robinson et al. (1996)	ND
Thistle Island	Breeding colony present	1999	van Weenen (1999)	ND
Troubridge Island	1966	2013	Bool and Wiebkin (2013)	3000-5000 in 1966-1992 (Copley 1996)
Wardang Island	8000	2004	Lawley (2004)	
Wedge Island	100	2004	J. van Weenen unpubl. data (2004)	Breeding colony present in 1975 (Robinson et al. 1996)

Appendix 10.3 (cont.): Known breeding colonies and population estimates of little penguins in the Great Australian Bight region.

Breeding Colony	Population estimate	Last	Source	Comments
Cape Catastrophe (SA) to WA border				
Avoid Island (Sudden Jerk Is.)	presence only	1981	Copley (1996)	
Black Rocks	presence only	1981	Robinson et al. (1996); Copley (1996)	
Bunda Cliffs/Nullarbor Cliffs	100	2006	Wiebkin (2011)	
Dorothee Island	200	2004	Wiebkin (2011)	
Egg Island	presence only	1982	Robinson et al. (1996)	
Evans Island	500	2005	Wiebkin (2011)	
Eyre Island	presence only	1970's	Robinson et al. (1996)	
Fenelon Island	presence only	1982	Robinson et al. (1996)	
Flinders Island	20	2006	Wiebkin (2011)	
Four Hummocks	presence only	1980	Robinson et al. (1996)	
Freeling Island Nuyts Arch	presence only	1982	Copley (1996)	
Goat Island, off St Peter Island	presence only	1982	Robinson et al. (1996)	
Greenly Island	1500	2004	Wiebkin (2011)	Large numbers in 1948 (Finlayson 1948)
Lound Island	presence only	1982	Robinson et al. (1996)	
North Veteran Island	Breeding colony present	1980	Copley (1996)	
Olive Island	448	2013	This study	2290 in 2006 (Wiebkin 2012)
Pearson Island Group	12000	2006	Wiebkin (2011)	many in 1976 (Parker and Cox 1978)
Pearson Island	1366-1728	2013	This study	Breeding individuals
Rabbit Island, Coffin Bay	Breeding colony present	1976	Robinson et al. (1996)	
St Francis Island	presence only	1971	Robinson et al. (1996);	
St Peter Island	1000	2005	Wiebkin (2011)	Breeding Colony Present in 1982 (Robinson et al. 1996; Copley 1996)
Waldegrave Island	500+	2006	Wiebkin (2011)	600+ in 1991 (Copley 1996)
West (Little) Waldegrave island	Breeding colony present	1980	Robinson et al. (1996)	

Appendix 10.3 (cont.): Known breeding colonies and population estimates of little penguins in the Great Australian Bight region.

Breeding Colony	Population estimate	Last surveyed	Source	Comments
Recherche Archipelago to Bremer Bay (WA)				
Bellinger	presence only	pre 1996	Smith, L.E. and Johnstone, R.E (1987)	
Boxer Island	presence only	pre 1996	Copley	
Breaksea	presence only	1990	Copley	100-200 pairs 1978 (Copley 1996)
Charley Island	presence only	1981	Copley	
Cull	presence only	1992	Copley	30-40 pairs (Copley 1996)
Daw Island	presence only	pre 1996	Copley	
Doubtful Island	presence only	1978	Copley	
Figure of Eight Island	presence only	1981	Copley	
Forrest	presence only	1986	Copley	2 pairs (Copley 1996)
Goose	presence only	1998	Johnstone et al. 1998	
Hood	presence only	pre 1996	Copley	
Inshore	presence only	1986	Copley	a few pairs (Copley 1996)
Kermadec	presence only	pre 1996	Johnstone et al. 1998	
Lorraine Island	presence only	1983	Copley	a few pairs (Copley 1996)
MacKenzie Island	presence only	1981	Copley	7 pairs (Copley 1996)
Marts	Presence only	1998	Johnstone et al. 1998	
Mondrain Island	presence only	1981	Copley	
North Twin Peak	Presence only	pre 1996	Copley	
Observatory	presence only	1981	Copley	11-100 (Copley 1996)
Ram Island	Presence only	1981	Copley	2-10 pairs (Copley 1996)
Remark	presence only	1981	Copley	2-10 pairs (Copley 1996)
Rob	presence only	pre 1996	Copley	
Round Island	Presence only	pre 1996	Copley	
Salisbury	presence only	1992	Copley	
Sandy Hook	presence only	pre 1996	Copley	
Station	presence only	pre 1996	Copley	
Termination	presence only	pre 1996	Copley	
Westall	presence only	pre 1996	Copley	
Wickham	presence only	pre 1996	Copley	
Woody	presence only	pre 1996	Copley	

Appendix 10.4: Known breeding colonies and population estimates of flesh-footed shearwaters in the Great Australian Bight region.

