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Australian sea lions *Neophoca cinerea* at colonies in South Australia: distribution and abundance, 2004 to 2008

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ABSTRACT: The Australian sea lion *Neophoca cinerea* is an endemic species listed as vulnerable under the Commonwealth 'Environment Protection and Biodiversity Conservation Act' and as Endangered by IUCN. Assessing its abundance is difficult because of its supra-annual (17 to 18 mo) breeding cycle, and pupping seasons that are extended (about 6 mo but varying between colonies) and asynchronous in their timing between colonies. Based mainly on surveys at most sites in South Australia (SA) between 2004 and 2008, and information from the literature, estimates of abundance are provided for 39 breeding colonies and 9 haulout sites where pups are recorded occasionally. From this study it is estimated that in SA, 3119 Australian sea lion pups are born per breeding cycle, an increase on former estimates by at least 16% resulting from recognition of new breeding colonies, targeting surveys to coincide with maximum pup numbers and using mark-recapture procedures at some colonies. With the addition of 503 pups in Western Australia, the overall estimate of pup abundance for the species is 3622. This leads to an estimate of 14780 animals using the multiplier 4.08. Trend data for the Seal Bay colony on Kangaroo Island indicated that pup numbers decreased at 0.54% yr^{-1} in the 22 yr (16 pupping seasons) from 1985 to 2007. A cause of the decrease is believed to be bycatch in the demersal shark gillnet fishery, which overlaps with sea lion foraging areas nearby. Area closures declared during 2010 within several km of all Australian sea lion breeding sites in SA should reduce the incidence of bycatch mortality.

KEY WORDS: Australian sea lion · *Neophoca cinerea* · Otariid · Abundance · Distribution · Fishery bycatch

INTRODUCTION

The Australian sea lion *Neophoca cinerea* is 1 of 7 sea lion species in the world. Sea lions form around one-third of species in the Otariidae family of seals, which includes all fur seals and sea lions. Over recent decades there has been growing concern over the status of sea lion species. In the North Pacific Ocean, the Steller sea lion *Eumetopias jubatus* has been declared Endangered in parts of its range and is considered threatened with extinction in other parts (Trites et al. 2007). Although the total population of California sea lions *Zalophus californianus* in California (USA) and Mexico is increasing (Carretta et al. 2004), the Mexican stock is declining (Szteren et al. 2006). There have also been reductions in numbers of the Galapagos sea lion *Z. wollebaeki* (Alava & Salazar 2006), and the Japanese sea lion *Z. japonicus* is considered to be

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extinct (Wolf et al. 2007). Numbers of South American sea lions *Otaria flavescens* have declined considerably in recent years (Crespo & Pedraza 1991, Reyes et al. 1999, Schiavini et al. 2004), especially in the Falkland Islands (Thompson et al. 2005). The New Zealand sea lion *Phocarctos hookeri* (Chilvers et al. 2007) and Australian sea lion (McKenzie et al. 2005) have not recovered from historic sealing, and their population levels remain low.

The Australian sea lion is an Australian endemic, restricted to South Australia (SA) and Western Australia (WA). Its breeding range extends from The Pages Islands in SA to Houtman Abrolhos on the west coast of WA. Here, we report on its distribution and abundance in SA.

The Australian sea lion was subject to sealing in the late 18th and early 19th century (Ling 1999), resulting in a reduction in population size of unknown extent and extirpation of populations in Bass Strait and from many islands within their current range, such as East Waldegrave and Flinders Islands in SA (Shaughnessy et al. 2005, Robinson et al. 2008). It has not recovered since harvesting ceased, unlike the 2 fur seal species *Arctocephalus forsteri* and *A. pusillus doriferus* in southern Australia, for which recovery has been rapid in recent years (Shaughnessy et al. 1995, Kirkwood et al. 2005).

In February 2005, the Australian sea lion was listed as a Threatened species, in the Vulnerable category under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). In 2008, it was classified as vulnerable under the SA National Parks and Wildlife Act 1972 and as Endangered by the International Union for the Conservation of Nature (IUCN) on the basis of its small, genetically fragmented population and the risk of extinction in most major colonies from fishery bycatch (Goldsworthy & Gales 2008). The species forms the basis of tourism ventures on Kangaroo Island and elsewhere in SA and WA (Kirkwood et al. 2003).

Several aspects of the breeding biology of the Australian sea lion are unusual. A supra-annual breeding cycle of 17 to 18 mo was first reported by Ling & Walker (1978) and has been recorded in other studies (Gales et al. 1994, Shaughnessy et al. 2005). A consequence of the 17 to 18 mo breeding cycle is that pupping seasons do not occur at the same time each year. Furthermore, timing of pupping seasons is not synchronous between colonies (Gales et al. 1994), as illustrated in Fig. 1 for colonies in SA from 1995 to 2012. Population genetic studies indicate little or no interchange of females between breeding colonies, even those separated by short distances (Campbell et al. 2008).

Duration of pupping seasons varies between colonies. At Seal Bay it extends for 7 to 8 mo (McIntosh et al. 2006, Ling & Walker 1976), whereas at smaller colonies such as Nicolas Baudin Island it extends for only 5 mo (Shaughnessy 2008). This is much longer than pupping seasons for other seal species, most of which extend for about 2 mo (King 1983). These characteristics pose difficulties for assessing Australian sea lion abundance, because timing of surveys can affect the number of pups counted.

