Marine Environment and Ecology

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Effectiveness of the Great Australian Bight Marine Park in protecting the Australian sea lion (*Neophoca cinerea*) from by-catch mortality in shark gill-nets

Final report to
The Great Australian Bight Marine Park Steering Committee

SARDI Aquatic Sciences Publication No. F2009/000227-1
SARDI Research Report Series No. 357

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May 2009

Australian Government
Department of the Environment, Water, Heritage and the Arts

Government of South Australia
Department for Environment and Heritage

This report should be cited as:

Hamer, D.J., Ward, T.M., Goldsworthy, S.D., and Shaughnessy, P.D. (2009). Effectiveness of the Great Australian Bight Marine Park in protecting the Australian sea lion (*Neophoca cinerea*) from by-catch mortality in shark gill-nets. Report to Great Australian Bight Marine Park Steering Committee. SARDI Aquatic Sciences Publication No. F2009/000227-1, SARDI Research Report Series No. 357

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SARDI Aquatic Sciences Publication No. F2009/000227-1

SARDI Research Report Series No. 357

Printed in Adelaide, May 2009

Photos: Matthew Larsson (shark boat), Derek Hamer (Australian sea lions) and Simon Clark (Bunda Cliffs).

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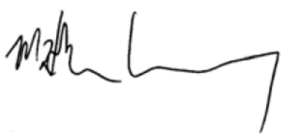

Signed:

Date: 6 May 2009

Distribution (via DEH): South Australian Research and Development Institute (SARDI) Aquatic Sciences Division; Great Australian Bight Marine Park (GABMP) Steering Committee; Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA); Primary Industry and Resources South Australia (PIRSA); South Australian Department for Environment and Heritage (DEH); Australian Fisheries Management Authority (AFMA).

Circulation: Public Domain.

EXECUTIVE SUMMARY

1. The Australian sea lion (ASL) is listed as *Vulnerable* under the Australian Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and as *Endangered* on the IUCN Red List. The ASL is vulnerable to anthropogenic impacts due to its low fecundity, typically small colony size and pronounced genetic differentiation between colonies, the latter brought about by philopatry. There is a small sub-population comprised of 10 breeding sites at Bunda Cliffs, within the Great Australian Bight Marine Park (GABMP). The GABMP was proclaimed during the mid to late 1990s and a key element in its development was the protection of the ASL. It is comprised of a Sanctuary Zone (SZ) and a Conservation Zone (CZ) in South Australian waters and a Marine Mammal Protection Zone (MMPZ) and Benthic Protection Zone (BPZ) in Commonwealth waters.

2. Entanglement records and anecdotal reports of by-catch mortalities suggest ASLs have operational interactions with commercial fisheries, which has been identified as a threatening process under the EPBC Act. A demersal shark gill-net fishery has operated in the GAB since the early 1990s and considerable effort is expended in the CZ and MMPZ when they are open to fishing between 1 November and 30 April. These factors suggest gill-netting may impact on the ASL sub-population at Bunda Cliffs.

3. Approximately 10 years have elapsed since the GABMP was proclaimed. However, the level of protection it provides ASLs, particularly from by-catch in shark gill-nets, has not been quantified. This study was conducted to assess the effectiveness of the GABMP in protecting ASLs at Bunda Cliffs from by-catch in shark gill-nets. This was done by i) examining the long-term trend in pup abundance, ii) determining the foraging behaviour of lactating females, iii) identifying the proportion of time lactating females spent in different parts of the GAB, iv) measuring the level of by-catch in shark gill-nets and v) assessing the impact of by-catch on the status of the Bunda cliffs ASL sub-population.

4. The most reliable survey of pup abundance was conducted in 1994 when 86 pups were counted and 161 were estimated to be present. Based on a sex ratio of 1:1, these figures suggest 43 or 86 female pups were present. There are no other robust counts available since that time. Consequently, historical trends and current sub-population size could not be determined.

5. Nine lactating ASLs tracked from two breeding sites located in the western and central parts of the Bunda Cliffs spent 24.1% and 53.4% of their time in the GABMP, respectively. On average, ASLs from the western site travelled 83 km south-southwest, well beyond the GABMP boundary, 15-16 km to the south. On average, ASLs from the central site travelled 30 km to the south on average, also beyond the GABMP boundary, 21-22 km away.

6. Over the two year study period, 113 net-sets were observed. Three of the four by-catch mortalities observed occurred within the GABMP (one in the CZ and two in the MMPZ), between 2 and 7 km from Bunda Cliffs. One by-catch mortality was observed outside the GABMP. The by-catch mortality rate was higher inside (0.021 mortalities per km of gill-net set) than outside the park (0.004 mortalities per km of gill-net). Although by-catch rates are higher inside the GABMP than outside, similar numbers of by-catch mortalities were estimated in each area because of the higher level of shark gill-netting effort outside the park. Specifically, it was estimated that the numbers of by-catch mortalities

were 11 inside and 10 outside the GABMP over the two year study period. This equates to 38 inside and 51 outside the park over the last 10 years since the park was proclaimed.

7. Estimates calculated from by-catch rates and fishing effort data for the entire GAB region, excluding consideration of the GABMP, suggest 31 by-catch mortalities occurred during the two year study period and 152 have occurred since the park was proclaimed. These estimates are higher than the sum of those calculated separately for inside and outside the GABMP, because i) the by-catch mortality rate inside the GABMP was higher than outside, ii) fishing effort was higher outside than inside the park and iii) the level of observer coverage was approximately three times higher inside than outside.

8. Quantitative population viability analyses (PVA) were used to predict responses of the Bunda Cliffs ASL sub-population to by-catch mortality. Twenty possible scenarios were examined and the effects of sub-population size, intrinsic rate of growth and level of by-catch mortality on the viability of ASLs at Bunda Cliffs were explored. Even under the most optimistic scenarios (302 females and 5% growth), PVA predicted that low levels of by-catch mortality would reduce the rate of intrinsic growth and the highest by-catch level would result in decline. In cases where the lower population estimate was used (161 females), the highest rates of by-catch mortality soon lead to quasi extinction, regardless of the rate of intrinsic growth. In 12 of the 16 scenarios in which by-catch occurred, quasi extinction times of 13-177 breeding cycles were predicted.

9. This study suggests the performance of the GABMP in conserving the Bunda Cliffs sub-population of the ASL could be improved. There are two main findings that need to be addressed.
    i. The status of ASLs at Bunda Cliffs is poorly understood because the only reliable pup count was conducted in 1994. Historical trends and current population size could not be determined because sampling effort was often low, many surveys were carried out when pup abundance was not at its peak, juveniles were often confused with pups and the methods used to record data were not consistent among surveys.
    ii. The GABMP does not effectively protect ASLs at Bunda Cliffs from shark gill-netting. High rates of by-catch mortality occur inside the park when it is open to fishing. Comparable levels of by-catch mortality were estimated to occur outside the park where ASLs mainly forage and gill-netting effort is high. PVA results suggest that even under the most optimistic scenarios, by-catch mortality reduced the rate of growth of Bunda Cliffs sub-population. Under less optimistic scenarios the sub-population declined.

10. To increase the effectiveness of the GABMP in protecting ASLs at Bunda Cliffs from by-catch mortality in shark gill-nets, there is a need to reduce the level of ASL by-catch mortality within the GABMP and across the GAB region. To measure the effectiveness of the GABMP in protecting ASLs in the future, there is also a need to establish a rigorous program for monitoring pup abundance.

ACKNOWLEDGEMENTS

The authors thank Kirie, Philios and Lenny Toumazos (The Fish Factory Pty. Ltd.) and Stav Parissos (Theo Parissos and Sons Pty. Ltd.) provided support and vessel access. We are also grateful to skippers Matthew 'Boof' Larsson (*FV Lutarna*), Geoff McDonald (*FV Jean Bryant*), Alan 'Pumper' Austin (*FV Opal Star*) and Mark 'Scrubber' Reynolds (*FV Marian H*). Alex Ivey (SARDI Aquatic Sciences) assisted during the observer program. Deb Frazer (Environmental Biodiversity Services), Brad Page (SARDI Aquatic Sciences) and Simon Clark (SA DEH) assisted with Australian sea lion captures at Bunda Cliffs. Peter Codrington, Peter Bache, Don Skinner (State Emergency Service – Vertical Rescue Team) and their team of specialists facilitated access to the base of the Bunda Cliffs to catch sea lions. Trent Timmis, Matt Daniels and John Garvey (AFMA), Terry Walker and Matias Braccili (MAFRI) provided historical SESSF logbook data. Steven Mayfield and Jason Tanner (SARDI Aquatic Sciences) reviewed drafts of this report. We would particularly like to thank the Great Australian Bight Marine Park (GABMP) Steering Committee and Simon Clark (former GABMP Manager) for providing the funds, opportunity and enthusiasm to undertake this study.

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1. INTRODUCTION

1.1 Overview

Operational interactions between wild fisheries and marine mammals occur in many locations around the world (e.g. Northridge, 1984 & 1991; Beverton, 1985; Hofman, 1990; Dawson 1991; Woodley and Lavigne, 1991; Gosliner, 1999; Northridge and Hofman, 1999; Harwood, 2001; Shaughnessy et al., 2003; Wilkinson et al., 2003; Hamer and Goldsworthy, 2006; Hamer et al., 2008). They typically occur when fishing activities and marine mammals converge on the same fish stock or area and often lead to entanglement induced drowning (Hamer and Goldsworthy, 2006; Hamer et al., 2008). The impact of operational interactions between seals and commercial fisheries has been widely discussed (Beverton, 1985; Shaughnessy and Payne, 1985; Woodley and Lavigne, 1991; Wickens, 1995; Lavigne, 1999; Aurioles-Gamboa et al., 2003; Shaughnessy et al., 2003; Wilkinson et al., 2003; Hamer and Goldsworthy, 2006; Goldsworthy and Page, 2007; Sepulveda et al, 2007; Campbell et al., 2008b; Underwood et al., 2008). However, there are only a few reported cases of the implementation and subsequent assessment of mitigation measures for pinnipeds (fur seals and sea lions) and other marine mammals (Gosliner, 1999; Wilkinson et al., 2003; Campbell et al., 2008b; Hamer et al., 2008).

Many pinniped populations were decimated or extirpated by commercial harvesting from the early 19th to mid 20th centuries (Taylor, 1982; Roux, 1987; Wickens et al., 1991; Ling, 1999; Bradshaw et al., 2000a; Harwood, 2001; David and van Sittert, 2008). Operational interactions with commercial fisheries became an issue of concern in the middle of the 20th century and are currently their biggest threat (Bonner, 1989; Woodley and Lavigne, 1991; Pemberton et al., 1994; Lavigne, 1999; Shaughnessy et al., 2003; Hamer and Goldsworthy, 2006). Despite the contemporary threat posed by fisheries, many seal populations have recovered from sealing, in some cases at least in part by the emigration of sexually mature females from adjacent unaffected areas (Roux, 1987; Bradshaw et al., 2000a; Shaughnessy et al., 2000).

Pinnipeds can be protected from the effects of commercial fishing by spatial closures, such as marine protected areas (MPAs), that prohibit fishing activities in regions critical for breeding and foraging (Botsford et al., 1997; Roberts, 1997; Boersma and Parrish, 1999; Reeves, 2000; Hooker and Gerber, 2004). For example, MPAs have been used to protect the endangered Hawaiian monk seal (*Monachus schauinslandi*), Mediterranean monk seal (*M. monachus*), New Zealand sea lion (*Phocarctos hookeri*) and the Australian sea lion (*Neophoca cinerea*) from commercial fishing activities near their breeding colonies and foraging grounds (Department for Environment, Heritage and Aboriginal Affairs, 1999; Lavigne, 1999; Wilkinson et al., 2003; Campbell et al., 2008b; Pires et al., 2008). However, protecting pinnipeds is challenging because they typically range over large areas between coastal breeding sites and oceanic foraging grounds (Staniland et al., 2007; Baylis et al., 2008a). The success of MPAs is contingent on detailed planning based upon extensive knowledge of the ecology of the pinniped species and the nature of the fishery that may threaten it. The effectiveness of MPAs is best determined by monitoring the abundance of the species it is designed to protect, both before and after its implementation (Botsford et al., 1997; Roberts, 1997; Boersma and Parrish, 1999; Reeves, 2000; Hooker and Gerber, 2004).

