Marine Ecosystems

Maintaining the monitoring of pup production at key Australian sea lion colonies in South Australia (2011/12)

Simon D Goldsworthy, Andrew D Lowther and Peter D Shaughnessy

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October 2013

Final report to the Australian Marine Mammal Centre

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Cover photo: Australian sea lion pups on Cap Island, a new breeding colony discovered in 2011.

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1 EXECUTIVE SUMMARY

This project maintained pup production monitoring of a number of key Australian sea lion (ASL) breeding colonies within South Australia between late 2011 and early 2013. This included surveys at Seal Bay and the Seal Slide on Kangaroo Island, Lilliput and Blefuscu Islands in the Nuyts Archipelago, and Olive and Jones Islands off the west Eyre Peninsula. The breeding status and pup production were also determined for Nuyts Reef and a number of islands off the western and lower Eyre Peninsula including Cap, Rocky (North), Rocky (South), Greenly, Four Hummocks, Little Hummock and Price Islands, and Curta Rocks. Opportunistic aerial surveys also permitted assessment of breeding chronology for a number of colonies in the Nuyts Archipelago and off western Eyre Peninsula.

Pup production for the 2011/12 breeding season at Seal Bay was estimated to be 251 (range 249-256), based principally on twice-weekly surveys of new pup births and deaths, and Petersen (mark-recapture) estimates, as well as direct counts of pups in Pup Cove. This estimate is similar to those from the previous three breeding seasons (2010: 267-276; 2008/09: 268-275; 2007: 254-256).

Pup production at the Seal Slide was estimated to be 13 for the 2011/12 breeding season using cumulative mark and count procedures. Estimates of pup abundance with a high level of confidence at the Seal Slide are now available for the last seven breeding seasons (since 2002-03), and range between 9 and 16 over this period. No trends are apparent at this stage.

Pup production estimates at Lilliput and Blefuscu Islands based on the Petersen method were 69 (95% CL, 64-78) and 67 (95% CL, 60-78), respectively. These are the fifth pup abundance surveys undertaken at these colonies, and the third using the Petersen method. Petersen estimates for the three seasons are similar for Lilliput Island (64, 66 and 69 in 2007/08, 2010, 2012, seasons respectively), but they suggest a decline for the 2012 season at Blefuscu Island (99, 108 and 67 in 2007/08, 2010, 2012 seasons, respectively).

Estimated pup production at Olive Island based on the Petersen method was 129 (95% CL 126 – 132). Petersen estimates of pup production are available for five consecutive breeding seasons at Olive Island. These data show a pattern of alternate high and low pup production for the 2006 (206 pups), 2007 (161), 2008/9 (221), and 2010 (173) seasons, respectively, but a further decline for the 2011/12 (129) breeding season.

A single ground survey was undertaken on Jones Island on 12 March 2012 when a total of 12 pups were sighted. The estimate for the 2011/12 season is similar to previous surveys between 2001/02 and 2008/09 which have ranged between 7 and 15 pups.

Four helicopter surveys were undertaken: 19-21 November 2011, 22 March 2012, 2 August 2012, and 27 February 2013. They provide new information on breeding status, timing of breeding and pup production for a number of islands in the Great Australian Bight and off western and southern Eyre Peninsula. On two surveys of Nuyts Reef, at the beginning and about 4 months into the breeding season, a total of 44 pups were counted. Two surveys were also undertaken of Rocky (North) Island in consecutive (2011 and 2012/13) breeding seasons with 44 and 47 pups being counted, respectively. Three new breeding colonies were identified, Cap Island (38 pups), Rocky (South) Island (12 pups) and Little Hummock Island (10 pups). The total number of known colonies (>5 pups) in South Australia has increased from 39 to 42, and the total number of breeding locations from 48 to 51.

Pup numbers were surveyed at Four Hummock (middle island, 10 pups) and Price Island (17 pups). Surveys undertaken on 27 February 2013 identified that the breeding season had just commenced on Olive and Nicolas Baudin Island (1 and 4 pups, respectively), but had not commenced on Lilliput, Blefuscu, Pearson, Dorothee and West Waldegrave Islands. This information will help inform the timing of future surveys.

Remote field cameras were trialled as a means to monitor breeding chronology, to optimise survey timing and quality, and improve logistical planning and resourcing. Two camera systems were tested over 133 days at Dangerous Reef, providing images on most days, although there were problems with transmission of images to email through the 3G network. Pups were clearly identifiable in many images, as were their pelage patterns, providing a means to estimate pup age and therefore the stage of the breeding season. This technique could be used to monitor breeding chronology of key ASL monitoring sites, and newly developed Next G network capable cameras will be trialled in the near future to assess if this technology can successfully transmit images from the key ASL monitoring sites.

The Australian Fisheries Management Authority (AFMA) have been notified of the new ASL colonies, and on 22 May 2013 they implemented 4 nm gillnet closure around Cap and Rocky (South) Islands as part of the Southern and Eastern Scalefish and Shark Fishery Closure Direction No. 7 2013. The measures are aimed at reducing the risk of ASL from these colonies becoming bycatch in the demersal gillnet shark fishery.

2 INTRODUCTION

The Australian sea lion (ASL - *Neophoca cinerea*) is Australia's only endemic seal species and is its least numerous. It is unique among pinnipeds, being the only species that has a non-annual breeding cycle, which is also temporally asynchronous across its range. It has the longest gestation period of any pinniped, as well as protracted breeding and lactation periods. The evolutionary determinants of this unusual reproductive strategy remain enigmatic. These factors, and the species' small population size (~14,700 individuals), which is distributed over numerous, small colonies, make the ASL vulnerable to extinction (Goldsworthy *et al.* 2009a). Recent population genetic studies have indicated little or no interchange of females among breeding colonies, even for those separated by short distances (Campbell *et al.* 2008, Lowther *et al.* 2012). The important conservation implication that follows is that each breeding colony is a closed population. In light of this, and with the identification of unsustainable bycatch of ASL in demersal gillnet fisheries (Goldsworthy *et al.* 2010c), conservation and management measures need to focus at the colony level. The species is listed as Vulnerable under the threatened species category of the Commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act), as Vulnerable under the South Australian *National Parks and Wildlife Act* (1972) and as Endangered by the International Union for the Conservation of Nature (IUCN) Redlist.

In 2005, a report to the Commonwealth Government detailed the impediments to growth in ASL populations (McKenzie *et al.* 2005). The report highlighted the inadequacies of population assessment methods used and identified that the quality of data on pup abundance was typically poor and not available for many populations The report identified these limitations as being highly significant because management for the recovery of the ASL will need to be underpinned by an ability to detect changes in the status of populations over time.

As part of a study funded by Department of the Environment, Water, Heritage and Arts (DEWHA) in 2006, and the Australian Centre for Applied Marine Mammal Science (ACAMMS) in 2007/08 (Goldsworthy *et al.* 2007c, 2008b, 2009b), the appropriateness of two new methods for estimating pup production in small and large ASL subpopulations was evaluated. In addition, a population survey strategy was developed, which identified key and/or representative colonies within regions across the range of the species that could be targeted for ongoing monitoring of trends in pup production.

The survey method developed for large ASL subpopulations (>40 pups) utilised individual re-sight histories of tagged pups in conjunction with mark-recapture techniques using the

Petersen estimate (Goldsworthy *et al.* 2007c, 2008b, 2009b). This approach has recently been refined to enable estimation of apparent survival and net pup production between recapture sessions, enabling *cumulative pup production* to be estimated throughout the breeding season (Goldsworthy *et al.* 2010b). At small ASL subpopulations (<40 pups) a *cumulative mark and count* (CMC) method was developed (Goldsworthy *et al.* 2007c). The principal reason for developing these methods was to provide repeatable survey approaches which enable accurate pup production estimates with defined confidence limits. McKenzie *et al.* (2005) and Goldsworthy *et al.* (2009a) noted that because of the large number of ASL breeding sites and their asynchronous breeding patterns, achieving high quality trend data across all breeding sites over time was unlikely to be achievable, especially considering the difficulty and expense required to reach many of the sites. They recommended focusing efforts on obtaining high-quality pup census data from consecutive breeding seasons from a sub-set of key and/or regionally representative colonies as the best strategy for obtaining trend data across the range of the species.