In a review of the biology of the Australian sea lion, Goldsworthy et al. (2009b) listed 76 breeding sites (48 in SA) and 151 locations where the species has been recorded ashore without evidence of breeding (haul-out sites, 91 in SA). Based on pup count data collated from many sources, Goldsworthy et al. (2009b) estimated that a minimum of 3610 pups were born per breeding cycle in recent years, of which 86% were in SA (3107 pups) and 14% in WA.

In SA, most islands with sea lion breeding colonies are in Conservation Parks managed by the SA Department for Environment and Natural Resources (DENR; Robinson et al. 1996). Aspects of the ecology of the Australian sea lion and threats to which it is subjected were described by Goldsworthy et al. (2009b).

The present paper updates and extends data for sea lion colonies on the west coast of Eyre Peninsula presented by Shaughnessy et al. (2005). It documents pup abundance of Australian sea lion colonies in SA based on surveys conducted between April 2004 and April 2008. Almost all of the information is from unpublished reports, which include survey results in greater detail as well as calculations. New data are presented for 1 breeding colony. Several colonies were not visited during the study period, and reference is made to published estimates for them. The area covered extends from The Pages Islands in the south-east to the cliffs of the Great Australian Bight in the north-west (Fig. 2).

MATERIALS AND METHODS

Study colonies. Descriptions of islands that support sea lions were provided by Robinson et al. (1996) from the biological survey of SA offshore islands, and details of colonies were provided by Shaughnessy

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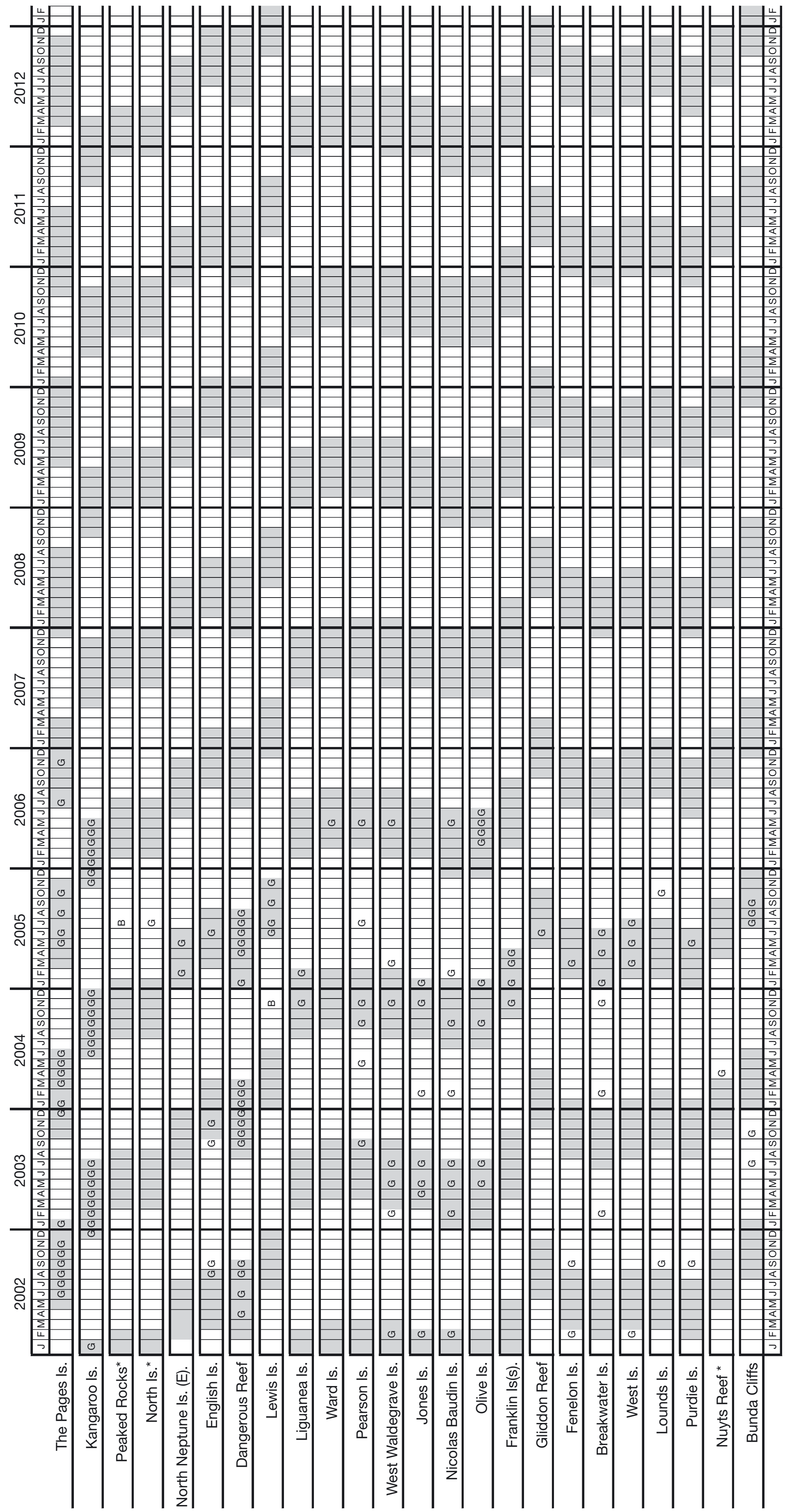
Fig. 1. *Neophoca cinerea.* Diagrammatic representation of pupping season commencement and duration at Australian sea lion colonies in South Australia between 2002 and 2006, with predicted seasons to 2012 (from Goldsworthy et al. 2007a). G: ground survey; B: boat-based survey. Shaded areas show actual or predicted breeding seasons, which span 6 mo for small colonies and 7 to 8 mo at larger colonies, except at The Pages Islands, where it appears to be longer or more variable. Asterisks mark sites of uncertain status and season commencement that require further surveys. Sites where breeding has been reported but data are lacking (unshaded areas) include: South Neptune, Albatross, Four Hummocks (N), Price, Rocky North, Greenly and Masillon Islands