Region	Population	Last surveyed	Source	Comments
Recherche Archipelago to Bremer Bay				
Ben Island	Presence only	No date	Copley (1996)	
Boxer Island	Presence only	No date	Copley (1996)	
Canning Island	100-500	1982	Copley (1996)	
Charley Island	5001-1000	1982	Copley (1996)	
Corbett Island	Presence only	No date	Copley (1996)	no date = pre 1996
Daw Island	Presence only	No date	Copley (1996)	
Figure of Eight Island	Presence only	1950	Copley (1996)	
Frederick Island	87-209 (148±61)	2012	Lavers (2015)	500-1000 burrows 1981 (Lane 1982)
Gulch Island	0	2014	Lavers (2015)	2000 burrows recorded 1987 (Johnstone and Smith
Gunton Island	11	2012	Lavers (2015)	A few pairs recorded 1985 (Storr 1991)
Harlequin Island	15-200	No date	Copley (1996)	
Little Island	Presence only	1990	Copley (1996)	
MacKenzie Island	Presence only	1981	Copley (1996)	
Mondrain Island	Presence only	1976	Copley (1996)	
North Twin Peak Island	Presence only	No date	Copley (1996)	
Ram Island	100-500	1981	Copley (1996)	
Renmark Island	100-500	1981	Copley (1996)	
Round Island	Presence only	No date	Copley (1996)	
Sandy Hook Island	<200	2012	Lavers (2015)	
Thomas	Presence only	No date	Copley (1996)	
Woody Island	60-142	2012	Lavers (2015)	117±98 pairs recorded 2000-2003 (Powell et al.
Wickham Island	0	2012	Lavers (2015)	8000 burrows recorded previously (Johnstone and
Goose Island	0	2012	Lavers (2015)	250 burrows recorded in 1985 (Storr 1991)
Cliff Island	Presence only	no date	Copley (1996)	
Long Island	500	2014	Lavers (2015)	Presence recorded 1981 (Lane 1982d)
Owen	2000	2014	Lavers (2015)	
Rabbit	Presence only	no date	Copley (1996)	
South Twin Peaks	Presence only	no date	Copley (1996)	

Appendix 10.4: Known breeding colonies and population estimates of flesh-footed shearwaters in the Great Australian Bight region.

Region	Population estimate (breeding pairs)	Last surveyed	Source	Comments
Gulf St. Vincent and Spencer Gulf				
Lewis Island	928	2015	This study	
Smith Island	6721	2015	This study	

11. GENERAL DISCUSSION

11.1 The vision: addressing scientific knowledge gaps for iconic species and apex predators

The GAB region has been identified as critical habitat for a range of apex predator species, and has been suggested to support the greatest density and biomass of these species in coastal Australian waters (Goldsworthy *et al.* 2013, Rogers *et al.* 2013). However, basic information on the distribution and relative abundance of many key iconic and apex predator species in the GAB is limited, hampering our understanding of why this region is important to these species. This is especially pertinent for threatened, endangered and migratory species (matters of national environmental significance), other listed species, and listed marine and cetacean species, where there are requirements under the *EPBC Act* to manage and mitigate the potential risks to them from human activities and impacts.

Theme 4 of the GAB Research Program, *Ecology of Iconic Species and Apex Predators* sets out to address key knowledge gaps (Rogers *et al.* 2013). Baseline information on species' distribution, status and trends in abundance in the GAB region was identified as the critical gap for iconic species and apex predators (Rogers *et al.* 2013). Project 4.1 *Status, distribution, and abundance of iconic species and apex predators in the GAB*, explicitly addressed this gap by undertaking a range of surveys using multidisciplinary methods to assess the status, distribution and abundance of key species in the GAB region. These included inshore and offshore aerial and offshore vessel-based acoustic and visual surveys for cetaceans, offshore pelagic long-line-based surveys incorporating satellite telemetry of pelagic sharks, and ground and aerial surveys on offshore islands to assess the status and trends in abundance of pinnipeds and some seabird species.