To determine the most appropriate sites for ongoing surveys, Goldsworthy *et al.* (2007c) undertook a distance analysis among ASL subpopulations and identified 11 metapopulations across the species range, seven in South Australia (SA) (Figure 1) and four in Western Australia (WA). However, there were only four metapopulations in SA where accurate, repeatable, cost effective and logistically-feasible surveys could be undertaken each breeding season. Within each of these, one large (>40 pups) and one small (<40 pups) site were selected (8 in total) as regionally representative colonies to form the basis for ongoing surveys. These included Seal Bay and the Seal Slide (Kangaroo Island); Dangerous Reef and English Island (Spencer Gulf); Olive and Jones Islands (west Eyre Peninsula) and Lilliput and Blefuscu Islands (Nuyts Archipelago) (Figure 1). Surveys at most of these colonies have been undertaken each breeding season since 2007.

In addition to monitoring key sites, there is a need to maintain some level of monitoring for the remaining colonies. Pup numbers of some of the largest ASL colonies, such as West Waldegrave and Nicolas Baudin Islands, have never been estimated with confidence limits, and other sites have only been visited once or twice, and their breeding status and pup production remain uncertain. Some potential breeding sites have yet to be surveyed, or may only have been surveyed outside the breeding season. In 2009 and 2010, the Australian Marine Mammal Centre (AMMC) funded spot surveys of a number of sites that had not been surveyed since 1996, which were recorded as unconfirmed or possible breeding colonies by Gales *et al.* (1994).

One of the most critical methodological constraints to improving survey quality of key monitoring sites is ensuring that the timing of the first survey coincides with the 3rd or 4th month of breeding. As inter-breeding interval can range between 16-20 months (Shaughnessy *et al.* 2006), there is no way to be certain of the stage of breeding until the first survey trip is undertaken. This can result in significant survey inefficiencies (cost and time) when the first survey reveals that the breeding season is late (first survey is wasted), or poor survey quality if the breeding season commenced early and the opportunity to survey at optimal times is lost. This happened for most west coast Eyre Peninsula ASL colonies surveyed during 2010, where breeding commenced about 3 months earlier than expected, with the breeding season almost over by the time the first surveys were undertaken (Goldsworthy *et al.* 2012). To overcome this problem, in this study we aimed to trial remote field cameras programmed to take daily photographs sent via mobile phone networks to enable the monitoring of breeding chronology to be documented so that surveys could be optimally timed and resourced, and hence survey quality improved.

Aims and work plan

The aims of this study were to continue to provide data on the status and trends in abundance of ASL for 2011/12 by:

1. Undertaking pup production surveys at key monitoring sites, including: Olive and Jones Islands, Lilliput and Blefuscu Islands, Seal Bay and Seal Slide, and West Waldegrave Island.
2. Undertaking single surveys at sites where pup numbers have not been surveyed since 1996, and where breeding status remains uncertain (Four Hummocks, Price and Rocky North Island); and
3. Trialling the use of remote camera systems to monitor breeding chronology to enable surveys to be optimally timed and resourced.

Some changes to the work plan were required. A survey of West Waldegrave Island (April 2012) indicated that the ASL breeding season had finished some months earlier, preventing a survey from taking place. An additional survey was planned for early 2013, but an aerial survey in March 2013 indicated that breeding had still not commenced, so this survey has been moved into the next AMMC supported surveys for 2013/14. However, additional surveys of a number of offshore islands were made possible by extending helicopter surveys. These included surveys of Rocky (South), Greenly, Little Hummock, Cap and Rocky (North) Islands, Curta Rocks, and Nuyts Reef. Results from these surveys are presented in this report.

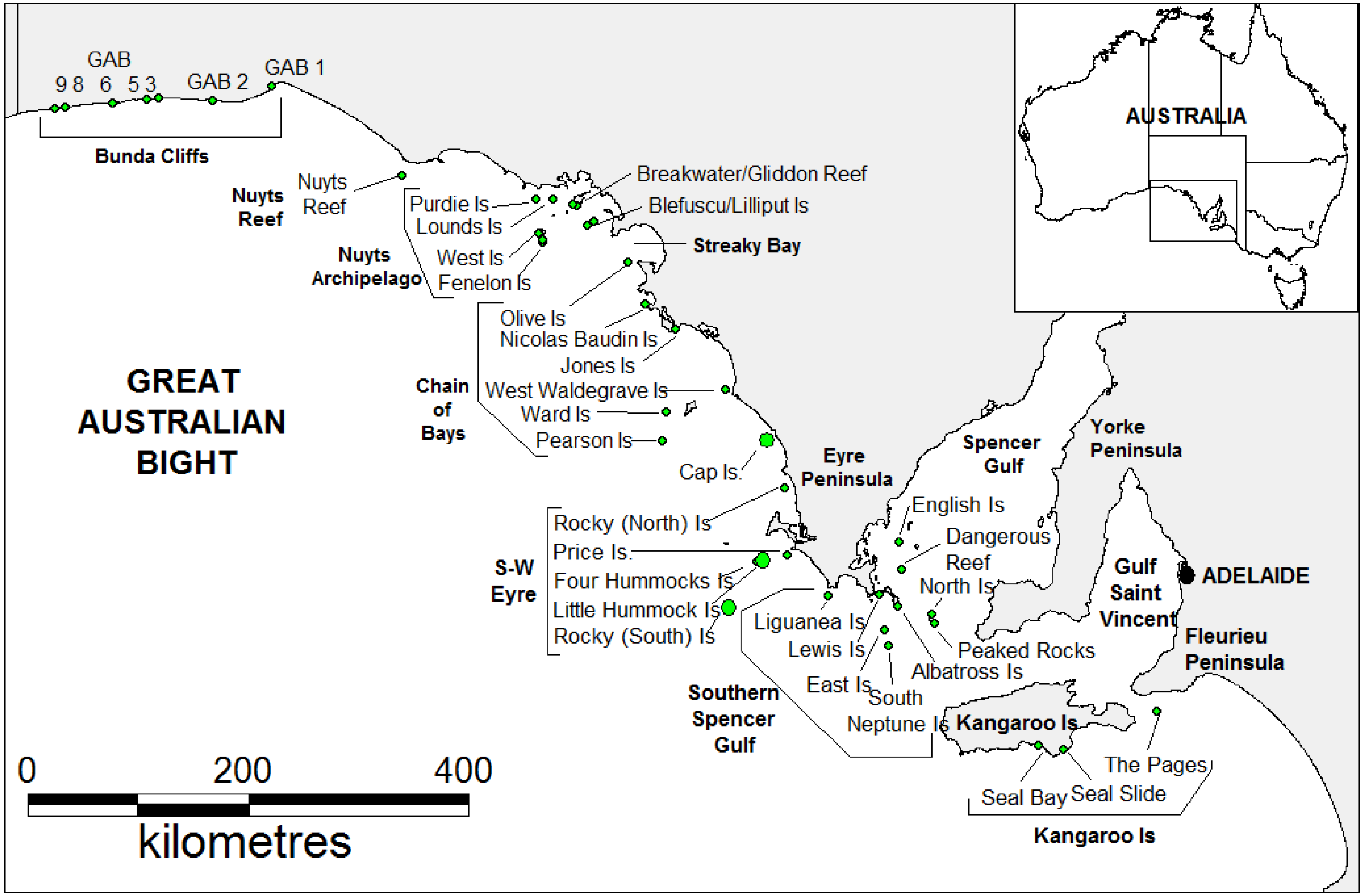

Figure 1. The location of Australian sea lion breeding colonies in SA and the seven metapopulations as described by Goldsworthy *et al.* (2007c). New breeding colonies identified in this study are noted by larger green circles (Cap, Rocky (South) and Little Hummock Islands).