1.2 Australian sea lions: statutory protection, status and threats

The Australian sea lion (ASL) was listed as *Vulnerable* under Sections 178 and 179 of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in 2005 and a draft recovery plan was released soon after, pursuant to Section 269 (Natural Heritage Trust, 2005). ASLs were also listed as *Vulnerable* under the SA *National Parks and Wildlife Act 1972* in 2008. The killing, taking or removing of ASLs is prohibited under Sections 51 and 196 of these two Acts, respectively. The conservation status of the ASL was also recognised internationally in 2008, when it was classified as *Endangered* on the International Union for the Conservation of Nature (IUCN) Red List.

The breeding range of ASLs extends 3500 km from the Houtman Abrolhos Islands in Western Australia (WA) to The Page Islands (east of Kangaroo Island) in SA (Figure 1; Gales et al., 1994; Bonner, 2004; Shaughnessy et al., 2005; Campbell et al., 2008). Pup production has been estimated at 2,441 to 3,610, equating to 9300 to 17,364 ASLs overall based on 'pup multipliers' ranging between 3.8 and 4.8 (Harwood and Prime, 1978; Gales et al., 1994; Dennis and Shaughnessy, 1996; Goldsworthy et al., 2003; Shaughnessy et al., 2003; Goldsworthy et al., 2009). Approximately 86% of ASLs occur in SA and 60% of all breeding sites produce less than 25 pups (Gales et al., 1994; Dennis and Shaughnessy, 1996; Shaughnessy and Dennis, 2002; Shaughnessy et al., 2005; Goldsworthy et al., in review).

Unlike the sympatric New Zealand fur seal (*Arctocephalus forsteri*), the ASL has failed to recover from sealing (Gales et al., 1994; Shaughnessy et al., 2003; Campbell et al., 2008a). Two unusual characteristics associated with their biology and behaviour make them particularly vulnerable to decline. Firstly, ASLs have a supra-annual breeding cycle of 17.4 to 17.8 months (Ling and Walker, 1976; Higgins, 1993; Gales et al., 1994; Gales and Costa, 1997; Shaughnessy et al., 2006). This is unique among pinnipeds and reduces their reproductive output by approximately one third compared with other species. Secondly, sexually mature female ASLs exhibit strong philopatry by exclusively returning to their birth place to breed. This behaviour inhibits emigration and dispersal and may have given rise to reproductive asynchrony observed between females from adjacent breeding sites (Higgins, 1993; Gales et al., 1994; Gales and Costa, 1997; Campbell et al., 2008a).

Low fecundity and philopatry may have hastened the extirpation of some ASL breeding sites during seal harvesting and may now be inhibiting their subsequent reestablishment. Breeding colonies at a number of sites within their current range have gone extinct, including Fisheries Island (Houtman Abrolhos Islands), Daw Island (Recherche Archipelago), East Waldegrave Island and Flinders Island (Investigator Group). Several others outside the current range have also disappeared, such as the Hunter and Furneaux Groups in Bass Strait (King and Marlow, 1979; King, 1983; Ling 1999; Warneke, 1984; Gales et al., 1994; Shaughnessy et al., 2005; Robinson et al., 2008). In addition, reproductive isolation has resulted in genetic differentiation between ASLs from adjacent breeding colonies or sub-populations (Campbell et al., 2008a). Therefore, the loss of these sub-populations may diminish their overall genetic diversity (Hewitt & Butlin, 1997; Campbell et al., 2008a).

One source of anthropogenic mortality of ASLs is by-catch in shark gill-nets. Some shark fishers have indicated that between a 'few' and 20 ASLs drown in their gill-nets annually, mainly in coastal waters (Shaughnessy et al., 2003). However, by-catch of ASL in shark gillnets was not recorded in Australian Fishery Management Authority (AFMA) logbooks prior to 1999. Only ten seals of unknown species have been reported entangled or killed since recording began (Hamer, 2007). Observations made at breeding sites at Seal Bay, South Page Island and Olive Island revealed high rates of entanglement in monofilament shark gill-net material, suggesting operational interaction rates may be higher than suggested by logbook records (Shaughnessy et al., 2003; Page et al., 2004; Goldsworthy and Page 2007; DJH personal observation). ASLs may initially survive operational interactions with shark gill-nets, but often die later from related injuries or from starvation because they cannot forage effectively (Fowler, 1987; Fowler et al., 1990; Page et al., 2004).

There is a paucity of information about the status of ASLs at most breeding sites. The Seal Bay colony is exposed to shark gill-netting and the population has been estimated to have declined by 1.1% per breeding cycle over the last 20 years (Shaughnessy et al., 2006) and by 3.3-4.5% more recently (Goldsworthy et al., 2008). In contrast, the Dangerous Reef colony has increased by 6.9% per year over five breeding cycles since 2001, after shark gill-netting was banned in Spencer Gulf (South Australian Government Gazette, 2002; Shaughnessy, 2004; Goldsworthy et al., 2007). By-catch mortality of ASLs in shark gill-nets may partly explain their decline at breeding sites exposed to shark gill-netting.

1.3 Sea lions of Bunda Cliffs

During the early 1990s, ASLs were observed at 24 sites along the base of Bunda Cliffs in the Great Australian Bight (GAB), over 200 km of coastline from the WA border to the head of the GAB (Dennis and Shaughnessy, 1996; Shaughnessy et al., 2005). Ten of these appeared to be breeding colonies (Figure 1). Little is known about their status, although 161 pups were estimated in 1994, equating to 613 to 774 ASLs overall, based on available pup multipliers (Gales et al., 1994; Dennis and Shaughnessy, 1996; Goldsworthy et al. 2003; Goldsworthy and Page 2008). These figures suggest Bunda Cliffs supported between 4.8 to 9.3% of ASLs in SA and 4.2 to 8.0% of the species overall at the time. The occurrence of ASLs on the Australian mainland is unique, because all other breeding sites are located on islands (although recent reports suggest a small breeding colony may exist at Point Labatt). Land access to the 15-30 m wide undulating terraces at the base of the cliffs is hindered by the 80 to 100 m vertical cliffs and seaward access is impeded by large boulders. The inaccessibility of these sites has protected these colonies from sealing (Edyvane, 1998). Bunda Cliffs may also be an important link in paternal gene flow between breeding populations in the Recherche Archipelago in WA, 650 km to the west, and the Nuyts Archipelago in SA, 300 km to the east (Hewitt and Butlin, 1997; Edyvane, 1998, Campbell et al. 2008a). The level of maternal gene flow between the breeding sites at Bunda cliffs is unknown and in this study they are treated as a contiguous sub-population, based on their isolation from other ASL breeding populations.

1.4 The Great Australian Bight Marine Park

The Great Australian Bight Marine Park (GABMP) is the largest MPA along the southern coast of Australia, covering over 21,500 km^2. The protection of ASLs at Bunda Cliffs was identified as a key aim in its development and also features in the current management plans (Edyvane, 1998; Department for Environment, Heritage and Aboriginal Affairs, 1999; Natural Heritage Trust, 2004; Department of the Environment and Heritage, 2005). The GABMP traverses waters under SA and Commonwealth jurisdiction. The SA component comprises a Sanctuary Zone (SZ) proclaimed in 1995 under an Act preceding the SA *Fisheries Act 2007* and a Conservation Zone (CZ) proclaimed in 1996 under the SA *National Parks and Wildlife Act 1972* (Natural Heritage Trust, 2004). Collectively, the SA components extend 300 km along the coastline from the WA border (GDA 1994: 129°00'E) to Cape Adieu (132°00'E), encompassing waters from the high water mark to the 5.6 km (3 nautical mile) offshore limit of SA waters (Figure 1). The Commonwealth component of the GABMP comprises the Marine Mammal Protection Zone (MMPZ) and the Benthic Protection Zone (BPZ), both proclaimed in 1998 under an Act replaced by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act; Natural Heritage Trust, 2004; Department of the Environment and Heritage, 2005). The MMPZ extends from the limit of SA waters south to 31°47'S (Figure 1). The SA and Commonwealth management plans are administered by the GABMP Steering Committee, which is comprised of representatives from the SA DEH, DEWHA, AFMA, Primary Industry and Resources South Australia (PIRSA), the SA Tourism Commission and the Chair of the Consultative Committee.

1.5 The Commonwealth demersal shark gill-net fishery

Demersal shark gill-net fishing commenced in the early 1970s in southern Australia and has changed little during that time (Walker et al., 2005). Gill-netting occurs during day and night, with trips lasting 6 to 16 days. Monofilament polypropylene gill-net is hung between a weighted foot rope designed to hold it stationary on the benthos and a floated headline to hold it upright in the water column (Figure 2). Pursuant to regulations under the *Fisheries Management Act 1991*, gill-net mesh size must be 150-165 mm, have a breaking strain of between 300 and 400 Newtons, stand no higher than 20 meshes (about three metres) and must not exceed 4,200 m in length in Commonwealth waters or 1,800 m in SA waters (Murphy and Richardson, 2002).

Shark gill-netting is managed by AFMA as part of the Southern and Eastern Shark and Scalefish Fishery (SESSF). Total allowable commercial catches (TACC) limits have been set for the two target species since 2001. Since 2007, the TACCs for gummy shark (*Mustelus antarcticus*) and school shark (*Galeorhinus galeus*) have been set at 1,783 tonnes and 240 tonnes, respectively (McGloughlin, 2004; Australian Fisheries Management Authority, 2007; Larcombe and Begg, 2008). The SESSF includes waters adjacent to SA, Victorian (excluding state waters) and Tasmanian coasts out to a depth of 183 m. Historically, catch and effort data were recorded as degrees of longitude and latitude, known as Marine Fishery Areas (MFAs), which measure 92-95 km along parallels of latitude at 31-34°S and about 111 km along meridians of longitude. Since July 2007, all vessels have recorded the location of fishing events in degrees and minutes (Department of the Environment and Heritage, 2006). Since the early 1990s, considerable effort has been expended in the GAB region, which is defined as the area between 127°E to 132°E and 31°30'S to 33°30'S and containing MFAs 101 to 106 and 112, (Figure 1).

Under the GABMP management plans, shark gill-netting is permanently banned in the SZ, but is permitted by statutory exemption in the CZ and MMPZ for six months each year, between 1 November to 30 April, and in the BPZ throughout the year (Department for Environment, Heritage and Aboriginal Affairs, 1999; Department of the Environment and Heritage, 2005). Under the current regime, gill-netting is permitted to occur close ASL breeding sites along Bunda Cliffs for half of the year. It is likely ASLs will encounter demersal gill-nets within and adjacent to the GABMP, because they predominantly forage on the benthos and often travel in excess of 60km in search of prey (Costa and Gales, 2003; Fowler et al. 2006; Fowler et al., 2007; DJH, unpublished data). It should be noted that an AFMA fishery closure extending 3.72 km (2 nm) from the coast along the western end of the GABMP was established in 2007.

1.6 Need and aims

This study addresses the need to assess the effectiveness of the GABMP in protecting the ASL from by-catch mortality in shark gill-nets. Specifically, this study aimed to:

1. Examine the long term trend in pup abundance at Bunda Cliffs;
2. Determine the foraging behaviour of lactating females from Bunda Cliffs;
3. Identify the proportion of time they spent in different zones across the GAB region;
4. Measure the level of by-catch mortalities in shark gill-nets in the GAB region;
5. Assess the impact of by-catch mortality on the current and long term status of ASLs at Bunda Cliffs.