11.2 Summary of achievements and highlights

The project made significant advances in improving our knowledge about the occurrence and distribution of short-beaked common dolphins and other cetaceans that use inshore habitats; the occurrence and distribution of baleen and toothed whales in offshore shelf, shelf-break and slope habitats; in characterising the spatial and temporal distribution and habitat use of pelagic sharks; and in assessing the abundance of pinnipeds and some seabird breeding populations on off-shore islands.

During the inshore cetacean aerial survey in eastern GAB coastal and shelf waters, five species of cetacean were identified, including southern right whales, humpback whales, minke whale, short-beaked common dolphins, and schools of bottlenose dolphins (*Tursiops* spp.). Short-beaked common dolphins were particularly abundant, with estimates of 20,000 – 22,000 individuals (0.67 – 0.73 dolphins/km^2) in the survey area, indicating that shelf waters of the eastern GAB represent important habitat for this species.

There were 58 cetacean sightings recorded during three offshore aerial surveys (~10,000 km transects representing ~100,000 km^2 surveyed) in the eastern and central GAB. Eight cetacean species were identified: pygmy blue whales, fin whales, sperm whales, pilot whales, killer whales, Risso's dolphins, short-beaked common dolphins, common or offshore bottlenose dolphins, and a probable beaked whale. Although blue whales were not sighted in the eastern GAB or south of Kangaroo Island, they were sighted along the Bonney Coast between Robe and Portland. Sightings of sperm whales, pilot whales, killer whales, Risso's dolphins, likely beaked whales and a fin whale were

concentrated in upper slope waters (160–200 m depth contours), with sperm whales mostly sighted in deeper, steeper terrain, while pilot whales, killer whales, Risso's dolphins, and likely beaked whales were in shallower, less steep terrain. In contrast, dolphin sightings were widely distributed in shelf and upper slope waters, from close inshore to just offshore of the shelf break. Killer whales are little known along Australia's southern coast, with only 6 sightings recorded over 12 years during aerial surveys (Gill *et al.* 2015). One group sighted equalled the largest group reported by Gill *et al.* (2015), and included a calf.

The offshore visual and acoustic survey encompassed an area of the eastern GAB that had previously not been systematically surveyed for cetaceans. Although survey effort was restricted due to bad weather, odontocete (toothed whale) vocalisations were detected during 15 discrete acoustic events that were recorded during 141 hours of passive acoustic monitoring. Sperm whales were acoustically detected on four occasions comprising a total of nine individuals. Two sperm whale acoustic events contained a single individual, one event contained three individuals and one event contained four individuals. Sperm whale encounters occurred in water depths between 500 and 2000 m. Four sighting events were recorded during 56 hours of visual effort which included three sperm whales from two encounters, one group of 100-150 pilot whales, and a beaked whale. Maximum entropy modelling was used to predict suitable sperm whale habitat in the GAB region using presence only data.

The offshore pelagic shark survey used a combination of pelagic long-line and satellite telemetry methods, with seven long-line sets undertaken over a 15-day period between the du Couedic Canyon, south-west of Kangaroo Island, and the continental shelf-break area south of Head of Bight. Five pelagic and oceanic shark species belonging to four families were recorded, including blue sharks, shortfin makos, common thresher, bigeye thresher and school sharks. White sharks were encountered at the Neptune Islands. The highest number and diversity of pelagic shark species encountered during the offshore long-line survey was at the du Couedic Canyon, one of the most significant bathymetric features in the region. At du Couedic Canyon, a large multiple predator species foraging aggregation was observed at the surface directly adjacent to the shelf-break and canyon head wall, including nine species of seabirds, pinnipeds (Australian fur seals), and cetaceans. Fourteen satellite tags were deployed on four shark species: blue shark (7) shortfin mako (1), white shark (5) and a single bigeye thresher. Analyses of movement data indicated that all species traverse widely, but all had significant focal areas in the GAB, and there was evidence of species-specific preference for different habitats and depth ranges. The occurrence of the predominantly subtropical and tropical species, the bigeye thresher in the GAB, and its subsequent migration through the south-east Indian Ocean to tropical waters off Exmouth (first tracking study for this species in Australia), Western Australia was a significant new scientific discovery. Deployment of bio-logging equipment on this shark and the data collected advanced the knowledge of the distribution of this rare, nocturnal oceanic predator.