Figure 2. Map of Seal Bay breeding colony, Kangaroo Island, extended to Bay 2 (EPA 2) of the Eastern Prohibited Area (EPA). Pup Cove, Western Prohibited Area (WPA), Main Beach and EPA comprise the main areas of the site.

3 METHODS

Field sites

Olive and Jones Islands

Olive Island (32.719° S, 133.695° E, Figure 1) was accessed by vessel from the township of Streaky Bay, with two visits made in January and February 2012. During each visit to the island, sea lion pup numbers were surveyed by direct counting of live pups, surveying of dead pups and mark-recapture. Each survey is defined as a session. The methodology for these approaches is detailed below.

Jones Island (33.185° S, 134.367° E, Figure 1) is situated at the entrance of Baird Bay on the west coast of the Eyre Peninsula, and was accessed by boat from the settlement at Baird Bay. The island was visited on one occasion during which a ground survey of pups was undertaken (12 March 2012).

Lilliput and Blefuscu Islands

Lilliput (32.434° S,133.693° E, Figure 1) and Blefuscu Islands (32.467° S, 133.644° E, Figure 1) are two small islets off East and West Franklin Island, respectively, in the eastern Nuyts Archipelago. These Islands were officially named in 2007, and have formerly been referred to as North East and South East Franklin, respectively (Dennis 2005, McKenzie *et al.* 2005). Mark-recapture surveys were undertaken on these islands between 4 and 6 July 2012.

Seal Bay and Seal Slide

Seal Bay is part of the Seal Bay Conservation Park situated on the south coast of Kangaroo Island, centred on 35.996° S, 137.327° E (Figure 1). The ASL colony comprises four main areas that are referred to as Pup Cove (2 km west of the visitor centre), Western Prohibited Area (WPA), Main Beach (MB), including the sand dunes and swales inland from MB and the scrub behind the swales (referred to as the Road Reserve), and the Eastern Prohibited Area (EPA) (Figure 2). Limestone promontories separate the WPA and EPA from MB. Most pups are born in the WPA and at the western end of MB, with smaller numbers of pups born in Pup Cove, inland from the WPA and MB, in the dunes behind the eastern end of MB, and in the EPA (Goldsworthy *et al.* 2007c, McIntosh *et al.* 2012). The WPA and EPA were declared in 1972 under the *National Parks and Wildlife Act, 1972* (SA Government Gazette, December 7, 1972, pp. 2543-2544) for the “purposes of conserving the native animals on that portion of the Seal Bay Conservation Park described”.

The ASL colony known as the Seal Slide (36.028° S, 137.539° E, Figure 1) is located in the Cape Gantheaume Wilderness Protection Area, on the south-east coast of Kangaroo Island. The colony can be accessed by 4WD vehicle and was visited frequently during the 2011/12 breeding season.

At Seal Bay, three methods were used to estimate pup production during the 2011/12 breeding season: direct counts of live and dead pups; the cumulative survey of new births and deaths throughout the colony (referred to as ‘cumulative pup production’); and mark-recapture methods using the Petersen estimate (Goldsworthy *et al.* 2008a). The methodology to survey the Seal Slide followed that described by Goldsworthy *et al.* (2007a) for small colonies and is referred to as the cumulative mark and count (CMC) method. The methodology for these approaches is detailed below.

Survey methodology

Live and dead pup counts

The number of live pups was counted while slowly walking around the colony, taking care not to disturb animals. Live pups were recorded in one of three categories: black pups (considered to be <4 weeks), brown pups (approximately 4 - 20 weeks) and moulted pups (>20 weeks age) (McKenzie *et al.* 2005). We recorded the number of pups that had died since the previous visit. To avoid double counting, dead pups were covered with rocks when they were counted. The number of dead pups was added to give the number of cumulative dead pups where multiple surveys were conducted during a breeding season. When that number was added to the number of live pups, it provided an estimate of pup production to that date.

Mark-recapture

Direct counting of pups to estimate their abundance is known to underestimate total pup abundance, because pups that are hidden from view (sightability bias) or absent from the colony (availability bias) at the time of the survey are not included. The influence of these factors on estimates of pup numbers can be reduced to some degree by undertaking a mark-recapture procedure. Mark-recapture methods have been used to estimate pup production at fur seal colonies in Australia since 1988 (Shaughnessy *et al.* 1995, Shaughnessy and

McKeown 2002, Kirkwood *et al.* 2005), but have only recently been applied to estimating pup production in ASL populations at Seal Bay, Dangerous Reef, and Olive, North Page and South Page Islands (McIntosh *et al.* 2006, Shaughnessy *et al.* 2006, Goldsworthy *et al.* 2007a, McIntosh *et al.* 2012).

A mark-recapture procedure was used to estimate the number of live pups at Seal Bay, Olive Island and Lilliput and Blefuscu Islands. At Seal Bay, pups were externally marked by clipping the fur of the rump and also by implanting Passive Integrated Transponder tags (PIT tags: TIRIS™ RFID 23mm) subcutaneously using sterile single-use needles. PIT tags (micro-chips) were inserted in the clipped area, parallel to the spine and close to the tail to minimise gravitation. At other sites, pups were tagged with individually numbered plastic tags (Dalton® Size 1 Supertags), applied to the trailing edge of each fore-flipper. During each field trip, individual re-sight records were collected for marked individuals with the aid of binocular observations. As noted above, a record of dead pups was obtained by placing rocks on top of carcases to avoid repeat counting. Records of the total number of tagged, untagged and newly recorded dead pups were noted on each field trip (i.e., at each session).

Individual re-sights of tagged pups were usually undertaken over a minimum of three days prior to recapture surveys; they were used as the sample of ‘marked’ individuals in the population available for the recapture surveys on the last day. During recapture surveys, the individual identity of tagged pups was determined by reading tag numbers with binoculars. The number of untagged pups seen was also recorded, as was the number of recently dead pups that had not been marked. Pups sighted in future surveys (i.e., known to be alive) were included as being available for re-sighting in previous recapture sessions.

Mark-recapture estimates of pup numbers (N) were calculated using a variation of the Petersen method (attributed to D.G. Chapman by Seber 1982) with the formula:

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

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 of this estimate is calculated as:

$$\mathrm{var}(\hat{N}) = \frac{(M+1)(n+1)(M-m)(n-m)}{(m+1)^2(m+2)}$$

where, several mark-recapture estimates ($\hat{N}_j$) are made (one from each recapture session), they are combined by taking the mean (*N*) using formulae from White and Garrott (1990) (pp. 257 and 268):

$$N = \sum_{j=1}^{q} \frac{\hat{N}_j}{q}$$

Where, *q* is the number of estimates for the colony (i.e., the number of recapture sessions). The variance of this estimate is calculated as:

$$\mathrm{var}(N) = \frac{1}{q^2}\sum_{j=1}^{q}\mathrm{var}(\hat{N}_j)$$

Following Kuno (1977), the square root of var(*N*) gives the standard error (*SE*) for the estimate, and the 95% confidence limits are calculated as:

$$N \pm (1.96 * SE)$$

The Petersen estimate yields an accurate result as long as a number of conditions are met (Caughley 1977). These include: the probability of capturing an individual is the same for all individuals in the population; no animal is born or immigrates into the study area between marking and recapturing; marked and un-marked individuals die or leave the area at the same rate; and no marks are lost.