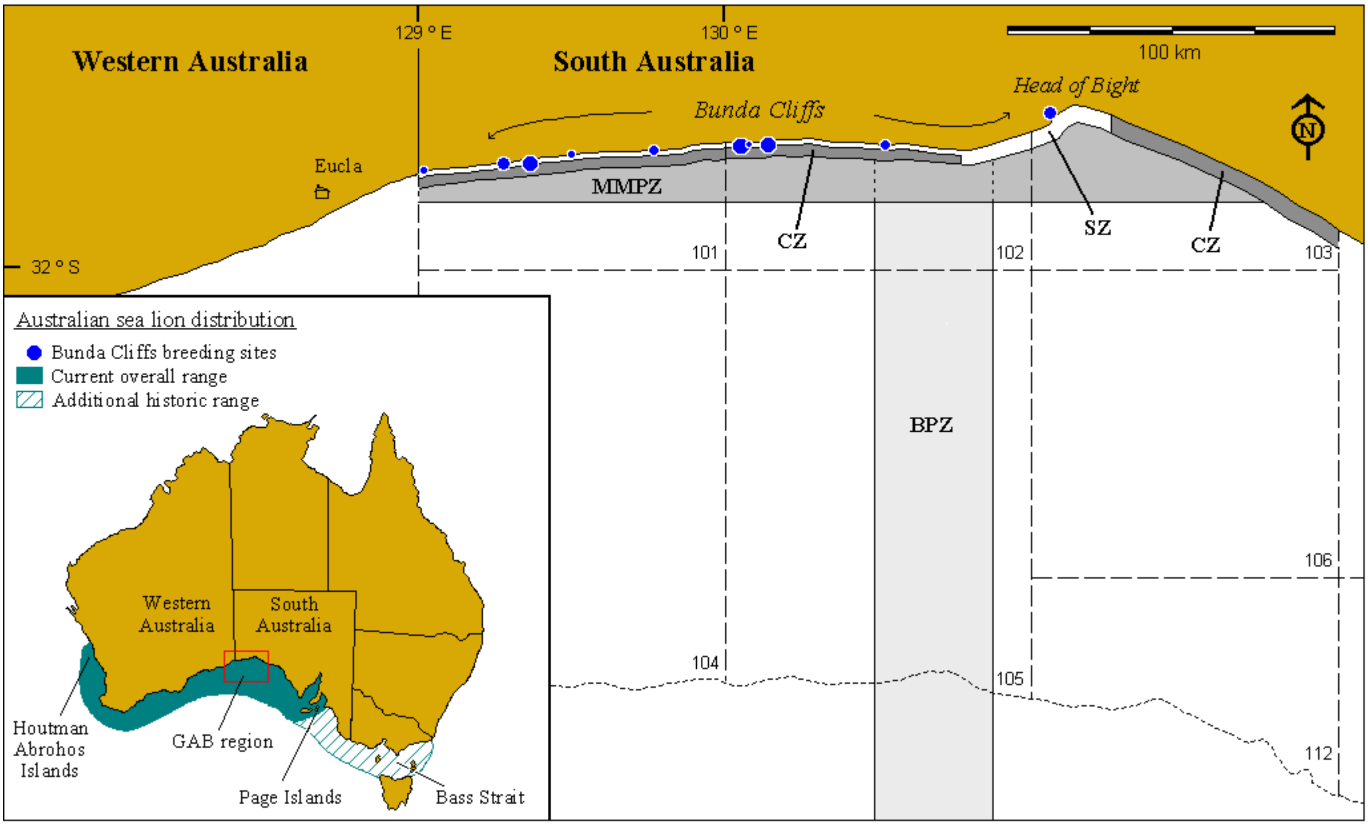


Figure 1. Location of the 10 Australian sea lion breeding sites at Bunda Cliffs (the 14 recorded haul-out sites are scattered in between), plus the current and historical range of ASLs along the southern and southwest coastlines of Australia. Also shown is the location of the Great Australian Bight Marine Park (GABMP; comprising the: Sanctuary Zone – SZ, Conservation Zone – CZ, Marine Mammal Protection Zone – MMPZ and Benthic Protection Zone – BPZ) and Australian Fishery Management Authority (AFMA) Marine Fishery Areas (MFAs 101 to 106 and 112).

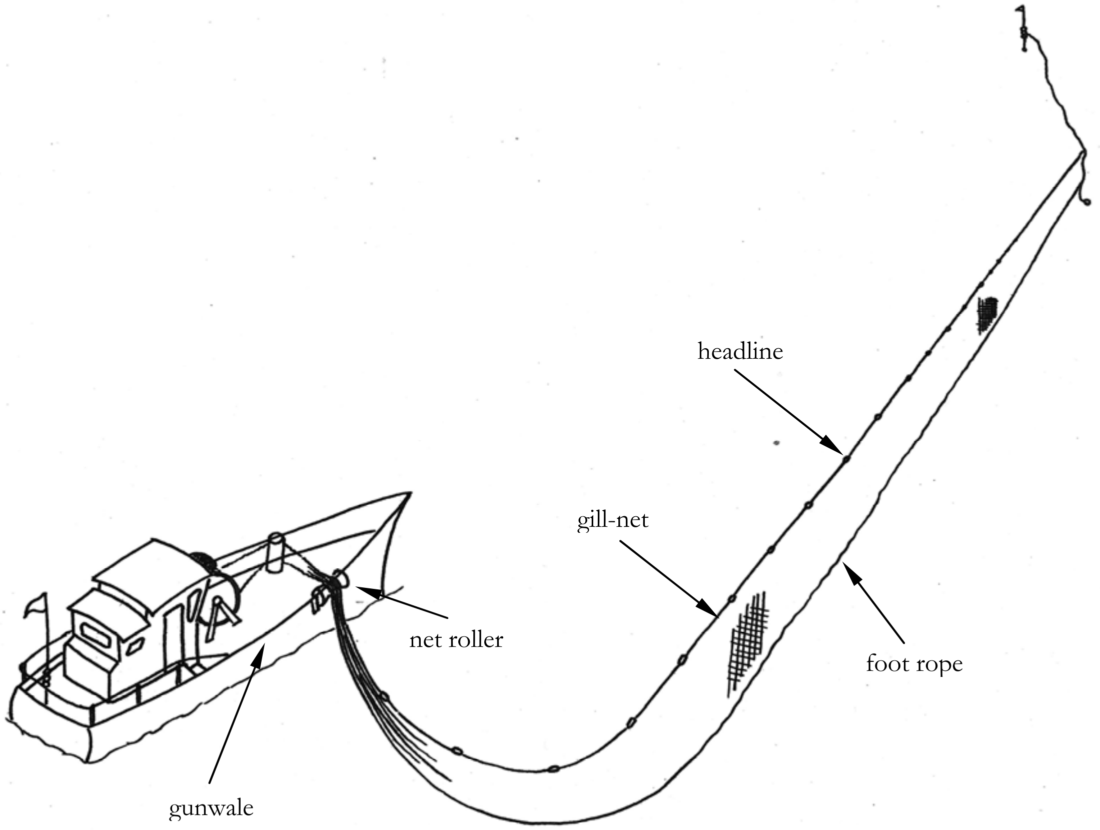


Figure 2. Schematic diagram of a demersal shark gill-net being hauled, depicting the lay of the net on the benthos and its ascent through and out of the water, then over the net roller.

2. METHODS

2.1 Pup abundance at Bunda Cliffs

Pup abundance surveys were conducted at Bunda Cliffs between 1994 and 2007, with the aim of establishing trends in sub-population size (Dennis and Shaughnessy, 1996; Dennis, 2005). Pups are the most suitable age class for estimating abundance because they typically remain ashore during the breeding season and are distinguishable from other age classes (Berkson and DeMaster 1985). Results of the 1994, 1995 and 2001 surveys were obtained from the literature (Dennis and Shaughnessy, 1996; Dennis, 2005), while the results of subsequent surveys come from an SA Department for the Environment and Heritage (DEH) database.

All counts were based on cliff-top surveys using binoculars and telescopes. Counts may have been underestimates due to some pups being concealed by rock ledges and boulders, or overestimates (especially in recent SA DEH surveys) because they included an unknown proportion of small juveniles from the previous season. The accuracy of the timing of surveys was explored using available breeding calendars (Shaughnessy and Dennis, 2003; Shaughnessy et al., in prep.) and information about the proportion of pups that were brown (0-5 months old) or moulted (5+ months old; Shaughnessy et al., 2005). The level of survey effort across the 10 breeding sites and 14 haul-out sites was also calculated.

2.2 Spatial distribution of foraging effort

Equipment deployment

Satellite linked platform transmission terminals (PTTs; KiwiSat 101, Sirtrack, Havelock North, New Zealand) were attached to lactating ASLs at the two largest breeding sites at Bunda Cliffs (Dennis and Shaughnessy, 1996), referred to as the western site (B8: GDA 1994: 31°38'35"S, 129°22'59"E) and the central site (B5: 31°35'20"S, 130°03'E). The number of pups counted at these sites in 1994 was estimated to be 38 and 43, respectively (Goldsworthy et al., 2003). Lactating ASLs were identified by the presence of a suckling pup, a pup resting in contact with her, or the production of milk in the absence of a pup.

Nine PTTs were deployed in total. Four were deployed at the western colony after the end of a breeding season in April 2006 and five were deployed at the central colony during the next breeding season in May 2007. Access to the colonies was facilitated by the SA State Emergency Service (SES) Vertical Rescue Team, using specialised abseiling and climbing equipment. A purpose-built v-net was used to capture the animals. To anaesthetise the animals, Isoflo™ (100% isoflurane, Veterinary Companies of Australia, Artarmon, Australia) was administered via a mask attached to a gas anaesthesia apparatus fitted with a Cyprane Tec III vaporiser (Advanced

Anaesthetic Specialists, Melbourne, Australia). The degree of induction was controlled by adjusting the concentration and delivery rate of Isoflo™. Vital signs were monitored to determine the degree of induction including heart rate, rate and depth of breathing and degree of openness of the airway, gum colour, capillary return, plus eye and tail reflexes.

The PTT was positioned alongside the mid-dorsal line beside the spine, at a point 10 centimetres posterior of the axillae (fore-flipper pits). Attached was made to the guard hairs using a layer of Araldite® 2107 (a flexible, two-pack epoxy adhesive; Huntsman Advanced Materials, Basel, Switzerland). Standard length (in a straight line from nose to tail) and axillary girth (taken posterior of the axillae) were measured (±0.5 cm). Procedures conducted were approved by the University of Adelaide Animal Ethics Committee (S-008-2006) and conducted under a SA DEH permit (A-24684).

Data analysis

PTT location data were obtained from Service Argos Inc. (Toulouse, France). Class 3, 2, 1, 0 and A positions were used in the analysis, while class B and Z positions were omitted due to their inaccuracy (Sterling and Ream, 2004). Each PTT was configured to cease transmitting when the ASL was hauled out for longer than one hour, but recommenced when it re-entered the water. This allowed the end of one trip and the beginning of the next to be identified. Some animals are known to haul out for between one and three days, so the haul-out time was removed from the analysis to avoid overestimating the amount of time individuals spent foraging in grid cells adjacent to colonies.

Mean and maximum distances from the colony and mean direction travelled were reported for each tracked ASL. Mean direction was calculated by using location data for distances greater than five km from the natal site to avoid directional errors arising from small inaccuracies at the beginning and end of each foraging trip.

The amount of time tracked ASLs spent in each 1 km^2 grid cell was calculated using the statistical package R (version 2.3.0, R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria) and *timeTrack* (version 1.1-5, M. D. Sumner, University of Tasmania, Hobart, Australia). Average linear swim speed between two locations was also calculated over each 15 minute period. Erroneous locations were detected and redistributed by assigning a maximum possible linear swim speed of 7.2 kmh^{-1} (Reidmann, 1991; McConnell et al., 1992).