2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
J F M A M J J A S O N D
The Pages Is.
Kangaroo Is.
Peaked Rocks*
North Is.*
North Neptune Is. (E).
English Is.
Dangerous Reef
Lewis Is.
Liguanea Is.
Ward Is.
Pearson Is.
West Waldegrave Is.
Jones Is.
Nicolas Baudin Is.
Olive Is.
Franklin Is(s).
Gliddon Reef
Fenelon Is.
Breakwater Is.
West Is.
Lounds Is.
Purdie Is.
Nuyts Reef*
Bunda Cliffs

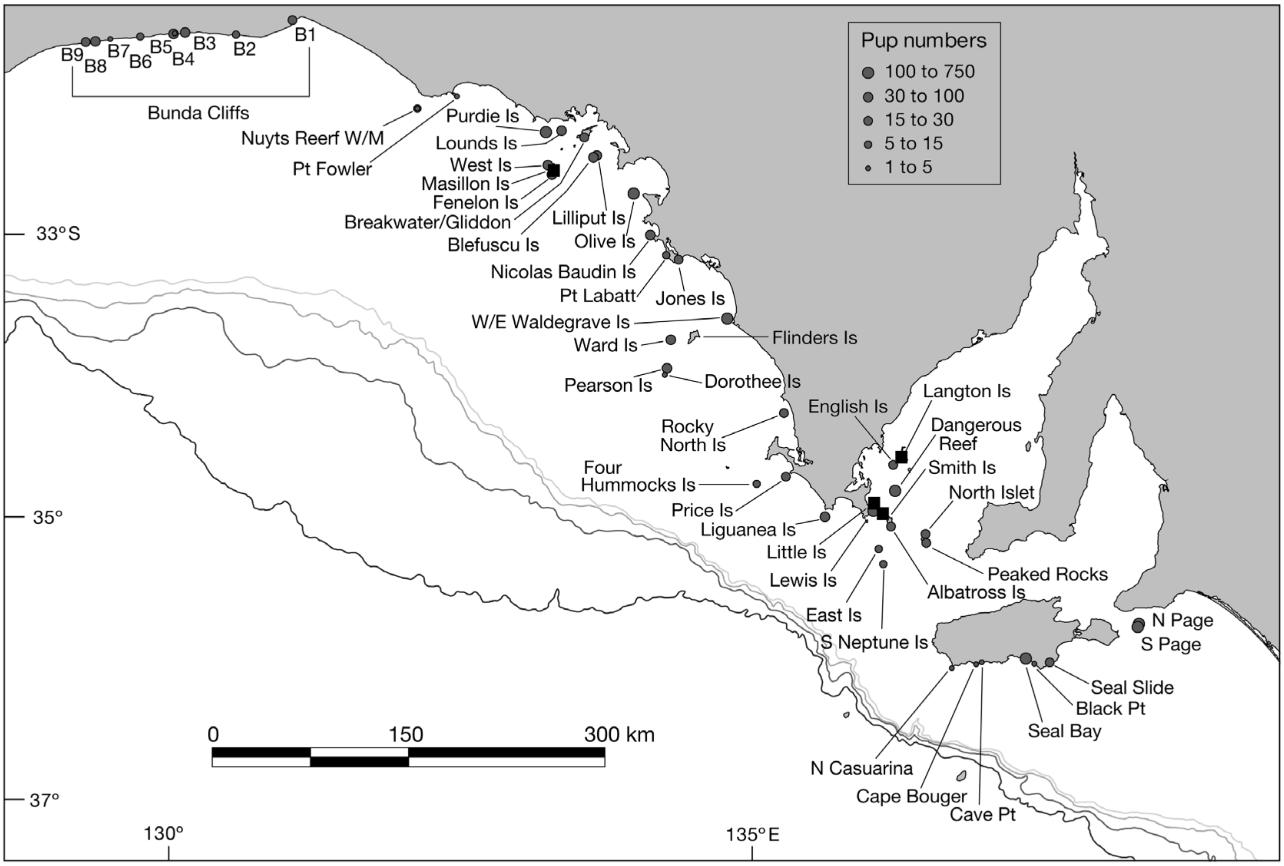


Fig. 2. *Neophoca cinerea.* Coastline of South Australia showing the location of sites used by Australian sea lions. Circles: breeding colonies and haulout sites with occasional pupping, with size of the circles indicating relative colony size. Black squares: potential breeding sites. The location of 2 former breeding colonies is also shown: Flinders Island and East Waldegrave Island. Depth contours are 200, 500, 1000 and 2000 m

et al. (2009a). Colonies are listed in Table 1 in order of decreasing longitude, following the order in Appendix 1 of Goldsworthy et al. (2009b), which is also the source of geographical positions.