The project compiled the most comprehensive synthesis of recent and historic surveys of pinniped populations throughout the GAB region, including trends in their abundance. The study highlighted that the GAB region is important for Australia's pinniped biodiversity, with significant populations of all of Australia's three resident mainland species occurring here: Australian sea lion, long-nosed fur seal and Australian fur seal. The region is especially important for the Australian sea lion and long-nosed fur seal, with an estimated 93% and 98% of each species' Australian populations occurring here, respectively. The population status of both species contrasts markedly, with Australian sea lion populations in low abundance and declining across their range, while long-nosed fur seal populations have undergone a major recovery and growth over the last 30+ years. Australian fur seal

populations are centred on Bass Strait, with only about 18% in the GAB region, however the western extent of the species range has recently expanded into the eastern GAB region off South Australia. For all species there is a marked geographic skew in their population distributions, with the eastern GAB region containing more than 80% of the Australian sea lion and long-nosed fur seal populations, and Bass Strait containing more than 80% of the Australian fur seal population. The study identified that while populations of both fur seal species have largely recovered or are in the latter stages of recovery (following early colonial sealing which ended almost 190 years ago), populations of the threatened Australian sea lion are smaller than previously estimated and presently undergoing a rapid decline. This level of decline across the GAB region was estimated to be equivalent to a 76% decline over three generations (~38 years), meeting the IUCN criteria for 'Endangered' (>505 and <80% decline over three generations). Of significant concern is the finding that almost 40% of individual breeding sites of this species assessed across the GAB region meet the 'Critically endangered' IUCN criteria (>80% decline over three generations).

The project collected abundance data on three key seabird species at some of their offshore island breeding sites. The three focal species included seabirds from three distinct foraging guilds: crested terns (resident surface plunge divers); little penguins (resident non-flying diving seabirds); and flesh-footed shearwater (highly migratory near surface forager). Crested tern breeding colonies were surveyed using aerial photography during the nesting period, the study providing the first abundance estimates for Lounds Island (3,119 breeding pairs) and Nuyts Reef (1,438 pairs), and the first estimates of breeding abundance at North Neptune Island (408 pairs) and South Neptune Island 428 pairs) since 1967. Little penguins were surveyed at two important breeding sites off the western Eyre Peninsula (Olive and Pearson Island) using a combination of burrow transects, census plots and direct burrow counts. These surveys were compared to similar surveys undertaken in 2004. Notwithstanding the significant challenges in interpreting results using different survey methods and potential differences in the timing of surveys relative to the peak of breeding, the comparison suggests a potential decline of 80% and 66% since 2004 at Olive and Pearson Islands, respectively. Flesh-footed shearwaters were surveyed using burrow transects and direct burrow counts at their only known breeding sites in the eastern GAB. The surveys estimated 928 and 5,785 breeding pairs at Lewis and Smith Islands, respectively, representing the first quantitative surveys for this species in South Australia.

11.3 Challenges and opportunities

The GAB region is very large and remote, making access to its shelf, slope and oceanic waters and offshore islands logistically challenging and costly. These challenges have greatly limited the development of basic knowledge about the status, distribution, key habitats and abundances of iconic species and apex predators in the region, and underpin why there is such a dearth of basic information and baseline data on many of the region's key species. This study has compiled the most comprehensive synthesis of the status, distribution and abundances of iconic species and apex predators in the GAB to date. Yet for many, if not most of the species, the basic information is still rudimentary or absent. The absence of baseline data presents a major challenge for the management of these species, many of which are matters of national environmental significance, because for most we cannot assess if their distribution and abundance have changed over time, or the extent and significance of impacts from past, present and future human activities on their status and persistence.

The paucity of information on these species, presents an enormous challenge and an opportunity to address key knowledge gaps, especially baseline information on species distributions, abundance,

status, trends and key habitats. These are identified in broad terms for the key iconic and apex predator species groups below.