Location fixes at the beginning and end of each foraging trip were often inaccurate or absent due to the height of Bunda Cliffs, which often blocked communication with the satellites, thus making it difficult to determine the time an ASL left or returned to the natal site. To account for this, exact coordinates for the breeding site were manually included in the data set as the first and last position of each foraging trip. R and *trip* (M. D. Sumner, University of Tasmania, Hobart, Australia) were used to allocate to each grid cell the additional time taken to travel between the breeding site and the first or last recorded location for each trip, based on the assumed linear swim speed.

The number of days each individual was tracked was standardised to eliminate spatial biases associated with individual patterns. The results were mapped using MapInfo Professional® and Vertical Mapper® (Versions 8.0 and 2.5 respectively, MapInfo Corporation, New York, USA). The amount of foraging time spent in each GABMP (SZ, the CZ and the MMPZ) management zone and each AFMA (MFAs 101 to 106 and 112) management zone was calculated to determine its importance to lactating ASLs.

2.3 Shark gill-netting effort

AFMA provided effort data for shark gill-net fishers in the GAB region between January 1998 and December 2007, which approximates the period since the proclamation of the GABMP. Gill-netters recorded effort as net-sets by date (month and year) and MFA. The number of net-sets was converted to kilometres of gill-net set by multiplying the maximum permissible net length of 1,800 m in SA waters and 4,200 m in Commonwealth waters by the number of net-sets. This was done because discussions with fishers and personal observations (DJH) indicated that most fishers used the maximum permitted net lengths most of the time. The three coastal MFAs (101 to 103) in the GAB region traversed both SA and Commonwealth waters. The total number of net-sets was apportioned to either SA or Commonwealth waters according to their relative area within each MFA, based on the assumption that effort was evenly distributed.

2.4 Observed by-catch mortalities, rates and estimates

Observers were deployed on shark gill-net vessels in the GAB region between February 2006 and January 2008. The primary objective was to determine the number, rate and nature of operational interactions between ASLs and shark gill-netting. Observations were made from slightly outboard of the gunwale to obtain an unimpeded view of the gill-net ascending vertically through the upper water column and onto the net roller on the bow (Figure 2). When possible, the age class and sex of ASLs that were killed, and whether or not they were landed, was recorded. The rate of by-catch mortality was calculated as the number observed per km of gill-net set observed in each of the GABMP and AFMA management zones where mortalities occurred.

The observed rates of ASL by-catch mortalities inside and outside the GABMP, in each MFA and across the GAB region, were multiplied by fishing effort (km of gill-net) to estimate the number of by-catch mortalities that may have occurred over those two time periods. The periods of interest were the two year study period (January 2006-December 2007) and since the proclamation of the GABMP (January 1998-December 2007). Estimates of by-catch mortalities across one 17.6 month breeding cycle were calculated by dividing the estimates derived from the study period (i.e. 24 months: January 2006-December 2007) by 1.36. This approach assumed the rate of by-catch was constant over time and that fishing and foraging effort were evenly distributed throughout each zone.

2.5 Impact of by-catch mortality on the sub-population

Quantitative population viability analyses (PVA) are typically used to determine the capacity of populations of a given size and demographic structure to sustain anthropogenic mortality. In this study, PVA was conducted using model-based simulations in RAMAS Metapop® (Version 5.0, Applied Biomathematics, New York, USA) to explore how the Bunda Cliffs ASL sub-population may respond to different levels of by-catch mortality in shark gill-nets. Several aspects of the methodology draw upon examples found in the literature (see: Shaffer, 1981; Reed et al., 2002; Otway et al., 2004; Goldsworthy and Page, 2007; Underwood et al., 2008).

The most comprehensive and reliable count of ASLs comes from a survey undertaken at Bunda Cliffs in August 1994 (Dennis and Shaughnessy, 1996). An estimate of pup abundance was also calculated, based on ground counts within the colony at two sites that yielded about twice as many pups as the cliff-top counts at the same locations (Dennis and Shaughnessy, 1996). The number of female pups was calculated for both the count and the estimate, based on a sex ratio of 1:1 reported for ASL pups at Seal Bay (McIntosh, 2007).

A female only model was constructed, because the offspring they produce are the metric exclusively used to measure the status of colonies and populations among all sea lion and fur seal species. A life history table (Leslie matrix) composed of fecundity and survival estimates in all age classes is integral to the PVA in RAMAS Metapop® (Akçakaya, 1998). Data from female ASLs at the Seal Bay breeding colony that suggest ASLs reach sexual maturity at 3.8 years (n = 10) and live for approximately 24 years (n = 66; McIntosh, 2007). Limited survival and fecundity estimates are available for the ASL or other sea lions. Mean estimates derived from three annually breeding fur seal species (Northern fur seal *Callorhinus ursinus*: Lander, 1981; Barlow and Boveng, 1991; Antarctic fur seal *Arctocephalus gazelle*: Boyd et al., 1995; South American fur seal *A. australis*: Lima and Paez, 1997) were redistributed across 1.5 year age classes to approximate the 17.6 month breeding cycle of ASL. A similar approach was used to study the impact of by-catch mortality on the New Zealand sea lion, in the absence of empirical estimates of fecundity and survival (Woodley and Lavigne, 1993).

The resulting life table was used to run an initial simulation in RAMAS Metapop®, using the most optimistic estimate of population size calculated for Bunda Cliffs at the beginning of the time series. The model was run over 100 breeding cycles (147 years) with 300 replications and produced an increasing population trajectory. Values for fecundity and survival in each age stage were adjusted by a factor of 0.9284 to produce an intrinsically stable model (i.e. population growth was not exhibited at any time), reflecting a sub-population in equilibrium with its environment and devoid of anthropogenic impacts (Krebs and Davies, 1997; Table 1). The survival and fecundity values in the life table were then adjusted by a factor of 1.0493 to produce a population growing intrinsically by about 5% each breeding cycle, in the absence of anthropogenic factors such as fishery by-catch. This is a slightly conservative increase compared with the 6.9% growth rate reported at Dangerous Reef between 1994 and 2007 (Goldsworthy et al., 2007), but generous for a small sub-population of large mammalian predators that are unlikely to be in the recolonisation phase (Roux, 1987; Krebs, 1985; Krebs and Davies, 1997; Shaughnessy, 2004). A declining model was not examined, because it would not be possible to determine the extent by-catch mortality was already contributing to the decline.

The female ASL age classes exposed to mortality in gill-nets were determined on the basis of their foraging capacity. Pups (0 to 1.5 years old) were not considered to be exposed to mortality because they mainly forage in waters of around 30 m depth and near to their natal colony, where minimal gill-net fishing occurs (Fowler et al., 2006). The remaining age classes (1.5 to 25.5 years) were considered to be exposed to shark gill-netting because they typically forage in depths exceeding 68 m (Fowler et al., 2006) and distances up to 147 km from their natal site (Hamer et al., 2007), where most shark gill-netting occurs.

Five levels of by-catch mortality were explored to determine the proportion of ASLs that may be removed from the Bunda Cliffs sub-population during each breeding cycle. Given the remoteness of Bunda Cliffs from other ASL population centres, it was assumed that all of the by-catch mortalities in the GAB region involved animals originating from Bunda Cliffs. The numbers of mortalities that occurred inside and outside the GABMP were estimated to assess its effectiveness in protecting ASLs from Bunda Cliffs. The by-catch levels considered were zero mortalities (no by-catch), four and eight female mortalities inside the GABMP (based on estimates derived from half and all of the four observed mortalities being female), plus 11 and 22 female mortalities across the GAB region (again, based on estimates derived from half and all of the four observed mortalities being female).

A total of twenty scenarios were modelled to determine the viability of the ASL sub-population at Bunda Cliffs, based on upper and lower estimates of sub-population size, upper and lower estimates of intrinsic growth and the five levels of by-catch mortality. Model outcomes were generated in RAMAS Metapop® and grouped by population size and growth rate. Each model was run over 100 breeding cycles (147 years) with 300 replications.

Four outputs were of particular relevance to this study. Quasi extinction time was calculated as the number of breeding cycles from the beginning of the time series in 1994 that it would take for a declining sub-population to fall below a threshold of 19 females. This threshold was calculated using a female pup multiplier of 3.8 that was derived from the initial age-structured abundances calculated from the stable life table, based on the assumption that a breeding population must have at least five pups (Shaughnessy, 2004; National Seal Strategy Group, 2007). The number of females after 100 breeding cycles (in the year 2141) and the number females and female pups after 11 breeding cycles (in the year 2010) were also calculated. It should be noted that density-dependent effects (i.e factors affecting carrying capacity in increasing populations) and Allee effects (i.e. factors affecting functional breeding systems in declining populations) were not considered in the PVA. This may have resulted in unrealistic predictions at the end of the time series of some scenarios.

Table 1. Summary of fecundity and survival estimates from the life table used in quantitative PVA of the Bunda Cliffs ASL sub-population. Values were derived from three annually breeding fur seal species and redistributed across 1.5 year time stages to approximate the 17.6 month breeding cycle of the ASL and adjusted to fall within known age at sexual maturity and longevity.

	Stable (0%)		**Increasing (5%)**	
Age class (years)	Fecundity	Survival	Fecundity	Survival
0 – 1.5	0	0.6035	0	0.6333
1.5 – 3	0.0279	0.7242	0.0293	0.7599
3 – 4.5	0.2275	0.8263	0.2387	0.8671
4.5 – 6	0.3412	0.8379	0.3580	0.8792
6 – 7.5	0.5317	0.8332	0.5579	0.8743
7.5 – 9	0.5782	0.8286	0.6067	0.8695
9 – 10.5	0.6035	0.8193	0.6333	0.8597
10.5 – 12	0.5872	0.8147	0.6162	0.8549
12 – 13.5	0.5315	0.8007	0.5577	0.8402
13.5 – 15	0.5013	0.7845	0.5260	0.8232
15 – 16.5	0.4526	0.7288	0.4749	0.7647
16.5 – 18	0.4294	0.6963	0.4506	0.7306
18 – 19.5	0.3783	0.5988	0.3970	0.6283
19.5 – 21	0.3482	0.5408	0.3654	0.5675
21 – 22.5	0.2483	0.4108	0.2605	0.4311
22.5 – 24	0.1787	0.3412	0.1875	0.3580
24 – 25.5	0.0348	0.1137	0.0365	0.1193

3. RESULTS

3.1 Pup abundance at Bunda Cliffs

Eighteen surveys were conducted between 1994 and 2007, but only six occurred during the 10 breeding seasons that took place over that period (1994, 1995/96, 2001, 2004, 2005/06 and 2006/07; Table 2). The inferred chronology of breeding seasons based on a 17.6 month breeding cycle and 7 to 8 month duration suggested nearly half of the surveys undertaken since 2001 occurred outside the breeding season (Figure 3). The percentage of breeding and haul-out sites at which counts were made varied between 96% in 1994 and 8% in 2004. Since 2001, surveys have not included B1 (a cave that is thought to have collapsed since 1994), H1 to H4 or H11. The number of pups counted was positively related to the percentage of sites surveyed (linear regression; arcsine transformed data: $F_{1,5} = 34.54$, $P < 0.01$, $R^2 = 0.87$).