Estimating pup numbers by counting. The usual method for monitoring abundance of Australian sea lions has been for 2 or 3 observers to walk through a colony counting live and dead pups; these are referred to as 'direct counts'. In general, only single counts were possible because the disturbance caused some pups to hide under rocks or enter the sea. If subsequent visits to the colony were planned, dead pups were marked with paint or covered with rocks to avoid recounting. Pup numbers are chosen as the index of abundance because pups are easily recognisable, most stay ashore when people enter a colony, and they are manageable if the estimating technique requires handling (Berkson & DeMaster 1985). In addition, most pups are ashore at one time, unlike other age classes in which a variable proportion is ashore. For 2 colonies with difficult access (Albatross Island and Masillon Island), counts were made from a vessel. Point Labatt colony is at the base of a steep cliff, and counts were made from the cliff top.

Pupping seasons last for several months, and the cumulative number of pups born increases sigmoidally (Fig. 3). For each colony, the first visit for a pupping season was timed to be near its commencement based on predictions in Fig. 1. The number and size of pups on the first visit was used to refine the estimate of when pupping had begun. For instance, pups aged less than 4 wk can be recognised by their small size, loose skin folds, and a relative lack of coordination. In addition, many pups aged less than 3 wk have a relatively pale crown and dark mask across their face (Ling 1992). After estimating the date of the beginning of a pupping season, a visit calculated to be near its end was scheduled, when maximum pup numbers were expected. If only a single visit was made to a colony, it was scheduled to be about a month before the pupping season was predicted to end, to coincide with maximum pup numbers ashore. Near the end of a pupping season, only small numbers of pups are born daily and hence the timing of the visit to count at the end of the season

Table 1. *Neophoca cinerea.* Best estimates of abundance of Australian sea lion pups at 39 breeding colonies and 9 haulout sites with occasional pupping in South Australia, based on surveys in unpublished reports from 2004 to 2008 and estimates from the literature. Estimates include cumulative counts of dead pups. Estimation methods are: (1) Mark-recapture (Petersen), (2) Direct count, (3) Cumulative mark and count. For breeding colonies in which the Petersen estimate was calculated, 95% confidence limits are included in brackets below the estimate of pup numbers

Site	Latitude, longitude	Estimated no. of pups	Date	Method	Source
Breeding colonies					
North Page Is.	35.76° S, 138.30° E	258 (243–272)	Oct 05	1	Shaughnessy (2005b)
South Page Is.	35.77° S, 138.29° E	331 (318–345)	Oct 05	1	Shaughnessy (2005b)
Seal Slide, Kangaroo Is.	36.03° S, 137.54° E	16 (14–18)	Oct 07	1	Goldsworthy et al. (2008a)
Seal Bay, Kangaroo Is.	36.00° S, 137.33° E	260 (254–272)	Dec 07	1	Goldsworthy et al. (2008b)
Peaked Rocks	35.19° S, 136.48° E	24	Mar 90	2	Gales et al. (1994)
North Islet	35.12° S, 136.48° E	28	Jul 05	2	Shaughnessy et al. (2009a)
Dangerous Reef	34.82° S, 136.22° E	709 (636–783)	Jan 07	1	Goldsworthy et al. (2007b)
English Is.	34.64° S, 136.20° E	27	Jun 05	2	Shaughnessy et al. (2009a)
Albatross Is.	35.07° S, 136.18° E	15[a]	Jul 05	2	Shaughnessy et al. (2009a)
South Neptune, Main Is.	35.33° S, 136.11° E	6	Feb 08	2	S. Goldsworthy, present study
East Is., North Neptune	35.23° S, 136.07° E	14	May 05	2	Shaughnessy et al. (2009a)
Lewis Is.	34.96° S, 136.03° E	131 (116–146)	Jul 07	1	Goldsworthy et al. (2008a)
Liguanea Is.	35.00° S, 135.62° E	43	Nov 04	2	Shaughnessy et al. (2009a)
Price Is.	34.71° S, 135.29° E	25	Jan 96	2	Shaughnessy et al. (2005)
Rocky Is. North	34.26° S, 135.26° E	16	Jan 96	2	Shaughnessy et al. (2005)
Four Hummocks Is. (north islet)	35.76° S, 135.04° E	12	Jan 96	2	Shaughnessy et al. (2005)
West Waldegrave Is.	33.60° S, 134.76° E	157	Jul 03	2	Shaughnessy et al. (2005)
Jones Is.	33.19° S, 134.37° E	15	Nov 07	3	Goldsworthy et al. (2008a)
Ward Is.	33.74° S, 134.28° E	45	May 06	2	D. Armstrong, in Robinson et al. (2008)
Pearson Is.	33.95° S, 134.26° E	35	Jul 05	2	K. Peters & B. Page, in Goldsworthy et al. (2009b)
Point Labatt	33.15° S, 134.26° E	6	Mar 05	2	Shaughnessy (2005a)
Nicolas Baudin Is.	33.02° S, 134.13° E	98	May 06	2	Shaughnessy (2008)
Olive Is.	32.72° S, 133.97° E	206 (191–223)	Jun 06	1	Goldsworthy et al. (2007a)
Lilliput Is.	32.45° S, 133.67° E	64 (62–69)	Feb 08	1	Goldsworthy et al. (2009a)
Blefuscu Is.	32.46° S, 133.64° E	99 (92–106)	Feb 08	1	Goldsworthy et al. (2009a)
Gliddon Reef	32.32° S, 133.56° E	7	Jun 05	2	Shaughnessy et al. (2009a)
Breakwater Is.	32.32° S, 133.56° E	17	Jun 05	2	Shaughnessy et al. (2009a)
Lounds Is.	32.27° S, 133.37° E	34	Apr 08	2	Goldsworthy et al. (2009a)
Fenelon Is.	32.58° S, 133.28° E	40	Apr 08	2	Goldsworthy et al. (2009a)
West Is.	32.51° S, 133.25° E	56	May 05	2	Shaughnessy et al. (2009a)
Purdie Is.	32.27° S, 133.23° E	132	May 05	2	Shaughnessy et al. (2009a)
Nuyts Reef (west islet)	32.12° S, 132.13° E	12	Apr 04	2	Shaughnessy et al. (2005)
Bunda Cliffs B1	31.57° S, 131.06° E	15	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B2	31.59° S, 130.58° E	5	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B3	31.58° S, 130.13° E	31	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B5	31.59° S, 130.03° E	43	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B6	31.60° S, 129.76° E	12	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B8	31.64° S, 129.38° E	38	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B9	31.65° S, 129.31° E	17	Sep 95	2[b]	Goldsworthy et al. (2003)
Subtotal		3099			
Haulout sites with occasional pupping					
Black Point, Kangaroo Is.	36.04° S, 137.41° E	1	Jan 02	2	Shaughnessy et al. (2009b)
Cave Point, Kangaroo Is.	36.03° S, 136.96° E	3	Feb 90	2	Shaughnessy et al. (2009b)
Cape Bouguer, Kangaroo Is.	36.04° S, 136.91° E	3	Feb 99	2	Shaughnessy et al. (2009b)
North Casuarina Is.	36.07° S, 136.70° E	3	Feb 96	2	Shaughnessy et al. (2009b)
Dorothee Is.	34.00° S, 134.25° E	1	Jan 96	2	Shaughnessy et al. (2005)
Point Fowler, Camel-foot Bay	32.01° S, 132.44° E	1	Aug 94	2	Dennis & Shaughnessy (1996)
Nuyts Reef (middle islet)	32.14° S, 132.14° E	3	Mar 90	2	Gales et al. (1994)
Bunda Cliffs B4	31.59° S, 131.06° E	2	Sep 95	2[b]	Goldsworthy et al. (2003)
Bunda Cliffs B7	31.62° S, 129.51° E	3	Sep 95	2[b]	Goldsworthy et al. (2003)
Subtotal		20			
Total		3119			