Cumulative pup production

The number of pup births between consecutive mark-recapture surveys $\hat{B}_{1-2}$ was estimated as:

$$\hat{B}_{1-2} = \hat{N}_2 - \hat{N}_1\hat{\varphi}_{1-2}$$

where, $\hat{N}_1$ is the estimated total number of pups born based on Petersen estimates plus cumulative dead pups up until Session 1, and $\hat{N}_2$ is the number of pups estimated in session 2. $\hat{N}_2 - \hat{N}_1$ is therefore the net pup production between Sessions 1 and 2 (i.e. the number of births minus the number of deaths that have occurred between each session). $\hat{\varphi}_{1-2}$, is the apparent survival of pups between Session 1 and 2, and is estimated as the proportion of the marked pups known to be alive in session 1 (M_1) that were known to be alive in Session 2 (or M_2 / M_1). This approach was repeated to estimate the number of births that occurred between

Sessions 2 and 3, and sessions 3 and 4. Total cumulative pup production (N_c) was hence estimated as:

$$N_c = \hat{N}_1 + \hat{B}_{1-2} + \hat{B}_{2-3} + \hat{B}_{3-4}$$

Confidence limits (± 95% CL) for N_c were estimated by substituting $\hat{N}$ for the +95% CL and -95% CL of each (Shaughnessy *et al.* 2011).

Seal Bay population and growth estimates

At Seal Bay, more detailed analysis of the pup numbers was possible because a longer time series is available, which has been possible because of access to the colony by vehicle.

Of the three methods used to estimate pup production, direct counts of live and dead pups, the cumulative survey of new births and deaths, and mark-recapture methods using the Petersen estimates, the first two methods provide an absolute minimum. The overall estimate of pup production was taken as the largest of the three estimates. The mortality rate of pups was calculated as the number of cumulative dead pups at the end of the breeding season, divided by the overall estimate of pup production. Median date of birth and the period over which 90% of births occurred were determined using a modified probit analysis of cumulative pup production data (Caughley 1977).

To estimate the population growth rate at Seal Bay we considered three models fitted to the natural logarithm of maximum pup counts and pup production in each breeding season. The models tested were: (1) a simple linear regression model; (2) a multiple linear regression model that included a factor (Period) to allow for the non-annual interval between breeding seasons of the ASL; and (3) a model using generalised least squares (GLS) to estimate and adjust for any auto-correlation in maximum pup counts/pup production between breeding seasons (Zuur *et al.* 2009) .

The model equation for (2) was:

$$\log(Pups) = \beta_0 + \beta_1 Season + \beta_2 Period$$

where ‘*Pups’* was either the maximum live-pup count or the pup production estimate, ‘*Season’* was the breeding interval (set at 18 months) and ‘*Period’* was a factor that alternated between breeding seasons to account for the sesquiannual breeding cycle of the ASL (~18 months) (McIntosh *et al.* 2012). For (1), the model equation was similar, with the omission of the '*Period*' factor. The statistical significance of the candidate models was considered using Analysis of Deviance and by consideration of the 95% confidence intervals of model parameters. Models were fitted using the statistical package and environment R version 2.15.1.

Seal Slide population estimate

The methodology to survey the Seal Slide followed that described by Goldsworthy *et al.* (2007a) for small colonies and is referred to as the cumulative mark and count (CMC) method. During each visit to the colony, attempts were made to mark as many pups as possible by clipping a small patch of hair on the rump and inserting RFID microchips under the skin in the rump. The number of marked, unmarked and dead pups sighted on each of several visits was recorded and, if possible, more pups were marked. Marked pups seen at the Seal Slide were scanned for a microchip with an RFID antenna to determine where they were born. Dead pups were covered with rocks to ensure they were not recounted on subsequent visits. Pup numbers were estimated for each visit from the numbers of marked pups, accumulated dead pups, plus the number of live unmarked pups. The last item was determined in several ways, and the maximum taken as the number of pups born to date. For the first visit, it was simply the number of unmarked, live pups seen. For later surveys, it was the maximum number of unmarked pups seen in one of the previous surveys less pups marked since then.

Seal Bay - micro-chipping and demography program

Pups older than two-months of age and un-attended by an adult female were captured by hand, weighed in a canvas bag using a spring balance to the nearest 0.1 kg; sexed and measured (standard length - nose to tail in a straight line to the nearest ± 0.5 cm). Each pup was externally marked by clipping the hair across the rump, and a Passive Integrated Transponder tag (PIT tag: TIRIS™ RFID 23mm) was subcutaneously implanted using a sterile single-use needle. PIT tags (micro-chips) were inserted in the clipped area, parallel to the spine and close to the tail to minimise gravitation.

Throughout the breeding season and between breeding seasons, hand-held scanning of animals was undertaken regularly throughout the colony. To successfully identify seals with a micro-chip, the Radio Frequency Identification (RFID) reader was held near the animal at a distance of up to 10 cm from the insertion site. Mother-pup pairs were also targeted throughout the breeding season to assess the tagged status of the pups, as well as to identify the mother if it had been micro-chipped.

Remote camera trials to monitor breeding chronology

Remote cameras (Hunting/Wildlife Camera 3G Pro, Camtek Surveillance Products) were used to collect images of breeding activity and breeding chronology in ASL colonies. The camera systems were motion activated (within 20 m) and enabled to transmit collected images via Multimedia Messaging Service (MMS) and 3G mobile network to email. Each camera contained a 16 MB SD card to record images. Cameras were mounted on a star-picket with a 1500 mAh solar panel to maintain camera operation indefinitely (Figure 3). Solar panels were orientated to true north, and cameras set at right angles to minimise glare (Figure 3). Three remote camera systems were trialled as part of this study. Two in SA were installed on Dangerous Reef, the third was installed on an island in the Recherche Archipelago (deployed by Wildlife Officers from Department of Environment and Conservation, WA). Dangerous Reef Camera 1 was programmed to record images between 1320 and 1420 hrs local time, and Camera 2 between 1243 and 1420 hrs. Due to problems with transmission of images to email, most images were not obtained until cameras were retrieved. At the time this report was prepared, the WA camera had not been recovered, so only results from the SA trials are presented here.

Figure 3. Remote camera system with solar panel installed on Dangerous Reef (Photo, Mark Whelan).

4 RESULTS AND DISCUSSION

Olive and Jones Islands

Olive Island

A total of 43 pups were marked as part of the mark-recapture program in early 2012 at Olive Island. Only two mark-recapture sessions were undertaken, between 8 and 9 January and 23 and 28 February 2012. Petersen estimates of the number of live pups were greater during the second session (mean 112, 95% CL 103 - 120) than the first (mean 95, 95% CL 89 - 101, Tables 1 and 2). The addition of 15 cumulative dead pups until the second session provided an estimate of 127 pups in February 2012 (95% CL 118 - 135, Table 1).

Based on tag re-sights between sessions 1 and 2 (Table 2), the apparent survival rate (φ) was 0.881. Based on Petersen estimates of live pups plus cumulative dead pups, and using the cumulative pup production method, the net increase in pup numbers between session 1 and 2 is estimated to be 28 (95% CL 25 – 31), giving an overall estimate of pup production at Olive Island for the 2011/12 breeding season of 129 (95% CL 126 – 132, Table 1).