The relative percentage of brown and moulted pups counted during each survey suggests only two were conducted during the peak of the breeding season, in 1995 and 2001, when numbers of each were approximately equal (Figure 4). Based on the high percentage of moulted pups, surveys undertaken in 1994 and 2005 may have occurred late in the breeding season. In contrast, the low percentage of brown pups observed in surveys in 2004 and 2007, suggest these surveys were undertaken early in the breeding season. As a result, the 1995 and 2001 surveys may be the only two surveys conducted during the peak of the breeding season. There are a number of problems with the data collected during pup surveys, including: i) low and variable sampling effort; ii) inaccurate timing of surveys resulting from opportunistic visitations; iii) incorrect identification of small juveniles as moulted pups caused by the distance at which surveys were conducted (i.e. the cliff top) and iv) the configuration of the database creating confusion between whether the number of pups observed at a breeding site was zero or it had not been visited.

The 1994 survey, in which 86 pups were counted, appears to be the most reliable and comprehensive conducted at Bunda Cliffs (Dennis and Shaughnessy, 1996). A ground count conducted in conjunction with the survey at two of the 10 breeding sites yielded almost twice as many pups as the cliff top counts. These data were used to derive an estimate of 161 pups for the sub-population. Assuming a sex ratio of 1:1, this equates to 43 female pups from the direct counts and 81 from the derived estimate.

3.2 Spatial distribution of foraging effort

Four lactating ASLs were tracked from the western site and yielded 971 days (mean = 243, range = 189-273, s.d. = 37, n = 4) of location data, while the five from the central site yielded 215 days (mean = 43, range = 33-63, s.d. = 13, n = 5), producing a grand total of 1186 days (overall mean = 132; Table 3). The mean distance they travelled from the western site was 83 km (s.d. = 35;

mean maximum 180 km) and from the central site was 30 km (s.d. = 18; mean maximum 69 km; Table 3; Figure 5). Therefore, the mean and mean maximum distances travelled by ASLs from the western site were 2.8 and 2.6 times greater than ASLs from the central site, respectively. These differences were significant (ANOVA: $F_{1,7}$ = 43.73, P < 0.01; mean maximum: $F_{1,7}$ = 211.72, P < 0.01).

In general, ASLs tracked from the western site travelled in a south westerly direction (mean bearing = 205°, range = 174-228, s.d. = 26), while animals from the central site travelled south (mean bearing = 187°, range = 172-210, s.d. = 39), although they were not significantly different (ANOVA: $F_{1,7}$ = 2.34, P = 0.17; Table 3). There was no spatial overlap between ASLs tracked from the western and central sites, although eight of nine swam further than the 63 km separating the sites.

Under the GABMP management regime, ASLs from the western site spent 24.1% of their time at sea within the park, including 14.4% in the SZ and CZ, and 9.7% in the MMPZ (Table 4; Figure 5). They also spent 75.9% of their time at sea in Commonwealth waters off SA (45.4%) and WA (30.5%) where they were unprotected. The ASLs from the central site spent 53.4% of their time at sea in the GABMP, with 27.3% in the SZ and CZ, and 26.1% in the MMPZ. The remaining 46.6% was spent to the south of the GABMP in Commonwealth waters off SA.

Under the AFMA management regime, ASLs from the western site spent 41.7% of their time at sea in MFA 101 where the colony is located, 27.8% in MFA 104 and 30.5% in Commonwealth waters off WA (Table 4; Figure 5). ASLs from the central colony spent 62.8% of their time in MFA 102 where the colony is located, 7% in MFA 105 and 30.2% in MFA 101.

3.3 Shark gill-netting effort

Between January 1998 and December 2007, 56,750 net-sets were conducted in SA, of which 4,500 occurred in the GAB region. This equated to 197,689 km and 16,375 km of gill-net fishing effort in SA and GAB region, respectively. During the 24 month study period (January 2006 to December 2007), 3,175 km of gill-net was set in the GAB region, of which 538 km was set in the GABMP.

In the GAB region, annual effort ranged from 786 km of gill-net in 2002 to 3,175 km in 2007 (Figure 6). Fishing effort in the GAB region declined from 3001 km in 1998 to 786 km in 2002. This 73.8% decline coincided with target stock depletion in the late 1990s (namely school shark) and the introduction of quota in 2001. Fishing effort subsequently increased by 37.7% from 2002 to 1154 km in 2005 and by a further 293.5% to 3175 km in 2007, reflecting renewed interest in shark gill-netting in the GAB region (Figure 6). Overall, 18.1% of fishing effort over the 10 year period occurred during the 24 month study period.

Over the 10 year period, cumulative monthly effort in the GAB region ranged between 328 km in June to 3,876 km in November (Figure 7). November accounted for 26.7% of all fishing effort in the GAB region, while 61.8% of occurred between 1 November and 30 April, when the GABMP was open to fishing. Levels of fishing effort ranged between 613 km in MFA 112 to 4,536 km in MFA 104 (Figure 8). The latter MFA is situated offshore and adjacent to the WA border and accounted for 26.5% of all fishing effort in the GAB region. A comparatively low level of fishing effort occurred in MFA 102 (894 km) and a moderate level occurred in MFA 101 (1,909 km), both of which are coastal MFAs and include most of the Bunda Cliffs.

3.4 Observed by-catch mortalities, rates and estimates

Five voyages and 60 days of fishing were monitored on commercial shark gill-net fishing vessels in the GAB region over the 24 month study period. A total of 431.4 km of gill-net (113 shots) was observed, including 145.8 km (45 shots) inside the GABMP when the CZ and MMPZ were open to commercial fishing (Table 5). The observer program monitored 27.1% of fishing activity in the GABMP and 13.1% accross the GAB region during that time.

Four ASL by-catch mortalities were recorded (Table 5; Figure 5). All fell out of the gill-net when it was lifted above the waterline and were not hauled aboard the vessel. Two of the four ASLs killed were positively identified as sexually mature females, based on their size,morphology and pelage colouration. The other two animals were a bull and a juvenile of undetermined sex. Therefore, half of the by-catch was confirmed to be sexually mature females.

Three of the four ASL by-catch mortalities were observed in the GABMP (Table 5; Figure 5). One occurred in the CZ just outside the SZ and two in the MMPZ just outside the CZ. The other mortality occurred about 46 km south of the GABMP. Four non-lethal operational interactions also occurred and involved ASLs being observed feeding on sharks (that were presumably taken from the gill-net) or swimming alongside the vessel. One occurred in the CZ and one in the MMPZ, while the other two occurred 1 and 49 km south of the GABMP.

The mortality rate inside the GABMP was higher at 0.021 ASL per km and lower outside at 0.004 per km (Table 5). The overall mortality rate for the GAB region was 0.008 ASLs per km of gill-net. In contrast, the ASL mortality rate reported in AFMA logbooks for SA between October 1999 and October 2004 was 0.000049 per km of gill-net, based on seven mortalities and 143,752 km of gill-net effort. Estimated mortality rates reported in this study inside and outside the GABMP were 507 and 97 times higher than those reported in logbooks for all of SA, while the mortality rate for the entire GAB region was 116 times higher.

The extrapolated estimates of ASL by-catch mortality during the study period were 11 in the GABMP, 10 outside and 31 across the entire GAB region (Table 5; Figure 5). The sum of mortality estimates inside and outside the GABMP are not equal to the estimate for the entire GAB region, because of differences in the mortality rates and levels of fishing effort inside and outside the park. Specifically, the mortality rate inside the park was high but fishing effort was low, whereas the situation was reversed outside the GABMP. In addition, observer coverage was approximately three times higher inside the park than outside It was estimated that for a single breeding cycle eight mortalities (four females) occurred within the GABMP and 22 (11 females) occurred across the entire GAB region. This suggests that since the GABMP was proclaimed, 38 by-catch mortalities have occurred within the GABMP and 152 occurred across the GAB region.

3.5 Impact of by-catch mortality on the sub-population

Based on the count of 43 female pups and the derived estimates of 81 female pups, age-structured models indicated the Bunda Cliffs sub-population included 166 (low population size) or 302 females (high population size) at the beginning of the time series. This suggests that 123 or 221 females, not including pups, were exposed to by-catch mortality in shark gill-nets. Based on the lower population estimate of 166 females, by-catch rates were 0, 3.3, 6.5, 8.9 or 19.7% per breeding cycle (Table 6a and 6b), whereas for the higher estimate of 302 females, by-catch rates were 0, 1.8, 3.6, 4.9 or 10% per cycle (Table 6c and 6d).

The stable sub-populations did not change with zero by-catch, but declined under all other levels of by-catch examined (Table 6a and 6c; Figure 9a and 9c). The stable sub-population of 166 females went extinct after 64 breeding cycles if the by-catch level was 3.3% and 13 cycles if the by-catch level was 17.9% (Table 6a; Figure 9a). The stable sub-population of 302 females went quasi extinct after 161 breeding cycles if the by-catch level was 1.8% and in 30 cycles if by-catch level was 10% (Table 6c; Figure 9c). On average, quasi extinction times were 2.4 times longer in the large stable sub-population compared with the small stable sub-population.

The sub-population of 166 females with 5% intrinsic growth grew to 20,849 females over 100 breeding cycles in the absence of by-catch, but continued to grow even when the by-catch level was 3.3%, with 1163 females present after 100 breeding cycles (Table 6b; Figure 9b). However, it went quasi extinct in 177 breeding cycles when the by-catch level was 6.5% and in 17 cycles when the by-catch rate was 17.9%. On average, quasi extinction times were 2.3 times longer for the small increasing sub-population than the small stable sub-population. The sub-population of 302 females and 5% intrinsic growth grew to 37,283 females after 100 cycles in the absence of by-catch (Table 6d; Figure 9d) and continued to grow when the by-catch level was high as 4.9% (429 females after 100 cycles). However, this population went quasi extinct in 60 cycles when the by-catch level reached 10%.

Table 2. Summary of ASL pup counts from the 24 sites at Bunda Cliffs over 10 breeding seasons, between 1994 and 2007. The percentage of sites surveyed is also presented. Months in which surveys were conducted are presented in Figure 3. Some pup counts may have included juveniles from the previous season.

	Breeding and haul-out sites																								Summary	
Breeding season	B1	B1.1	B2	B3	B4	B5	B6	B7	B8	B9	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	% sites surveyed	total pups
1994	11	-	2	3	1	3	2	3	5	7	1	1	1	1	6	1	4	3	0	3	9	8	3	8	96	86
1995/1996	13	-	2	13	1	18	5	0	16	7	-	0	0	0	-	1	0	0	0	0	0	2	2	8	88	88
1996/1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
1999/2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
2001	0	3	3	16	16	16	3	0	0	0	2	-	-	-	0	0	0	0	-	0	-	1	0	3	79	63
2002/2003	-	-	-	9	0	-	0	0	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	14
2004	-	-	-	6	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	11
2005/2006	-	-	5	11	6	-	4	4	5	3	-	-	-	-	7	-	5	4	-	1	-	5	4	3	58	67
2006/2007	-	-	-	8	2	13	2	-	5	5	-	-	-	-	-	0	-	-	-	1	-	0	-	1	42	37

Table 3. Summary of morphometric, tracking and foraging data for nine lactating female ASLs tracked from two sites at Bunda Cliffs in 2006 and 2007. Deploymenet period (days) is also presented.

	Status & morphometric data			Tracking duration			Direction and distance summary				
							Distance (km)			Bearing	
Seal I.D.	Observed status	Axillary girth	Standard length	Deployed	Recording ceased	Days	Mean	S.D.	Max.	Mean	S.D.
Western site (B8): 2006											
55933	with pup	104.5	170.0	22-04-06	28-10-06	189	93	41	187	228	15
55962	lactating	95.0	164.0	23-04-06	21-01-07	273	65	29	181	211	22
55973	suckling	103.0	166.0	22-04-06	30-12-06	252	99	29	193	205	37
55975	lactating	98.5	162.0	23-04-06	05-01-07	257	74	40	158	174	29
Mean		**100.3**	**165.5**			**243**	**83**	**35**	**180**	**205**	**26**
Total						**971**					
Central site (B5): 2007											
55938	suckling	98.0	166.0	26-05-07	14-07-07	49	26	16	68	192	36
55940	lactating	96.0	161.0	26-05-07	28-06-07	33	39	16	63	168	22
55964	with pup	88.0	159.0	26-05-07	01-07-07	36	16	14	53	210	44
55974	lactating	–	–	27-05-07	27-07-07	34	25	20	66	172	53
55978	suckling	92.0	161.5	26-05-07	28-07-07	63	44	26	84	192	42
Mean		**93.5**	**162.0**			**43**	**30**	**18**	**69**	**187**	**39**
Total						**215**					
Overall mean		**96.9**	**163.7**			**132**	**53**	**27**	**117**	**195**	**33**
Grand total						**1186**					

Table 4. The proportion of time spent in the GABMP (SZ, CZ and MMPZ) and the GAB region (in MFAs) by lactating ASLs tracked from two sites at Bunda Cliffs in 2006 and 2007.