[a]Partial count from a boat. [b]Based on data presented by Dennis & Shaughnessy (1996); the 9 Bunda Cliffs sites are also referred to as Great Australian Bight (GAB) 1 through 9

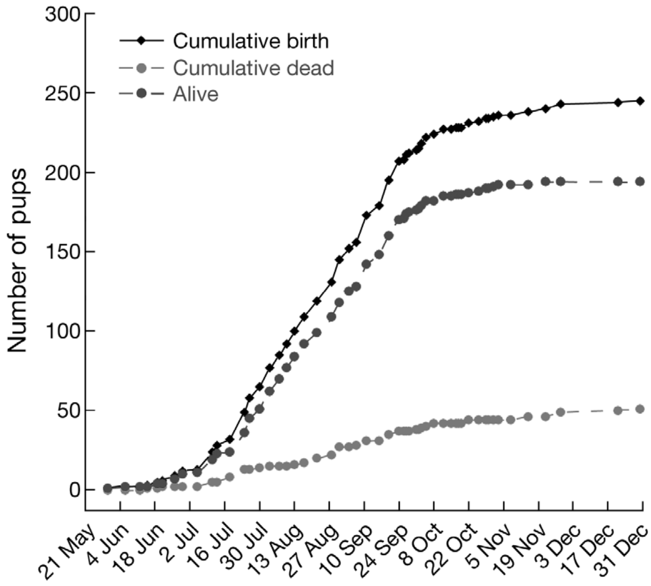


Fig. 3. *Neophoca cinerea.* Changes in the number of cumulative pup births, deaths, and live pups counted during twice-weekly surveys of Australian sea lion pups at Seal Bay between 30 May and 30 December 2007 (from Goldsworthy et al. 2009b)

is not critical. Several visits during a pupping season improved the accuracy of the count of dead pups and assisted in assessing how the pupping season was progressing.

Classifying young Australian sea lions can be difficult because moulted pups can be confused with small juveniles of similar size born in the previous pupping season, most of which are older than 18 mo. Small juveniles can be recognised by their cranial development, particularly their longer noses. When the lanugo coat of pups is moulted at about 5 mo of age, it is replaced with a silver grey and cream pelage. When juveniles born in the previous pupping season moult aged about 18 mo, their emerging silver grey coat shows through their old outer hair, which is ginger coloured and differs from that of recently moulted pups.

Estimating pup numbers with marked pups. There are 2 biases in determining the abundance of Australian sea lion pups by direct counting: availability bias and sightability bias (Shaughnessy et al. 2006). Availability bias results from pups being born over several months, and arises because some have not been born at the time of counting or, near the end of the pupping season, some pups may have moved away or be in the sea nearby. Consequently, single estimates are likely to underestimate the number of pups born in the pupping season. Sightability bias may be especially important for live pups not attended by an adult female, which are not always easy to see, especially if they are solitary and sleeping in a rock hole or under a bush. Furthermore, in some colonies pups run away from counters and are easily missed.