With respect to cetaceans, for many species there exists only basic knowledge on the general biodiversity of the region. Many of the 27 species recorded in the GAB (Kemper *et al.* 2005) have extensive oceanic distributions, and are rarely sighted. Even for species that frequent and breed in coastal waters (e.g. common and bottlenose dolphins, southern right whale), there is limited baseline information on their distribution, population structure, abundance and trends (Bannister 2011; Möller *et al.* 2012; Bilgmann *et al.* 2014). The aerial inshore surveys conducted between Ceduna and Coffin Bay as part of this study have provided the first assessment of the abundance of common dolphins in that area, and add to recent surveys undertaken in Spencer Gulf, Gulf St Vincent and the Investigator Strait (Möller *et al.* 2012). There are opportunities to undertake similar surveys across the remainder of the GAB region to assess the distribution and abundance of dolphin species for which there are presently no data. Comprehensive surveys across the entire GAB region, and different seasons would improve our understanding of overall abundance, and how abundance varies across the region (identifying critical areas/habitats) and by season. For southern right whales, long-term aerial surveys of the south-western subpopulation (WA to Ceduna, SA) have shown a significant increase in abundance of 6.8% per year between 1993 and 2010 (Bannister 2011). The south-eastern subpopulation has not shown the same level of recovery and is relatively depleted (Pirzl 2008). Despite the importance of the GAB as the most significant calving ground for the species in Australia, there is limited data available on the population size and vital rates. A recent pilot study using aerial helicopter surveys and photography to monitor the main calving ground at the Head of Bight demonstrated this approach as an efficient and effective way to monitor the size, survival and reproductive rates of this population (Mackay and Goldsworthy 2015). It presents an opportunity to improve our basic understanding of this endangered and key iconic species in the GAB region.

For slope and oceanic cetacean species, our basic information on species distribution, key habitats and relative abundance remains poor. The offshore aerial cetacean surveys undertaken as part of this project were only the second ever to be undertaken in slope waters west of Kangaroo Island. Similarly, the offshore passive acoustic surveys undertaken in this project provided the first systematic surveys for odontocete whales from previously un-surveyed areas in the eastern GAB. From previous aerial surveys, it appears that at certain times the eastern GAB waters are a more important foraging ground for pygmy blue whales than waters of the Bonney Upwelling (Cape Jaffa to Cape Otway) (Gill *et al.* 2011). Although no pygmy blue whales were sighted west of Kangaroo Island in offshore aerial surveys undertaken in the GAB Research Program, it is clear that there is marked seasonal and annual variability in the pattern of use of the GAB region by pygmy blue whales and potentially other cetacean species. There is an opportunity with further aerial and passive acoustic surveys to improve our understanding of the temporal and seasonal pattern of use of the GAB region by pygmy blue whales and other cetaceans, and the oceanographic and environmental circumstances when the region provides important foraging habitat. Furthermore, results from the vessel-based passive acoustic surveys suggest that the eastern GAB provides important habitat for many odontocete species (e.g. sperm whales, pilot whales and beaked whale species), and an opportunity exists with further surveys of these shelf-break and slope habitat odontocete communities to develop baseline data on species distribution, key habitats and relative abundance.

For pinniped and seabird populations that breed in the GAB region, the potential to obtain good information on their distribution, abundances, status and trends is unprecedented relative to other iconic and apex predator species, because they are conspicuous and breed on land, and metrics of

their relative abundance (e.g. pup production, breeding pairs) are generally readily assessable. However, as most breeding sites are on offshore islands, access can be logistically challenging and costly. Among the iconic and apex predator species in the GAB, information on the status, distribution and abundance of the three resident pinniped species, Australian sea lions, long-nosed and Australian fur seals, is the most current and complete. This project was able to synthesise existing survey data sets for each species (Kirkwood *et al.* 2010; Shaughnessy *et al.* 2011; Campbell *et al.* 2014; McIntosh *et al.* 2014; Shaughnessy *et al.* 2014; Goldsworthy *et al.* 2015), and for some sites, augment with additional survey data to present the most complete assessment of the distribution, abundance and trends in populations of these species in the GAB region. For long-nosed fur seals and Australian fur seals, growth and population recovery over the last several decades are encouraging. However, for the Australian sea lion there are significant concerns about the status and trends in its populations, which are smaller than previously estimated and are declining rapidly. As a listed threatened species, Australian sea lion are a matter of national environmental significance, and ensuring that sufficient and effective monitoring is in place across the range of the species is a key priority of the species recovery plan (DSEWPaC 2013). Given that national funding for all pinniped monitoring ceased in 2014, there is a significant challenge to maintain the monitoring of key populations in SA, and improve the baseline data on the status of the species off the south coast of WA. Furthermore, given the unprecedented management measures introduced to mitigate the risks from bycatch mortality in the demersal gillnet fishery off SA (AFMA 2015), there is an opportunity (and need) to assess the extent to which these measures have been effective and adequate, and identify if there are other factors that may be contributing to lack of recovery in the species.