		Proportion of time spent			
Management regime	**Zone**	Western site % time	Central site % time	Combined % time	Combined hours
	Western Australia	30.5		26.8	5092.5
GABMP (SA DEH and DEWHA)					
	SZ & CZ	14.4	27.3	16.0	3041.7
	MMPZ	9.7	26.1	11.7	2214.8
	GABMP (Combined)	*24.1*	*53.4*	*27.7*	*5256.5*
	Unprotected (SA)	45.4	46.6	45.5	8640.6
	% total	**100.0**	**100.0**	**100.0**	
	Hours total	**16658.0**	**2331.6**		**18989.6**
	Km^2 total				
MFAs (AFMA)					
	101	41.7	30.2	40.3	7643.9
	102		62.8	7.6	1463.8
	104	27.8		24.4	4625.1
	105		7.0	0.9	164.4
	% total	**100.0**	**100.0**	**100.0**	
	Hours total	**16658.0**	**2331.6**		**18989.6**

Table 5. Summary of observed by-catch and rates of ASLs killed in shark gill-nets in the GABMP (SZ, CZ and MMPZ) and the GAB region (in MFAs where mortalities occurred). Estimates of by-catch mortality for the 2 year study period (January 2006 – December 2007; 1.36 ASL breeding cycles), for one 17.6 month breeding cycle (interpolated from the two year study period) and for the 10 year period from 3 years prior to the introduction of quota until the end of the study period (Jan 1998 – December 2007; 6.82 breeding cycles) are presented.

		Observer data summary				By-catch estimates					
		Jan 2006 – Dec 2007				*Jan 2006 – Dec 2007*			*One breeding cycle*	*Jan 1998 – Dec 2007*	
Management regime	**Zone**	Gill-net sets	Km of net	Mortalities	Rate per km	Fishing effort (km)	Mortality estimate	Coverage (%)	Mortality estimate	Fishing effort (km)	Mortality estimate
GABMP (SA DEH and DEWHA)											
	SZ & CZ	18	32.4	1	0.031	89.7	3	36.1	2	305.5	9
	MMPZ	27	113.4	2	0.018	448.4	8	25.3	6	1528.2	27
	Inside GABMP	**45**	**145.8**	**3**	**0.021**	**538.1**	**11**	**27.1**	**8**	**1833.7**	**38**
	Outside GABMP	**68**	**285.6**	**1**	**0.004**	**2754.7**	**10**	**10.4**	**7**	**14541.3**	**51**
MFAs (AFMA)											
	101	40	124.8	3	0.024	705.6	17	17.7	12	1193.4	29
	104	53	222.6	1	0.005	1192.8	5	18.7	4	5989.2	27
	GAB region*	**113**	**431.4**	**4**	**0.008**	**3292.8**	**31**	**13.1**	**22**	**16375.0**	**152**

* Includes MFAs 101 to 106 and 112

Table 6. Numerical summary of the responses of female ASL population trajectories at Bunda Cliffs since 1994 with lower and upper sub-population estimates (166 and 302 females, respectively), lower and upper trajectories of intrinsic growth (0% and 5%, respectively) and five levels of by-catch mortality (0 to 22 females in the first breeding cycle). Results are presented as quasi extinction times (number of breeding cycles to fall below 19 females), estimate of females in the sub-population after 100 breeding cycles in the year 2141 and estimates of females and female pups after 11 breeding cycles in 2010.

Initial (1994) population estimates			**Growth (%)**	**By-catch statistics**		**Sub-population response**			
Female population	Female pups	Females exposed	Excluding by-catch	Estimate in 1st cycle	% of females exposed	Quasi extinct (cycles)	Females 100 cycles	Females in 2010	Female pups in 2010
a. *Small, stable population*									
166	43	123	0	0	0	-	169	165	43
166	43	123	0	4	3.3	64	16	119	31
166	43	123	0	8	6.5	36	2	86	22
166	43	123	0	11	8.9	25	1	62	16
166	43	123	0	22	17.9	13	0	23	6
b. *Small, growing population*									
166	43	123	5	0	0	-	20849	297	77
166	43	123	5	4	3.3	-	1163	213	55
166	43	123	5	8	6.5	177	62	152	39
166	43	123	5	11	8.9	48	6	101	26
166	43	123	5	22	17.9	17	0	39	10
c. *Large stable population*									
302	81	221	0	0	0	-	305	304	82
302	81	221	0	4	1.8	161	66	254	68
302	81	221	0	8	3.6	77	14	209	56
302	81	221	0	11	4.9	59	7	176	47
302	81	221	0	22	10.0	30	1	103	28
d. *Large, growing population*									
302	81	221	5	0	0	-	37283	540	145
302	81	221	5	4	1.8	-	7711	450	121
302	81	221	5	8	3.6	-	1152	367	98
302	81	221	5	11	4.9	-	429	316	85
302	81	221	5	22	10.0	60	7	184	49

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994								X				
1995					X	X	X	X		X		
1996												
1997												
1998												
1999												
2000												
2001							X	X	X			
2002												
2003										X		
2004							X			X		
2005							X					
2006			X	X				X				X
2007				X								

Figure 3. Estimated timing of breeding among Australian sea lions at Bunda Cliffs between 1994 and 2007 (alternate light grey and dark grey lines). Months when surveys were undertaken are indicated with an 'X'. Timing of breeding estimated based on Shaughnessy (2004).

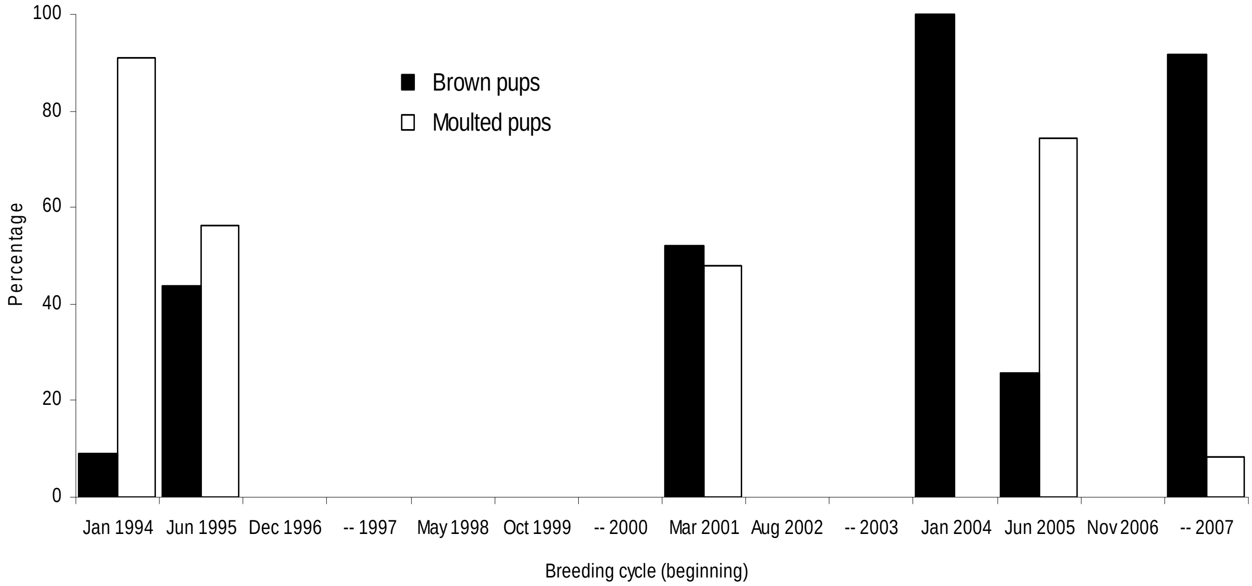


Figure 4. Percentage of brown and moulted Australian sea lion pups observed at Bunda Cliffs during surveys. Dates represent the month and yar in which breeding commenced, not the months that surveys were conducted.