In colonies where several visits per pupping season were possible, pups were marked to improve the accuracy of estimates by reducing the sightability bias, i.e. to reduce the problem of pups that were overlooked during direct counting (Goldsworthy et al. 2007a, 2008a). For small colonies (<40 pups), a cumulative mark and count method was developed in which each pup caught was counted and given the same mark by clipping a patch of hair on the back and/or marked with a microchip inserted in the midline of the back. At each visit, additional pups were marked if possible, numbers of marked, unmarked and dead pups were recorded, and dead pups were marked. Pup numbers were estimated at each visit from the sum of the number of pups marked, the cumulative number of dead pups and the number of live unmarked pups. Even in a small colony, not all pups present are visible at each visit; knowing how many had been marked improved the accuracy of each estimate. The maximum of the estimates from each visit was taken as the pup production estimate for the season.

In some large colonies (>40 pups), mark-recapture techniques were used at the end of the pupping season when the maximum number of pups was expected (Goldsworthy et al. 2007a, 2008a). Pups were marked by clipping hair on the back or by applying individually numbered tags to the fore-flippers. The marking team moved through each breeding colony catching pups that were readily available and distributing their effort uniformly. Recapture sessions covered the whole of each colony and were conducted visually without handling pups. There were several recapture sessions at each colony over 1 or 2 d; they began at least 1 d after pups had been marked in order to allow marked and unmarked pups to mix.

By distributing marks and conducting recapture sessions uniformly throughout the entirety of each breeding colony, the sampling process at resighting should be random with respect to the marking process, which is an important assumption of mark-recapture estimation. Care was taken to avoid recording pups more than once in each recapture session.

Statistical procedures used were the Petersen estimate plus counts of the cumulative number of dead pups. The estimate of live pup numbers (N) was calculated using a variation of the Petersen method (Seber 1982), with the formula

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

where M is the number of marked pups at risk of being sampled during recapture operations, n is the number of pups examined in the recapture sample, and m is the number of marked pups in the recapture sample. The variance (Var) of this estimate was calculated from

$$\text{Var} = \frac{(M+1)(n+1)(M-m)n-m)}{(m+1)^2(m+2)} \quad (2)$$

There were several mark-recapture estimates (N_j) for each colony (where j is the jth estimate), 1 from each recapture session. They were combined by taking the mean (N) for each colony using formulae from White & Garrott (1990):

$$N = \sum_{j=1}^{q} N_j / q \quad (3)$$

where q is the number of estimates for the individual colony (i.e. the number of recapture sessions). The variance of this estimate was calculated from

$$\text{Var } N = \frac{1}{q^2} \sum_{j=1}^{q} \text{Var } (N_j) \quad (4)$$

and 95% confidence limits were calculated from

$$N \pm \left\{1.96 \times [\text{Var } (N)]^{1/2}\right\} \quad (5)$$

For Seal Bay on Kangaroo Island, a more detailed approach was used because the colony extends for 2.5 km. Several methods were developed to monitor pup abundance: twice-weekly surveys to record all new births and deaths, the total number of pups marked with microchips, and mark-recapture using the Petersen estimator on 1 occasion near the end of the pupping season, plus direct counts of pups in an inaccessible part of the colony, Pup Cove (McIntosh 2007, Goldsworthy et al. 2008b).

During visits to colonies, behaviour of adult sea lions was noted to determine if a pupping season was imminent, continuing or finished. When adult males maintain several metres between each other and herd adult females, a pupping season is imminent or underway. If breeding has ended, adult males display a lack of interest in each other. Other indications that a pupping season has finished are that the smallest pups are older than 3 wk and that the largest pups have moulted completely.

Selecting best estimates of pup abundance in colonies. For some colonies, estimates were made in several pupping seasons and by more than 1 method; they are provided for each colony in the supplement at www.int-res.com/articles/suppl/n013p087.pdf. Mark-recapture estimates were used as best estimates where they were available because they are considered to be less biased than direct counts, in which some pups are overlooked. If only direct counts were available, the most recent was used, unless a count from an earlier season was considered more accurate. For example, counts obtained during visits to a colony early in a season were discarded in preference to a count obtained when maximum pup numbers were expected. In general, the largest estimate for each colony in 1 of the pupping seasons of the study period was taken as the best estimate because many estimates are likely to be biased downwards, being based on visits to colonies at non-optimal times (i.e. before or after pup numbers reached a maximum) and/or on non-optimal methods (e.g. direct counting).

Classification of sites used by Australian sea lions. We follow the classification of Australian sea lion colonies described by the National Seal Strategy Group & Stewardson (2007), which refers to surveys conducted in the last 20 yr: (1) breeding colony, 5 or more pups recorded in at least 1 survey, (2) haulout site with occasional pupping, 1 to 4 pups recorded in at least 1 survey, (3) haulout site, areas frequented by sea lions where pups have not been recorded.