Olive Island was recorded as a breeding colony in November 1977 when 52 pups were seen (Dennis 2005). Pups were also seen there in April 1979 (49 unclassed) (Ling and Walker 1979) and November 1990 (27 moulted and one dead) (Gales *et al.* 1994, Dennis 2005). Based on three ground counts undertaken between February and July 2003, 121 pups were estimated to have been born (117 pups were seen in July plus 4 dead in May 2003) (McKenzie *et al.* 2005). Ground counts undertaken in September 2004 and January 2005 estimated 131 pups (Shaughnessy *et al.* 2005). During the 2006 season, the highest ground count was 126 pups on 13 April with 24 dead recorded to that date (i.e. 150 in total). Combined Petersen and Cormack Jolly Seber estimates for the 2006 season determined that pup production was 206 (95% CL 191-267), and for 2007 it was 161 (95% CL 151 – 172) (Goldsworthy *et al.* 2007c). The estimate for the 2008/09 breeding season using similar methods was 221 (95% CL 195 – 247), for the 2010 breeding season it was 173 (95% CL 165 – 181) and for most recent 2011/12 breeding season it was 129 (95% CL 126 – 132) (Goldsworthy *et al.* 2012, this report). Based on the more accurate surveys undertaken over the last five breeding seasons, the pattern of alternate high and low pup production seasons, as observed at Seal Bay, may also be a feature of the Olive Island colony, although the recent seasons results showing a further decline from the 2010 season do not support this (Figure 4).

Given the limited time-series and high level of variation in estimated pup production between breeding seasons at this colony (mean 27%, range 22 - 37), more data are required before trends in abundance can be assessed with confidence (Figure 4).

Jones Island

A single ground survey was undertaken on Jones Island on 12 March 2012, when a total of 12 brown pups were sighted. Based on the activity of adult males and females, it appeared that breeding activity had recently ceased.

The first record of breeding at Jones Island was in August 1977 (2 pups) based on a ground survey, and the next survey when pups were seen was not until December 1990 (5 pups, Gales *et al.* (1994). More complete ground count data are available for the five breeding seasons: 1998/99 (9 pups), 2000 (6 pups), 2001/02 (12 pups), 2003 (7 pups) and 2004/05 (15 pups) (McKenzie *et al.* 2005). No data were obtained for the 2006 breeding season. The estimate of pup production for the 2007 season was 15 (Goldsworthy *et al.* 2010b). In the 2007/08 season a minimum of 11 pups were sighted (Goldsworthy *et al.* 2010b). In the 2010 season, 28 pups were counted, but given the advanced state of pups (most fully moulted) and the marked increase in numbers from previous seasons, it is probable that many had swum in from neighbouring colonies (such as West Waldegrave and Nicolas Baudin Islands, and Point Labatt) and therefore the estimate for that season was inflated (Goldsworthy *et al.* 2012). The estimate for the 2011/12 season of 12 pups is more consistent with previous surveys between 2001/02 and 2008/09.

Table 1. Summary of abundance estimates of ASL pups at Olive Island in the 2011-12 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture estimates, during two sessions, in January and February 2012.

Session	1	2
Date	**8-Jan**	**28-Feb**
Cumulative marked	42	43
Maximum unmarked counted	44	66
Maximum count (live)	75	94
Cumulative dead (unmarked)	6	15
Cumulative dead (marked)	0	0
Total cumulative dead	6	15
Maximum count (live) + cumulative dead	81	109
Cumulative marked + dead (unmarked) + max unmarked	92	124
Petersen Estimate (live)	95	112
Petersen Estimate Lower – Upper CL	89-101	103-120
(No. recapture estimates)		
Petersen Estimate (live) + cumulative dead	101	127
Lower – Upper CL	95-107	118-135
Apparent survival (φ) between sessions		0.881
Estimated pup production between sessions		28
Lower – Upper CL		25-31
Estimated cumulative pup production	101	129
Lower – Upper CL	95-107	126-132

Table 2. Details of Petersen mark-recapture estimates for Olive Island between January and February 2012. M = number of marked pups in the population, n = the total number of pups sampled and m = the number of marked pups in each recapture sample. N = the estimated pup population size, sd = standard deviation and V = variance. % = the percentage of marked pups in each sample, CV = the coefficient of variation. Nlo and Nup = the lower and upper 95% confidence limits (CL) of each estimate, respectively.

Date	Recapture No.	Marked M	Examined n	M-R m	N	sd	V	%	CV	Nlo	Nup
Session 1											
8-Jan-12	1	42	60	28	89	7	47	47%			
8-Jan-12	2	42	75	31	101	7	47	41%			
9-Jan-12	3	42	70	32	92	6	31	46%			
9-Jan-12	4	42	65	27	100	8	71	42%			
9-Jan-12	5	42	64	28	95	7	56	44%			
9-Jan-12	6	42	53	24	92	9	75	45%			
				Mean	**95**	**3.0**		**44%**	**3.2%**	**89**	**101**
Session 2											
23-Feb-12	1	38	94	28	127	10	97	30%			
24-Feb-12	2	38	77	27	108	9	74	35%			
24-Feb-12	3	38	67	23	110	11	122	34%			
25-Feb-12	4	38	71	26	103	9	74	37%			
28-Feb-12	5	38	79	24	124	12	148	30%			
28-Feb-12	6	38	58	22	99	10	104	38%			
				Mean	**112**	**4.1**		**34%**	**3.7%**	**103**	**120**