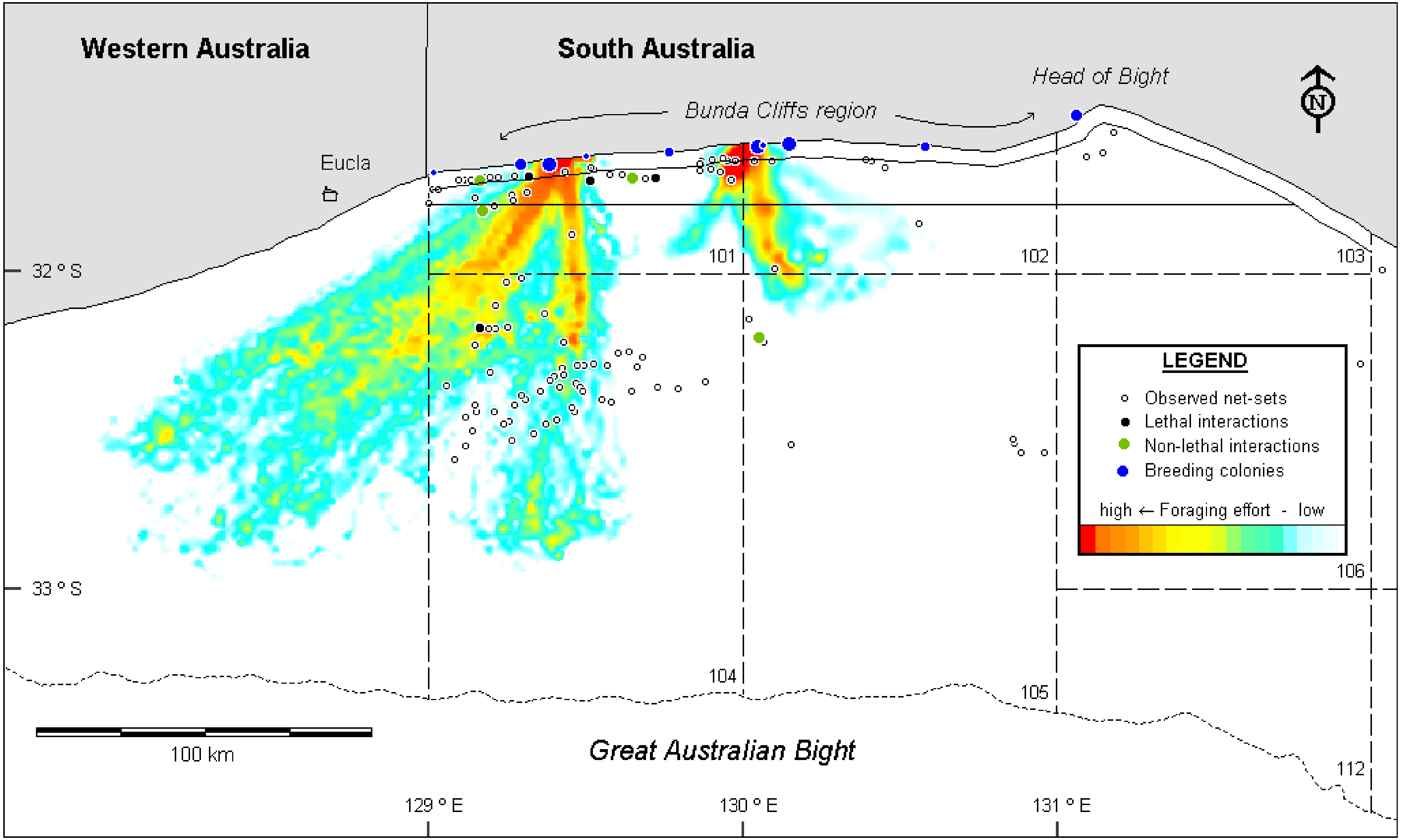
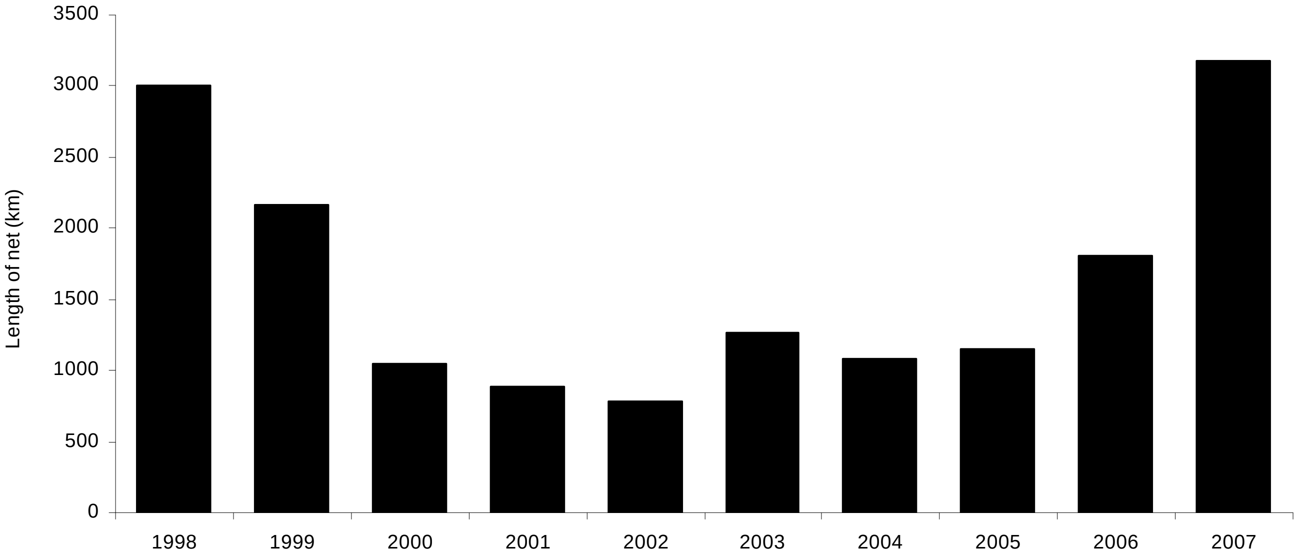
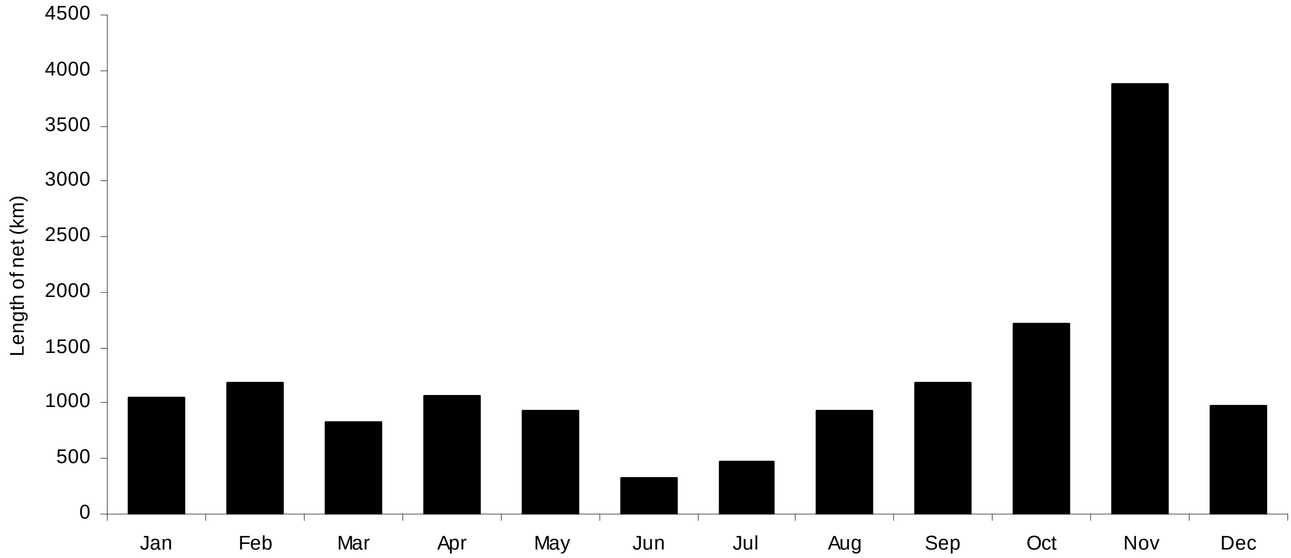


Figure 5. Summary of the spatial distribution of foraging effort of nine lactating ASLs tracked from two Bunda Cliffs colonies in 2006 and 2007. The location of breeding colonies, observed shark gill-net fishing activity, by-catch mortalities and non-lethal operational interactions are also presented.



Yearly trend – GAB region

Figure 6. Yearly (inter-annual) variation in shark gill-net fishing effort in the GAB region (AFMA MFAs 101 to 106 and 112), measured as kilometres of net set, in the 10 years between 1998 and 2007.



Monthly trend – GAB region

Figure 7. Monthly (intra-annual) variation in shark gill-net fishing effort in the GAB region (AFMA MFAs 101 to 106 and 112), measured as kilometres of net set, based on data collected over 10 years between January 1998 and December 2007.

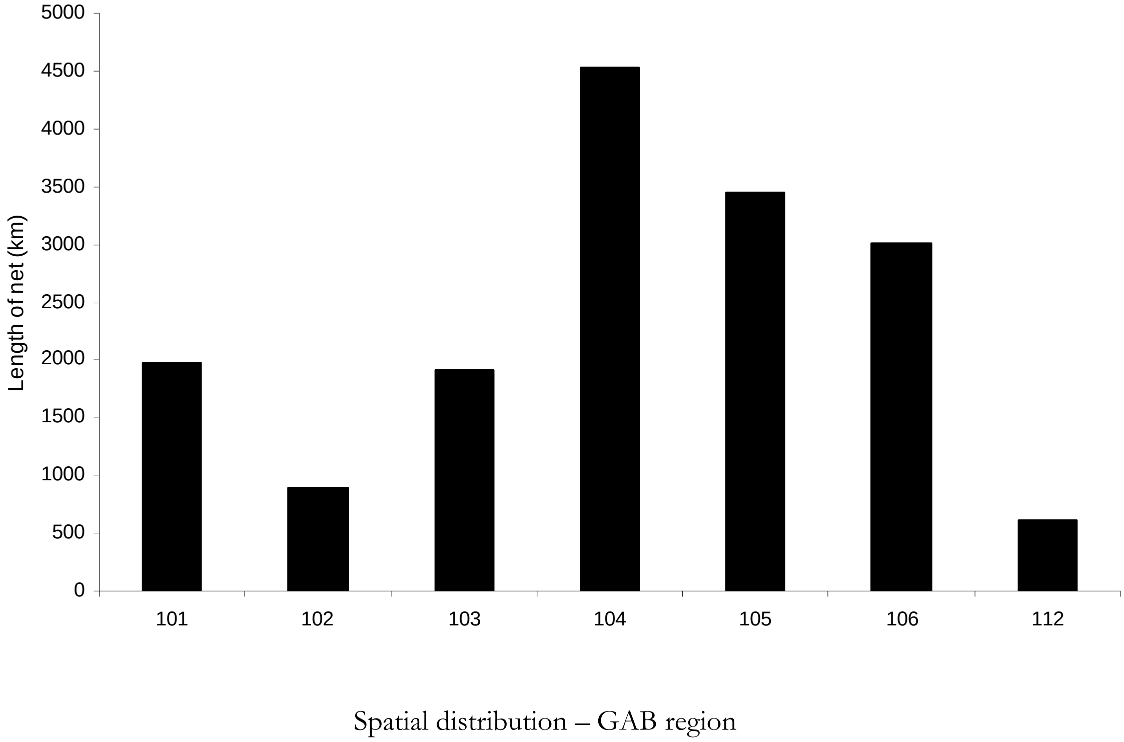


Figure 8. Spatial distribution of shark gill-net fishing effort in the GAB region (AFMA MFAs 101 to 106 and 112), measured as kilometres of net set.

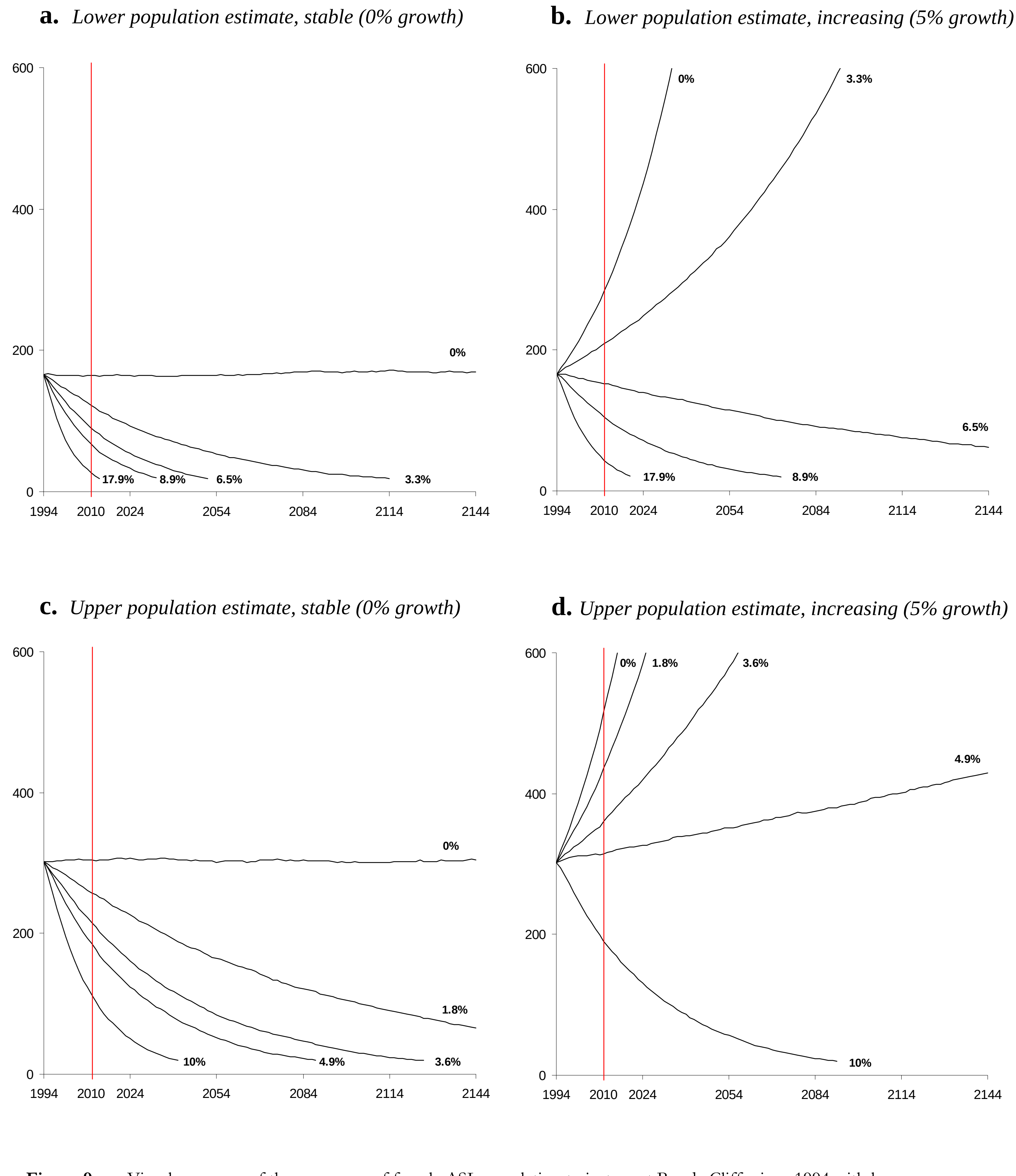


Figure 9. Visual summary of the responses of female ASL population trajectory at Bunda Cliffs since 1994 with lower and upper population estimates (166 and 302 females, respectively), lower and upper trajectories of intrinsic population growth (0% and 5%, respectively) and under five levels of shark gill-net by-catch mortality (0 to 22 females in the first breeding cycle). Results are presented as trajectories over 100 breeding cycles, either to the year 2141 or until they exceed 600 females or become quasi extinct (the number of females falls below 19). The red line depicts the status of the population under each scenario in 2010. The numbers next to each trajectory refer to the by-catch scenarios outlined in Table 6.