RESULTS

Breeding colonies

Best estimates of Australian sea lion pup numbers in 39 breeding colonies and 9 haulout sites with occasional pupping in SA are summarised in Table 1, along with the dates the estimates were made, the methods used and sources of information. For breeding colonies in which the Petersen estimate was calculated, 95% confidence limits are included in Table 1 with the estimate of pup numbers. For these 48 sites, estimates of pup numbers in SA total 3119, with 1 contribution for each site between 2004 and 2008. Pup population estimates for 26 of the breeding colonies from which best estimates have been chosen are from unpublished reports; details are provided in the supplement. The other 13 breeding colonies and all 9 haulout sites were not visited during this study; the most recent pup abundance estimates for these have been collated in Table 1 from the literature and unpublished reports. Some sites were only visited once, when small numbers of pups were seen (e.g. Price, Rocky North and Four Hummocks), and it is likely that pup numbers for each are underestimated.

Potential breeding colonies

Four islands in SA are potential breeding colonies because pups have been reported there. Three are in southern Spencer Gulf: Langton (34.60° S, 136.25° E), Smith (34.99° S, 136.03° E) and Little Islands (34.95° S, 136.03° E). At Langton and Little Islands, large pups were seen during surveys in 2005. Because they could have moved there from nearby breeding colonies (Dangerous Reef and Lewis Island, respectively), those islands should be considered as haulout sites unless better evidence for pupping is obtained.

At Smith Island, no pups were seen during a ground survey in November 2004 or from boats circling the island in June and July 2005. Previously, brown pups were reported there from an aerial survey in December 1995 (Shaughnessy et al. 2005). The island may have been misidentified during that aerial survey or the animals misidentified as pups.

The fourth potential breeding site is Masillon Island (32.56° S, 133.28° E) in Nuyts Archipelago, where 9 pups were reported in September 2002 (Robinson et al. 2003). They were presumably on the island's only beach, on its northern side; any pups born there would have a precarious time in high swells because the beach is narrow and the backing cliffs are steep. It seems likely that those pups had moved to Masillon Island from nearby Fenelon Island, where Robinson et al. (2003) reported brown pups on the same day. At Masillon in March and May 2005, no pups were seen among sea lions viewed from a boat and none were visible from a helicopter in April 2008. Therefore, Masillon Island should be considered as a haulout site, and monitored as a potential breeding colony.

DISCUSSION

Breeding sites of the Australian sea lion in SA

Five new breeding colonies were reported by Shaughnessy et al. (2005), who predicted that further colonies remained to be found in SA, and 5 are documented in the present study: East Island (North Neptunes), Lewis Island, Point Labatt, Gliddon Reef and Breakwater Island. Only small numbers of pups have been reported at several of the 48 breeding sites, highlighting the need to maintain their conservation status. Modelling by Goldsworthy & Page (2007) indicated that small colonies are particularly susceptible to extinction, even in the absence of any anthropogenic mortality such as that caused by fishery bycatch.

Potential breeding colonies

Four potential breeding sites are reported here. Thirteen such sites in SA were listed by Gales et al. (1994, their Fig. 2B), of which 5 have since been described as breeding colonies: East Island (North Neptunes, this study) and Price, Rocky North, Four Hummocks and West Waldegrave Islands, and 1 (Dorothee Island) as a haulout site with occasional pupping (Shaughnessy et al. 2005). For the other 7 potential breeding sites of Gales et al. (1994), no evidence has been found for breeding; however, search effort has been minimal.

The status of Middle Nuyts Reef remains uncertain, although it is recorded as a haulout site with occasional pupping in Table 1. It was included as a breeding site by Gales et al. (1994) on the basis of 3 dead pups found during a ground survey in March 1990. No pups were seen in a ground survey in April 2004 when 12 were on nearby West Nuyts Reef (Shaughnessy et al. 2005).

Comparison with previous pup abundance estimates

Estimates of abundance of Australian sea lions in SA resulted in a total of 3119 pups (Table 1), which differs slightly from an estimate by Goldsworthy et al. (2009b) because recent estimates for Lilliput and Blefuscu Islands are included. The present estimate exceeds 3 recent estimates of pup abundance in SA by at least 16%: 2115 by Goldsworthy et al. (2003), 1994 by McKenzie et al. (2005) and 2674 by Goldsworthy & Page (2007). The increase follows recognition of new breeding colonies, targeting visits for estimating pup numbers to coincide with maximum numbers ashore and incorporating a more recent estimate for Dangerous Reef (where numbers increased substantially). Furthermore, increases in large colonies follow the use of a mark-recapture estimating procedure to reduce sightability bias.

For the population of Australian sea lions in SA, this leads to an overall estimate of 12 726 animals using the multiplier 4.08 derived by Goldsworthy & Page (2007). With the addition of 503 pups from WA (summarised by Goldsworthy et al. 2009b), a minimum of 3622 pups are born per breeding cycle across the species' range, 86% of which are in SA and 14% in WA. The overall abundance estimate for the species is 14 780 animals.

For the 48 sites with pups in SA, the average colony size is 65 pups; for the 39 breeding colonies, the average size is 79 pups. It is important to continue monitoring the size of small colonies because they are most at risk of extinction from fishery-induced bycatch mortality (Goldsworthy & Page 2007).

Improving pup abundance estimates

This study highlights the importance of making several visits to a colony to estimate pup abundance. A visit early in the pupping season enables the estimate of its commencement date to be improved after judging the age of pups present. This enables a visit to be scheduled when the maximum number of pups is expected. Several visits to a colony are useful for estimating numbers of dead pups, some of which could be overlooked if there were only 2 visits, 1 at the beginning of the pupping season and another near the end.