One of the poorest understood groups of apex predators in the GAB region are the seabirds. For most species, there is only rudimentary data on species distributions, and little or no quantitative data on their abundances. Even for abundant and widespread species that breed in the GAB region, such as short-tailed shearwaters and white-faced storm petrels, there are no quantitative estimates of abundances for any breeding sites, and no means to assess if there have been large scale changes in their abundance over time. As migratory and listed marine species, both short-tailed and flesh-footed shearwaters are matters of national environmental significance. Declines in the abundance of flesh-footed shearwater populations have been observed at Lord Howe Island, and at some colonies in New Zealand and WA (Priddel *et al.* 2006; Reid *et al.* 2013; Waugh *et al.* 2013; Barbraud *et al.* 2014; Lavers 2015). We made the first quantitative estimates of the two SA breeding sites, and there is a need to undertake further surveys to determine their status and trends in abundance, their foraging movements and migration paths, and their genetic relatedness to other subpopulations. This is particularly important given that the breeding colonies at Lewis and Smith islands could represent a closed subpopulation based on their geographic isolation from other colonies in Australasia. For the two focal coastal seabirds (little penguins and crested terns), there is a need to improve information on the distribution of breeding sites, and the size of their populations. Given the marked decline that has been observed in some little penguin populations off the lower Fleurieu Peninsula and Kangaroo Island in recent decades, the additional inferred declines on two offshore islands off the western Eyre Peninsula in this study should provide further impetus to prioritise baseline surveys and further research on this species across the GAB to assess the extent of, and potential causes, for declines.

Because central-place foraging predators (seabirds and pinnipeds) raise offspring on land, the availability of key prey resources near their breeding colonies at key times (e.g. incubation and chick rearing in seabirds, lactation in pinnipeds) is critical to their reproductive success and the longer-term sustainability and maintenance of their breeding populations. As such, the monitoring of their

populations, including their foraging behaviour and breeding success, presents an opportunity to use these species as indicators of change of the marine ecosystems they depend on. This dependency on near-colony prey resources at certain locations and times makes central-place foraging seabirds and seals responsive to changes in prey availability, which have been shown to impact their foraging behaviour, reproductive performance and survival (Croxall *et al.* 1988, Rindorf *et al.* 2000, Boyd and Murray 2001, Boyd *et al.* 2006, Daunt *et al.* 2006, Hamer *et al.* 2006). Some impacts can be short-term (within a breeding season impacting chick/pup growth rates, survival, fledging/weaning success), or longer-term (broader demographic impacts on survival, recruitment, fecundity, age-structure, population growth rates and size). Monitoring the state and health of large marine domains such as the GAB region presents a considerable challenge. Central-place foraging seabirds and seals that breed on land, present an opportunity to be used as biological indicators of change and health of the marine ecosystems on which they depend. Building such ecological performance indicators into a management and monitoring framework for the GAB region presents an important challenge and opportunity.

This study has demonstrated that the GAB region is important for highly migratory species of pelagic sharks. Satellite tracking data indicate that for many of these species, the GAB represents core foraging habitat to which species return year after year, suggesting that it provides a predictable and reliable source of food. Outside these times, species may migrate to neighbouring seas in the Indian, Pacific and Southern Oceans, where they may also be subject to threatening processes. This dynamic and constant movement of animals through the GAB creates challenges in terms of understanding the importance of the GAB region, and for ensuring appropriate timing of surveys or other ecological studies. Hence, conducting representative surveys that inform conservation and management of these taxa in relation to cumulative anthropogenic impacts remains as one of the most difficult issues, will always be challenging, and require multi-jurisdictional arrangements, especially those that frequently migrate to distant foraging and breeding areas beyond our national jurisdictions. These species are important predators in the GAB region, and there remain knowledge gaps and opportunities to further our understanding of their diet in offshore habitats to better understand their functional role, trophic interactions and identify potential ecological stressors.