4. DISCUSSION

4.1 Trends in pup abundance and current status could not be determined

Despite efforts to monitor the ASL sub-population at Bunda Cliffs since 1994, their current status and trends in abundance remain unknown. The first survey of ASL pup abundance at Bunda Cliffs in 1994 provided the only reliable count, because it included observations at 23 of the 24 known breeding and haul-out sites (96%) and was undertaken at the end of the breeding season when pup numbers were likely close to their peak. There were 86 pups observed, with a total of 161 estimated in the sub-population. This equates to 43 and 81 female pups, respectively, based on a 1:1 sex ratio at birth. However, these results were 12 to 13 years old when this study commenced. More recent estimates of pup abundance could not be used because: i) the survey effort was low and varied; ii) about half of the surveys were undertaken outside the breeding season because they were opportunistically undertaken; iii) small juveniles may sometimes have been included in the pup count due to incorrect identification caused by the were observed from a large distance from the cliff top and iv) it was not possible to determine which sites had or had not been visited because the difference between dashes and zeros was indistinguishable in the database. Due to the uncertainty associated with these problems, the long term trend and current status of the sub-population is unknown. Future surveys to determine ASL pup abundance at Bunda Cliffs should include all 24 known sites and be made several times during the breeding season to determine the peak in pup abundance. Strict pup identification criteria should also be followed to distinguish moulted pups from small juveniles and data recording methods should adhere to scientifically rigorous protocols.

4.2 Sea lions spent substantial time foraging outside the GABMP

Female ASLs tracked from the western site at Bunda Cliffs only spent about one quarter of their time at sea within the GABMP. They travelled 83 km from their natal site on average and up to 193 km, typically travelling beyond MFA 101 to forage in MFA 104 and in waters off WA. These distances exceed those previously known for the species and are well beyond the boundary of the GABMP, situated only 15-16 km to the south and 35-36 km to the west of their natal site. In contrast, ASLs tracked from the central site spent about half of their time at sea within the GABMP and only travelled about one third the distance (mean 30 km; maximum 84 km), spending most of their time in coastal MFAs 101 and 102. Nonetheless, they still spent half of their time beyond the GABMP boundary, situated 21-22 km to the south of their natal site. These results demonstrate the importance of waters outside the GABMP for foraging ASLs based at Bunda Cliffs. They also indicate the potential range in foraging strategies used by ASLs from other sites along Bunda Cliffs. In addition, the results suggest each site may be a distinct population, further highlighting the vulnerability of ASLs in the GAB region. Importantly, the results suggest the GABMP is unable to completely protect ASLs from by-catch mortality in shark gill-nets, because they forage beyond its boundaries in waters where shark gill-netting is permitted throughout the year.

4.3 High rates of by-catch within the GABMP

Rates of operational interactions between ASLs and shark gill-netting in the GAB region were 5.3 times higher within the GABMP (0.021 mortalities per km of gill-net) compared with outside (0.004). Three of the four by-catch mortalities observed occurred in the GABMP during the six month period when it was open to shark gill-netting (one in the CZ and two in the MMPZ), between about 2 and 7 km from the Bunda Cliffs. These results demonstrate that opening the GABMP to shark gill-netting for half of the year reduces its effectiveness in protecting the ASL, which is a key aim of the GABMP management plans. A by-catch mortality rates of 0.035 ASLs per net-set was calculated across the GAB region in this study, which is about one third the rate reported for the Californian sea lion (*Zalophus californianus*) in the demersal halibut and angel shark gill-net fishery off California (0.1 per net-set; Julian and Beeson, 1998). It is unknown how the level of ASL by-catch reported in this study would compare to other fisheries if the individuals that fall all out the gill-net without being observed were included.

Although by-catch rates are higher inside the GABMP than outside, similar numbers of by-catch mortalities were estimated in each area because of the higher level of shark gill-netting effort outside the park. It was estimated that the numbers of by-catch mortalities were 11 inside and 10 outside the GABMP, over the two year study period. This equates to 38 inside and 51 outside the park over the last 10 years, since the park was proclaimed. These results suggest approximately one third to half of the by-catch mortalities estimated across the GAB region occurred within the GABMP. Estimates calculated from effort data and by-catch rates for the entire GAB region, excluding consideration of the GABMP, suggested 31 by-catch mortalities occurred during the two year study period and 152 have occurred since the park was proclaimed. These estimates are higher than the sum of those calculated separately for inside and outside the GABMP, because i) the by-catch mortality rate inside the GABMP was higher than outside, ii) fishing effort was higher outside than inside the park and iii) the level of observer coverage was approximately three times higher inside than outside. Despite these differences, opening the GABMP to shark gill-netting for half of the year reduces its effectiveness in protecting the ASL. ASLs also forage extensively outside the GABMP where substantial gill-netting occurs, indicating the park alone cannot entirely protect the Bunda Cliffs sub-population from the impacts of shark gill-netting.

The ASL by-catch rates calculated for the GAB region in this study are 116 times higher than those reported for SA in logbooks. This discrepancy may be partly explained by the technical difficulties associated with detecting ASL by-catch during normal fishing operations. All of the

ASL by-catch dropped out of the gill-net as it was lifted out of the water, just before it was hauled aboard the vessel. At this time, the attentions of the skipper and crew were predominantly focused on the deck of the vessel, where the catch was being landed. Consequently, the ASLs that fell from the net were not noticed by the skipper and crew. Based on the by-catch estimates obtained in this study, it seems likely that this situation may occur regularly. Some fishers in SA have suggested they kill a few to 20 ASLs each year (Shaughnessy et al., 2003), which is also higher than by-catch rates reported in logbooks.

4.4 Interpretation of risk analysis is limited by data quality

Overall, quantitative PVA predicted that i) stable sub-populations decline with any level of by-catch mortality, ii) growing sub-populations continue to grow until the by-catch mortality rate exceeded the intrinsic rate of growth, and iii) quasi extinction times are longer for larger sub-populations with higher growth rates. Even under the most optimistic scenarios modelled in this study, with a large population (302 females) and a high intrinsic growth rate (5%), the PVA predicted that low levels of by-catch mortality (up to 4.9%) would reduce the growth rate and the highest levels (10%) would result in decline. In the worst case scenarios, where the sub-population was small (166 females) and stable, quasi extinction was predicted in 13 breeding cycles under the highest rate of by-catch mortality (17.9%), which suggest quasi extinction of the Bunda Cliffs ASL sub-population could occur in the near future. In summary, the PVA predicted that the ASL sub-population at Bunda Cliffs would go quasi extinct in 13 and 177 breeding cycles, in 12 of the 16 scenarios where by-catch was included.

Despite these results, the lack of reliable information about status and demography of the ASL sub-population at Bunda Cliffs limits the capacity of the PVA to predict the sustainable level of by-catch mortality (Taylor, 1995; Ellner et al., 2002). This limitation prevented identification of the most likely scenario or sub-set of scenarios. However, quasi extinction times may be under-estimates for all scenarios modelled. Firstly, by-catch mortality may have been underestimated because some ASLs killed dropped out of the gill-net before they were seen by the observer. Secondly, the marked philopatry of ASLs in some regions (Campbell et al., 2008a) and the clear differences in foraging behaviour between the two sites suggest the colonies along the Bunda Cliffs may be genetically distinct. If this is the case, the impact of by-catch mortality would be greater than the results of the PVA suggest because smaller populations are more vulnerable to anthropogenic impacts (see Goldsworthy and Page, 2008). Thirdly, Allee effects, where reproductive success diminishes as the population size falls below a critical level, can accelerate declines (Beissinger and McCullough, 2002). In contrast, density dependent effects, such as competition for space and food, can reduce rates of population increase (Fowler, 1981; Clutton-Brock and Albon, 1984; Doige et al., 1984; Baldi et al., 1996; Goss-Custard and Southerland, 1997; Bradshaw et al., 2000b; Pistorius et al., 2001), suggesting the population size calculated for some scenarios may be overestimates.

As is the case in this study, PVA is often used to predict the fate of rare species or populations for which data are scarce or of low quality, both of which generate a high level of uncertainty (Ellner et al., 2002). For this reason, ecologists and resource managers should understand the limitations of data used in PVAs and the underlying statistical assumptions (Ellner et al., 2002; Reed et al., 2002). It has been suggested that data must be collected for five times the period over which future predictions are to be made in order for acceptable levels of certainty to be attained (Ellner et al., 2002). However, decisions about rare and declining species or populations must often be made quickly to ensure their conservation, before a long time series of data can be collected (Taylor, 1995; Brook et al., 2002; McCarthy et al., 2004). Nonetheless, the results of the PVA presented in this study should be used with caution and to augment alternative approaches for measuring, assessing and mitigating the impacts of fishery by-catch.

4.5 Summary and conclusions

The current status of ASLs at Bunda Cliffs is poorly understood despite the initial survey in 1994 and monitoring efforts made in the 12-13 years since then. Most of the observed ASL by-catch mortalities occurred in the GABMP, although the individuals tracked from Bunda Cliffs typically spent considerabl time outside the park in areas where shark gill-netting effort was higher. These results suggest equal numbers of ASLs are likely to be killed inside and outside the GABMP, even though one of the key aims of the park was to protect ASLs from anthropogenic impacts, such as shark gill-netting. For the most optimistic estimates of sub-population size and growth trajectory, all predicted levels of by-catch mortality diminished the capacity of ASLs to increase and the worst by-catch scenario caused the sub-population to decline. The least optimistic scenarios resulted in significant declines under low levels of by-catch mortality and quasi extinction in the near future under the highest by-catch rates. PVA may underestimate vulnerability of the sub-population to shark fishing because by-catch rates may be underestimated and breeding sites along Bunda Cliffs may be genetically distinct, increasing their vulnerable to by-catch mortality.

Despite the high level of uncertainty in the status of the Bunda Cliffs ASL sub-population, their status is likely to be at risk because i) gill-netting is allowed to occur within the GABMP for half of the year and ii) they also spend a substantial amount of time beyond the parks boundaries where gill-netting activities are permitted throughout the year. To increase the effectiveness of the GABMP in protecting ASLs at Bunda Cliffs from by-catch mortality in shark gill-nets, there is a need to reduce the level of ASL by-catch mortality within the GABMP and across the GAB region. To measure the effectiveness of the GABMP in protecting ASLs in the future, there is also a need to establish a rigorous program for monitoring pup abundance at Bunda Cliffs.

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