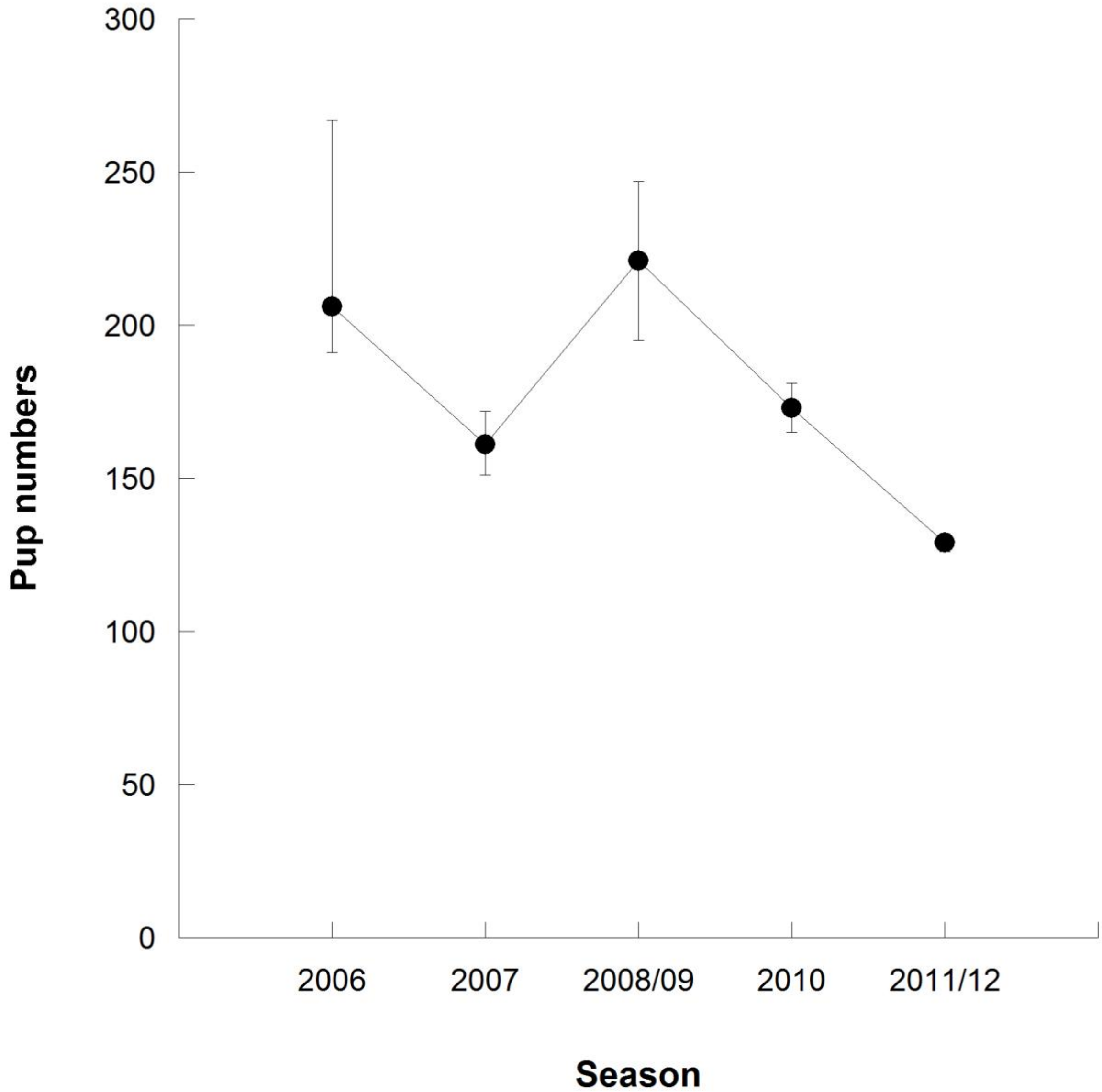

Figure 4. Trends in the estimated ASL pup production at Olive Island over five consecutive breeding seasons (2006 to 2011/12). Error bars represent upper (95%) and lower (absolute minimum) confidence limits; for the 2011/12 season they are too small to show.

Lilliput and Blefuscu Islands

At Lilliput Island a single mark-recapture survey of pup numbers consisting of six ground counts was undertaken between 4 and 6 July 2012. The pupping season at Lilliput Island was considered to have finished by the time this survey was undertaken, based on the pelage patterns of the pups. Over the six ground counts, an average of 41 pups were counted (range 40-43), of which 12 (29%) were classed brown and 29 (71%) fully moulted. Two dead pups were also sighted. A total of 26 pups were tagged on Lilliput Island. Results for the Petersen estimate of pup abundance for the single survey are presented in Table 3. Based on six recapture estimates, the total estimate of pup production was 69 (95% CL, 64-78), which included the two dead pups (Table 3).

At Blefuscu Island, a single mark-recapture survey of pup numbers consisting of six ground counts was undertaken between 6 and 7 July 2012. The pupping season at Blefuscu Island was considered to be nearing completion at the time this survey was undertaken, based on the pelage patterns of the pups. Over six ground counts, an average of 40 pups were counted (range 31-50), of which 1 (2%) were black (with a mate-guarded female), 1 (2%) black, 16 (40%) brown and 23 (56%) fully moulted. No dead pups were sighted. At Blefuscu Island, a total of 17 pups were tagged. Results for the Petersen estimate of pup abundance for the single survey are presented in Table 3. Based on six recapture estimates, the total estimate of pup production was 67 (95% CL, 60-78) (Table 3).

The survey estimates of pup production for Lilliput and Blefuscu Islands represent the fifth survey of pup abundance at these colonies, and the third using mark-recapture methods (Table 4). At Lilliput Island, a single ground count was undertaken in 1990 when 46 pups were sighted (Gales *et al.* 1994), and multiple ground counts were undertaken during the 2004/05 breeding season (10 January, 10 March and 6 April), when a maximum of 67 pups were counted (Goldsworthy *et al.* 2009c). The estimate for pup production for the 2007/08 breeding season using mark-recapture methods was 64 (95% CL, 62-69) (Goldsworthy *et al.* 2009b), similar to the estimate for the 2010, (66, 95% CL, 64-67) and 2012 (69, 95% CL, 64-78) breeding seasons (Goldsworthy *et al.* 2012, this study) (Table 4).

For Blefuscu Island, a single ground count was undertaken in 1990 when 75 pups were sighted (Gales *et al.* 1994) and multiple ground counts were undertaken during the 2004/05 breeding season (10 January, 10 March and 6 April), when a maximum of 84 pups were counted (Goldsworthy *et al.* 2009c). The estimate for pup production for the 2007-08 breeding season using mark-recapture methods was 99 (95% CL, 92-106) (Goldsworthy *et al.* 2009b), similar to the estimate for the 2010 breeding season: 108 (95% CL, 104-111) (Goldsworthy *et al.* 2012). The estimate for the 2012 season (67, 95% CL, 60-78) is lower than the mark-recapture estimates for the two previous breeding season. Given that most pups surveyed at Lilliput and Blefuscu Island were classed as moulted, it is possible that some pups were at sea or hauled out on the adjacent islands and therefore unavailable for survey.

Table 3. Details of Petersen mark-recapture estimates for Lilliput and Blefuscu Islands between 4 and 7 July 2012 to estimate the number of live pups in the population. M = number of marked (tagged) pups in the population, n = the total number of pups sampled and m = the number of marked pups in each recapture sample. N = the estimated pup population size (live only), sd = standard deviation and V = variance. % = the percentage of marked pups in each sample, SE = the standard error, and Nup and Nlo are the upper and lower 95% confidence limits of each estimate, respectively.

Location Date	Recapture No.	Marked M	Examined n	M-R m	N	sd	V	%	SE	Nlo	Nup
Lilliput Island											
4-Jul-12	1	26	36	12	76	12	142	33%			
5-Jul-12	2	26	40	13	78	11	132	33%			
5-Jul-12	3	26	42	15	72	9	79	36%			
6-Jul-12	4	26	40	17	61	6	37	43%			
6-Jul-12	5	26	40	19	54	4	19	48%			
6-Jul-12	6	26	33	14	60	8	58	42%			
				Mean	**67**	**3.6**		**39%**	**3.61**	**62**	**76**
				Dead	**2**						
				Min. Est	**69**					**64**	**78**
Blefuscu Island											
6-Jul-12	1	17	51	14	61	5	29	27%			
6-Jul-12	2	17	31	8	63	12	147	26%			
7-Jul-12	3	17	38	11	58	8	61	29%			
7-Jul-12	4	17	33	7	76	17	276	21%			
7-Jul-12	5	17	40	9	73	13	166	23%			
7-Jul-12	6	17	43	10	71	11	126	23%			
				Mean	**67**	**4.7**		**25%**	**4.73**	**60**	**78**

Table 4. Numbers of Australian sea lion pups estimated at Lilliput and Blefuscu Islands between 1990 and 2012. Timing of the surveys and the data sources are given as footnotes. Totals among colonies are presented for the five most complete surveys.

Breeding colony	1990[1]	2004/05[2]	2007/08[3]	2010[4]	2012[5]
Lilliput Is.	46 [A]	67[B]	64 (62-69)[C]	66 (64-67)[C]	69 (64-78) [C]
Blefuscu Is.	75 [A]	84[B]	99 (92-106)[C]	108 (104-111)[C]	67 (60-78) [C]

[1]September, November 1990 (Gales *et al.* 1994)
[2]November 2004; January-July 2005 (Goldsworthy *et al.* 2009c)
[3]November 2007, January-April 2008 (Goldsworthy *et al.* 2009b)
[4]October/November 2010 (Goldsworthy *et al.* 2012)
[5]July 2012 (This study)

[A]Single ground count
[B]Multiple ground counts
[C]Petersen (mark-recapture) estimates

Seal Bay and Seal Slide

Seal Bay - Pup production and population growth

Results of the surveys for pup births and deaths undertaken during the 2011-12 breeding season at Seal Bay are presented in Table 5 and Figure 5. The breeding season commenced on 2 October 2011 and ended on 20 June 2012. The duration of the breeding season was approximately 8 months. Based on probit analyses of the cumulative number of births, the median pupping date was 21 February 2012 (sd = 47 days), with 90% of births occurring over 156 days (5.1 months), between 5 December 2011 and 9 May 2012 (Table 6).