11.4 Remaining knowledge gaps and research priorities

Some of the key remaining knowledge gaps and research priorities for the iconic and apex predator species cetaceans, pinnipeds, seabirds and sharks) are summarised for each group below.

11.4.1 Cetaceans

- The diversity, and spatial and temporal distribution of cetaceans and their movement and migratory behavior on shelf, shelf-break and slope regions of the GAB.
- Comprehensive surveys for dolphins and other cetaceans across the entire GAB region, and across different seasons to estimate their overall abundance, and how abundance varies by season and across the region to identifying critical areas, habitats, and times.
- Estimates of population size and vital rates of southern right whales, especially for the Head of Bight population.
- Understanding of the temporal and seasonal pattern of use of the GAB region by pygmy blue whales and other cetaceans, and the oceanographic and environmental circumstances when the region provides important foraging habitat.

- Assess the importance of canyons and slope habitats in the GAB for odontocete species, and determine if there are resident populations of some species (e.g. sperm whales, beaked whales).
- Assess the potential impacts of increased noise from shipping, seismic surveys and construction on cetacean species in the GAB region.

11.4.2 Pinnipeds

- An ongoing, coordinated population monitoring program for Australian sea lions to adequately understand population size and trends at representative sites across the range. Baseline data on the status of breeding sites off the south coast of WA is a priority.
- Periodic (e.g. five yearly) coordinated surveys to assess the status and trends in abundance of populations of long-nosed and Australian fur seals in the GAB.

11.4.3 Seabirds

- Baseline data on the distribution and size of seabird breeding colonies in the GAB.
- Information of the status and trends in abundance of key seabird species and sites across the GAB. Key species include pelagic (short-tailed and flesh footed shearwaters, white-face storm petrels), and coastal species (crested terns and little penguins). Priorities are species which are suspected to be in decline (e.g. little penguins, flesh-footed shearwaters).
- Information on local and distant forging areas and diets of pelagic seabird species (shearwaters and petrels), and migration corridors and winter foraging areas for shearwaters.
- Information on the core foraging areas and diets of inshore (resident) seabirds.
- Information on the breeding chronology and breeding success of seabirds.

11.4.4 Pelagic sharks

- There remains a need to better resolve the shared habitats and migration pathways of listed pelagic sharks in the GAB. Importantly, these highly migratory species have international conservation and management profiles, and are valued by community and regional economies of southern Australia and neighboring Pacific and Indian Ocean regions.
- Listed species for which significant data gaps remain include the white shark, shortfin mako, two *Alopiidae* spp., and porbeagle.
- Gaps also remain in available dietary and foraging data for pelagic sharks in shelf slope, submarine canyons and near slope oceanic habitats. The information is required to understand the ecological functioning and dynamism in the upper trophic levels when applying ecosystem modelling approaches.

12. CONCLUSIONS

Results from this study support previous research that has identified the GAB region as critical habitat to a range of apex predator species, a region that potentially supports the greatest diversity, density and biomass of marine predators in coastal Australian waters. The scale, remoteness and logistical challenges in accessing the region's offshore islands, shelf, slope and oceanic habitats, has greatly limited the development of basic knowledge about the status, distribution, key habitats and abundances of its iconic and apex predator species. This project explicitly set out to address these

key knowledge gaps by undertaking a range of surveys using multidisciplinary methods to assess the status, distribution and abundance of key species in the region. These included inshore and offshore aerial and offshore vessel-based acoustic and visual surveys for cetaceans, ground and aerial surveys on offshore islands to assess the status and trends in abundance of pinnipeds and some seabird species, and offshore pelagic long-line surveys incorporating satellite telemetry for pelagic sharks. The key outcome of the project is the most comprehensive synthesis to date of the status, distribution and abundances of iconic and apex predator species in the GAB region. This included significant advances in knowledge about the occurrence and distribution of short-beaked common dolphins and other cetaceans using inshore habitats; the occurrence and distribution of baleen and toothed whales in offshore shelf, shelf-break and slope habitats; in characterising the spatial and temporal distribution and habitat use of pelagic sharks; and in assessing the abundance of pinnipeds and some seabird breeding populations on off-shore islands. Despite these advances, basic information for many of the key species in the region is still rudimentary. This presents a major challenge for the management of the region, especially for those species that are matters of national environmental significance where the imperative to mitigate potential risks from human activities and impacts is greatest. The project has identified knowledge gaps and research priorities, which if addressed, would significantly enhance management of these key species and the habitats on which they depend.