Mark-recapture estimates of pup numbers are an improvement on direct counts because they are more accurate. In large colonies they exceed direct counts: North Page and South Page Islands in 2005, where an average of 32% more pups were estimated by this technique than by direct counting (from data in Shaughnessy 2005b), Seal Bay in 2002–03 (87% more pups; McIntosh et al. 2006), Dangerous Reef in 4 pupping seasons between 1999 and 2006–07 (25% more pups; Goldsworthy et al. 2007b) and Olive Island in 2005–06 and 2007 (25% more pups; Goldsworthy et al. 2007a). Estimates of pup numbers in other large colonies by mark-recapture, and in small colonies by the cumulative mark and count method, should improve accuracy of abundance estimates and may result in larger estimates for Australian sea lions in SA than those presented here.

The protocol for estimating pup numbers in breeding colonies has been improved by scheduling visits close to when the number of pups reached its maximum for the pupping season, taking into account dead pups and using the mark-recapture method with the Petersen estimate when maximum pup numbers are expected. Estimating abundance of Australian sea lion pups is difficult because of the long breeding season during which some pups may move away from a colony before the maximum is reached, asynchrony of pupping seasons, physical barriers in colonies that make pups difficult to locate and rule out techniques like aerial photography, and the remoteness of many colonies which makes access difficult.

Estimates of pup abundance need to be refined further, by accounting for pups that might move away from a colony before the maximum is reached and improving the estimation procedure for dead pups (many of which are difficult to see). Emigration has been noted from Seal Bay, based on movements of tagged pups to other sites on Kangaroo Island (Ling & Walker 1979). Emigration was also responsible for pups seen at Lewis Island between March and July 2007 which had been marked at Dangerous Reef; they were taken into account in estimating pup numbers at Lewis Island (Goldsworthy et al. 2008a). In those instances, the emigration was recorded near or after the end of the breeding season of the source colony, when pups are large and mobile.

Recent assessments of abundance of Australian sea lion pups in a colony have involved several visits (usually 4) separated by about 1 mo. At each visit, pups are marked on both fore-flippers with uniquely numbered tags; on the first visit, dead pups are counted (D_1) and marked to avoid recounting; and, after the first visit, tag numbers of previously marked pups are recorded (Goldsworthy et al. 2010b). The first visit is made about 3 mo after the first pups are born, by which time many are large enough to be tagged and even the oldest of them are still ashore. The number of pup births between 2 consecutive visits (i and i–1) is estimated from the difference between the Petersen estimate on the latter visit (N_i) and the product of the Petersen estimate on the former visit (N_{i-1}) and the apparent survival of pups between the 2 visits. The latter is calculated from the proportion of marked pups known to be alive on the former visit that were known to be alive on the latter visit (M_i / M_{i-1}). Pup production (P) is estimated as:

$$P = N_1 + D_1 \sum_{i=2}^{4} N_i - N_{i-1}(M_i / M_{i-1}) \qquad (6)$$

where N_1 is the Petersen estimate of live pups on the first visit. This method assumes that the probability that a pup remains on the colony for the duration of the mark-recapture program and is available for live recapture (i.e. the fidelity probability) is 1; Goldsworthy et al. (2007a) demonstrated it was almost unity using a Cormack-Jolly-Seber model.

Although the difficulties noted above pose limitations, estimates presented here provide valuable conservation information for future comparisons. The status of Australian sea lions should be monitored by following trends in pup abundance in a representative series of breeding colonies across their range. Colonies should be chosen carefully, taking into account data available, accessibility for researchers, the geographical spread of colonies and their size; Goldsworthy et al. (2007a) have developed such a protocol which should be implemented.

Trends in abundance and fishery bycatch

The only Australian sea lion colony for which trend data have been published is Seal Bay, Kangaroo Island, where pup numbers have decreased since 1985. Trend analyses of the maxima of direct counts of live pups for 13 consecutive seasons from 1985 to 2002–03 using regression analysis and general linear modelling demonstrated a decrease of 0.77% yr^{-1}, or 1.14% per breeding cycle, being an overall decrease in pup numbers of 12.6% over 17.7 yr (Shaughnessy et al. 2006). Extension of that analysis for another 3 seasons to 2007 showed a slower overall decrease of 0.54% yr^{-1}, or 0.78% per breeding cycle, being a decrease of 11.1% over a 22 yr period (Goldsworthy et al. 2008b).

A quantitative assessment of the risks to Australian sea lion populations from bycatch in the rock lobster trap fishery and the demersal shark gillnet fishery off SA by Goldsworthy & Page (2007) suggested that risk of subpopulation extinction was high with even modest levels of bycatch in the gillnet fishery. They noted that one of the areas where estimated interaction probability between sea lion foraging and fishing effort in the gillnet fishery was high was immediately south of Kangaroo Island, close to the breeding site at Seal Bay where the population size has been decreasing.

Options for spatial management of effort (area closures) in the shark gillnet fishery to mitigate the bycatch risk to Australian sea lions have been developed by Goldsworthy et al. (2010a); these utilise models which combine sea lion foraging effort, sea lion bycatch data and population viability analyses. Consideration by management authorities (Australian Fisheries Management Authority, and Department of the Environment, Water, Heritage and the Arts) and stakeholders during 2010 resulted in declaration of area closures around all 48 sea lion breeding sites in SA out to 4 to 10 nautical miles (7.3 to 18.5 km), with the largest closures around colonies perceived to have the greatest risk of interactions (Australian Fisheries Management Authority 2010). This should reduce the incidence of bycatch mortality for many breeding sites.

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