Variation in the chronology of breeding across the last seven breeding seasons is presented in Figure 6. The mean breeding interval (period between successive median pupping dates) for the seven consecutive breeding seasons was 544 days (range 541-550, sd = 3.5) or 17.9 months (range 17.8-18.1, sd = 0.1) (Table 6).

The cumulative number of births recorded for the 2011-12 breeding season at Seal Bay was 249 (Table 5, Figure 5). Most pups were born at the Main Beach (MB) area west of the area accessed by the public (83 pups, 33.3%) and the EPA (73 pups, 29.3%), with 54 pups (21.7%) reported for the WPA and 39 pups (15.7%) for Pup Cove. As Pup Cove could only be surveyed from the cliff-line at various vantage points, the number of cumulative births for this area may be an under-estimate.

The maximum count of live pups was 84 on 16 April 2012, when the cumulative number of dead pups was 83. The cumulative number of pup deaths to the end of the breeding season was 104 on 20 June 2012 when the last new pup was recorded.

Details of 17 mark-recapture estimates are provided in Table 5. As the most accurate mark-recapture surveys are obtained towards the end of the breeding season, we have only used surveys undertaken after 95% of the cumulative pup births were recorded. The mean adjusted estimate (*AdjN*), which includes cumulative dead pups plus the remaining new births that occurred after a particular survey, was 251 with 95% CL 246-256; (Table 5, Figure 5). This is 2 more than estimated from the cumulative survey of new births (249), and 30 more than the estimate of minimum pup production, which was 219 (total live pups micro-chipped [115] plus cumulative dead pups at the end of the breeding season [104]) (Table 6).

Given that some births may have been missed using the cumulative surveys of new births (particularly in Pup Cove), the final estimate of pup production for the 2011-12 season at Seal Bay was 251 (range 249-256), with the lower bound set at the minimum pup production estimate and the upper bound set as the +95% CL of the adjusted (*AdjN*) Petersen estimate (Tables 5 and 6).

Seal Bay - trends in maximum live-pup counts, pup production and mortality

Trends in live-pup counts 1985 to 2011-12

Trends in direct counts of live pups extend over 19 consecutive breeding seasons between 1985 and 2011-12 (26 years) (Figure 7).

The linear regression model fitted to the log of maximum live-pup counts shows a significant decline of 1.66% per breeding season ($F_{1,17} = 9.705$, $P = 0.006$, $r^2 = 0.326$), equivalent to a 34% decline over 26 years. The multiple regression model also indicates a significant 1.66% decline per season with '*Period*' a significant factor, improving the model fit considerably ($F_{2,16} = 14.350$, $P < 0.0001$, $r^2 = 0.597$). A generalised least squares model to estimate and adjust for any auto-correlation detected the presence of auto-correlation in the data, with a lag of one breeding season. The model was fitted with an AR(1) structure and the correlation was estimated to be 0.3 but the lag was not statistically significant.

Trends in estimated pup production and mortality

Estimates of pup production (based on cumulative pup births or mark-recapture) and mortality rates of pups are available for seven consecutive breeding seasons between 2002-03 and 2011-12 (Figure 7). The linear regression model fitted to the log of estimated pup production showed no evidence of a trend ($F_{1,5} = 0.4926$, $P = 0.514$, $r^2 = 0.092$). Including the '*Period'* term in a multiple regression model did not change this result ($F_{2,4} = 0.2346$, $P = 0.212$, $r^2 = 0.310$). Pup production estimates for the seven consecutive breeding seasons since 2002-03 (Figure 7) indicate that the first four breeding seasons (2002–03 to 2007) show the same oscillation in pup numbers between high and low pup-production seasons as observed with the maximum live-pup counts, with 2002–03 and 2005–06 being low pup-production seasons and 2004 and 2007 being high pup-production seasons (Figure 7). However, the pattern does not continue for breeding seasons between 2007 and 2011–12, each of which is a high pup-production season. Part of this may be attributed to improvements in survey methodologies mid-way through the 2007 breeding season, when better access to the Eastern Prohibited Area (EPA) was approved for pup surveys.

Based on a pup production estimate of 251 pups for the 2011-12 breeding season at Seal Bay, and a total of 104 cumulative pup deaths at the end of the breeding season, the mortality rate for the breeding season is estimated to be 41.4%, the highest mortality rate recorded for any breeding season (Table 6, Figure 7). The average rate over the last seven breeding seasons is 30% (sd = 7.6); it has varied between about 20% and 41%, and oscillated between the low and high end of that range in consecutive seasons, with 2011-12 being a particularly high mortality season (Figure 7) (Goldsworthy *et al.* 2011). Pup mortality in the low mortality breeding seasons averaged 22.9% (sd = 2.6), while in the high mortality breeding seasons averaged 35.2% (sd = 4.3) (Table 6). There was no apparent trend in pup mortality between 2002 and 2011-12.

The best estimates of pup production and mortality commence in 2007, and hence cover just four breeding seasons. They are based on a consistent methodology of pup surveys with access being available to all parts of the Seal Bay breeding colony. As indicated above, the alternating pattern of high and low pup production apparent in the four breeding seasons up to and including 2007, and in the entire dataset of maximum live pup counts, is absent in the last four pup production estimates (Figure 7). The pattern of alternate high and low estimated pup mortality rates coincides with the alternating pattern in live pup counts, but continues to the most recent breeding season (Figure 7). The absence of these fluctuations in the estimated pup production since 2007 suggests that the alternating pattern in live pup counts is largely due to alternating high and low pup mortality seasons, which extend back to 1985 (Figure 7).

The factors that have contributed to this apparent pattern in pup mortality are unknown, but the pattern raises the question about what is driving the observed decline in live pup counts between 1985 and 2011-12. A greater time series of pup production estimates is required before the relationship between pup production, pup mortality and trends in live pup counts can be resolved.

Seal Bay - micro-chipping and demography program

Micro-chipping

In the 2011-12 breeding season, 251 pups were estimated to have been born at Seal Bay. Of these, at least 104 (41.4%) died before the end of the breeding season. Of the estimated 147 pups that survived, 115 (80%) were micro-chipped at the time this report was completed (Table 6), representing 46% of all pups estimated to have been born in the 2011-12 breeding season.

Birth rates and age distribution of females

During the 2011-12 breeding season, more systematic scanning of breeding females was introduced to monitor reproductive rates. This involved attempts to scan as many females as possible during the peri-natal period or later in order to identify known-age females and monitor age-specific and seasonal variation in natality (birth rate). The scanning covered 173 adult females associated with the 249 pups recorded in the cumulative survey of new births (i.e. 69% of breeding females). Of these 173 adult females, 55 (32%) had a micro-chip, and 54 could be aged. The youngest breeding females were ~4.5 years old (born in the 2007 breeding season), while the eldest known were ~9 years old (born in the 2003 breeding season), although this also coincides with the beginning of the Texas Instruments Registration and Identification System (TIRIS) micro-chipping program, so it is likely that older breeding females were also present. Only three 4.5 year-old females (6% of the 54 known-age females) gave birth, compared to 16 (30%) 6 year-olds, 24 (44%) 7.5 year-olds and 11 (29%) 9 year-olds (Figure 8). Effort will be increased in future seasons to scan as many breeding females as possible.

Between 1991 and 2001-02, approximately 50 pups were micro-chipped each season (Goldsworthy *et al.* 2007b). A greater micro-chipping effort was introduced by McIntosh (2007) in the 2002-03 and 2004 breeding seasons, when Destron microchips (12 mm, lower read-range) were replaced with TIRIS microchips (23 mm, with greater read-range).