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14. DATA MANAGEMENT

Data details						Curation and archive				Data access	
Data type	Description	Raw or derived data	Raw data sets created	Data processing and derivied datasets	Data format	Custodian	Data locations	Network path	Metadata	Use aggreements & licensing	Publication of datasets
Cetaceans - inshore aerial surveys	Aerial survey data of cetacean sightings	Raw	Sightings and effort data	Sighting locations, acoustic and visual effort	xlsx, jpg files	Flinders University	Flinders University SARDI network server	\\pirsapf2tr\user2\Refdata\Aqua\Envecol\TEPS\GAB RP\Project 4.1\Data sets\Inshore aerial cetacean surveys	See 1	See 2	Where practical, data sets will made publicly available.
Cetaceans - offshore aerial surveys	Aerial survey data of cetacean sightings	Raw	Sightings and effort data	Sighting locations, acoustic and visual effort	xlsx, jpg files	SARDI	SARDI network server	\\pirsapf2tr\user2\Refdata\Aqua\Envecol\TEPS\GAB RP\Project 4.1\Data sets\Offshore aerial cetacean surveys	See 1	See 2	Where practical, data sets will made publicly available.
Cetaceans - offshore acoustic/visual su	Vessel-based acoustic and visual survey data of cetaceans	Raw	Audio files (n=1461)	Acoustic detection locations	wav files	SARDI	SARDI network server	\\cluscbdfs02\USER30\SARDI\Env and Ecol\TEPS\Alice\Current Projects\GAB Science	See 1	See 2	Where practical, data sets will made publicly available.
				Click detection database	sql files			\\pirsapf2tr\user2\Refdata\Aqua\Envecol\TEPS\GAB RP\Project 4.1\Data sets\Offshore acoustic-visual surveys			
				Pamguard project file	psf files						
			Sightings and effort data	Sighting locations, acoustic and visual effort	xlsx						
				GPS data, Maps	gpx, xlsx files, ArcMap project						
Pinnipeds - offhsore island surveys	Ground surveys of pup abudance	Raw and derived	Pup numbers, timing of breeding	Estimates of pup production and trends in abundance	xlsx files	SARDI	SARDI network server	\\pirsapf2tr\user2\Refdata\Aqua\Envecol\TEPS\GAB RP\Project 4.1\Data sets\Pinniped surveys	See 1	See 2	Where practical, data sets will made publicly available.
Seabirds - offhsore island surveys	Ground and aerial surveys of nesting pairs, burrow density	Raw and derived	Counts of nesting pairs, burrow numbers, activity	Estimates of nesting pairs, active burrows, numbers	jpeg, xlsx files	SARDI	SARDI network server	\\pirsapf2tr\user2\Refdata\Aqua\Envecol\TEPS\GAB RP\Project 4.1\Data sets\Seabird surveys	See 1	See 2	Where practical, data sets will made publicly available.
Sharks - offshore pelagic long-line and satellite tracking	Offshore long-line surveys; satellite telemtry data	Raw	Satellite telemetry diag and prv files (n=108)	MiniPAT Summary, SST, time series, MinMAx Depth, MixLayer, Light loc and Histo data files (n=12).	diag, prv, and xlsx files	SARDI	SARDI network server	\\pirsapf2tr\user2\Refdata\Aqua\Envecol\TEPS\GAB RP\Project 4.1\Data sets\Pelagic sharks surveys-telemetry	See 1	See 2	Where practical, data sets will made publicly available.
			Distribution and abundance data (n=2)	Tracking vertical habitat analyses (n=24)	xlsx files						
				Filtered tracks by SSM method (n=2)	R script, csv files						
				Individual maps with time spent by sector and filtered tracks (n=8)	tiff, jpg files						

[1]A metadata record will be created and registered on the AODN catalogue for all raw and derived data sets generated as part of the GABRP. Where possible, data sets will be lodged with IMOS and made available through the AODN / IMOS Ocean portal.

[2]Where possible, data sets will to be made publically available (e.g. through the AODN / IMOS Ocean portal). In the event that a data set can't be made publically available, an electronic copy of the data set will be supplied to BP Australia.

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