Seal Slide - pup abundance

A total of five pups were marked over five surveys of the colony in the 2011/12 breeding season at the Seal Slide. Details of the number of unmarked, marked and dead pups sighted on each survey are presented in Table 7. The minimum number of marked, dead and unmarked pups in the population based on the re-sight and marking history is also presented. Based on these data, the minimum estimate of pups born in the subpopulation was 13, from the survey undertaken on 26 March 2012 (Table 7). No mark-recapture estimates were undertaken, so there are no confidence limits around this estimate.

Although records of pups born at the Seal Slide date back to 1975 (Dennis 2005), the quality of some surveys is uncertain. For example, there is the potential that many of the pups recorded at Seal Slide may have dispersed from Seal Bay. To counteract this possibility, Shaughnessy *et al.* (2009) restricted counts of pups to those observed within four months of the beginning of the breeding season at Seal Bay. While accounting for dispersal from Seal Bay, this adjustment may result in an underestimate of pup production as it will omit pups born during the last third of the breeding season. In the 2002-03 and 2004 breeding seasons, only pups <1 month old (and therefore assumed to have been born at the Seal Slide) were counted by experienced observers and the cumulative number of pups <1 month old was used to estimate the number of pups born during those seasons resulting in more accurate, reliable, and lower (9 and 11) estimates of pup production.

Estimates of pup abundance at the Seal Slide with a high degree of confidence are now available for the last seven breeding seasons since 2002-03 (Figure 9). The first two are from Shaughnessy *et al.* (2009): 9 pups in 2002-03 and 11 pups in 2004. The next four resulted from use of the CMC method: 10 pups, range 10-11 based upon the Peterson estimate in 2005-06; 15 pups, range 14-18 based upon the Peterson estimate in 2007; 12 pups in 2008-09 (Goldsworthy *et al.* 2007b, 2008a, 2010a), 10 pups in 2010 and 13 pups in 2011-12. The mean number of pups estimated at the Seal Slide over seven seasons is insufficient to provide robust estimates of trends in pup production at this site.

Table 5. Summary of surveys undertaken for new births and for dead pups, cumulative births and deaths, and direct counts of brown pups (BP), moulted pups (MP) and total live Australian sea lion pups at Seal Bay during the 2011-12 breeding season. Shaded area highlights those surveys undertaken when Petersen estimates were calculated.

	Date	New	New	Cumulative			Counts			Petersen M-R estimates					
									Total					*Adj*	
No.		Births	Dead	Born	Dead	Alive	BP	MP	live	M	n	m	*N*	*N*	SE
1	02-Oct	1	1	1	1	0	0	0	0						
2	04-Oct	1	1	2	2	0	0	0	0						
3	11-Oct	1	1	3	3	0	0	0	0						
4	07-Nov	1	1	4	4	0	0	0	0						
5	21-Nov	1	1	5	5	0	0	0	0						
5	01-Dec	2	0	7	5	2	2	0	2						
6	05-Dec	2	1	9	6	3	4	0	4						
7	08-Dec	2	1	11	7	4	5	0	5						
8	12-Dec	3	3	14	10	4	4	0	4						
9	15-Dec	2	1	16	11	5	5	0	5						
10	19-Dec	3	1	19	12	7	6	0	6						
11	22-Dec	2	0	21	12	9	10	0	10						
12	26-Dec	0	0	21	12	9	8	0	8						
13	29-Dec	4	2	25	14	11	10	0	10						
14	02-Jan	0	1	25	15	10	9	0	9						
15	05-Jan	6	0	31	15	16	14	0	14						
16	09-Jan	4	1	35	16	19	15	0	15						
17	12-Jan	6	1	41	17	24	20	0	20						
18	17-Jan	7	4	48	21	27	22	0	22						
19	19-Jan	4	1	52	22	30	25	0	25						
20	23-Jan	3	3	55	25	30	24	0	24						
21	26-Jan	6	3	61	28	34	27	0	27						
22	30-Jan	8	3	69	31	39	27	0	27						
23	02-Feb	6	3	75	34	42	33	0	33						
24	06-Feb	10	1	85	35	51	40	0	40						
25	09-Feb	8	1	93	36	58	42	0	42						
26	13-Feb	4	2	97	38	60	43	0	43						
27	16-Feb	20	4	117	42	76	48	0	48						
28	20-Feb	9	1	126	43	84	54	0	54						
29	23-Feb	7	3	133	46	88	47	0	47						
30	27-Feb	6	2	139	48	92	54	0	54						
31	01-Mar	15	2	154	50	105	67	0	67						
32	05-Mar	6	4	160	54	107	55	0	55						
33	08-Mar	10	5	170	59	112	62	0	62						
34	12-Mar	12	3	182	62	121	62	0	62						
35	15-Mar	6	6	188	68	120	73	0	73						
36	19-Mar	7	2	195	70	125	61	0	61						
37	22-Mar	4	1	199	71	128	70	0	70						
38	26-Mar	4	4	203	75	128	62	0	62						
39	29-Mar	5	3	208	78	130	81	0	81						
40	02-Apr	5	1	213	79	134	82	0	82						
41	05-Apr	2	0	215	79	136	75	0	75						
42	09-Apr	5	1	220	80	140	79	0	79						
43	12-Apr	1	3	221	83	138	60	0	60						
44	16-Apr	4	0	225	83	142	84	0	84						
45	19-Apr	1	2	226	85	141	69	0	69						
46	22-Apr	0	0	226	85	141	69	0	69						
47	26-Apr	4	1	230	86	144	68	1	69						
48	30-Apr	3	1	233	87	147	65	0	65						
49	03-May	1	1	234	88	146	60	0	60						
50	07-May	3	1	237	89	148	59	0	59	68	55	33	219	231	9
51	10-May	3	2	240	91	149	47	1	48	71	43	22	246	255	16
52	14-May	0	2	240	93	147	49	3	52	73	50	27	246	255	13
53	17-May	1	1	241	94	147	49	2	51	74	46	30	227	235	9
54	21-May	0	0	241	94	147	50	2	52	79	48	34	226	234	7
55	24-May	1	2	242	96	146	35	1	36	82	35	17	283	290	24
56	29-May	1	2	243	98	145	43	2	45	88	41	28	249	255	11
57	31-May	1	1	244	99	145	74	3	77	89	74	51	252	257	6
58	04-Jun	1	2	245	101	144	49	0	49	90	49	36	248	252	8
59	07-Jun	0	2	245	103	142	47	2	49	90	46	39	235	239	5
60	11-Jun	2	1	247	104	143	63	3	66	93	62	46	256	258	6
61	14-Jun	0	0	247	104	143	56	2	58	93	56	44	250	252	6
62	17-Jun	0	0	247	104	143	51	5	56	93	53	40	256	258	7
63	20-Jun	2	0	249	104	143	58	2	60	93	56	38	270	270	9
64	2-Jul	0	2	249	106	143	48	2	50	93	49	39	254	254	6
65	5-Jul	0	0	249	106	143	45	3	48	98	46	41	248	248	4
66	12-Jul	0	0	249	106	143	59	4	63	105	60	55	253	253	3
				249	106	143							**AdjÑ =**	**251**	**2.4**
													±95% CL (246 – 256)		

Table 6. Summary of the timing and spread of seven consecutive breeding seasons of the ASL at Seal Bay, and pup abundance estimates including cumulative births and deaths; maximum live pup count; total numbers of micro-chipped pups and minimum pup production (micro-chipped + cumulative pup deaths); adjusted mark-recapture Petersen estimates (AdjŇ); and the overall estimate of pup production. Estimated mortality rate is also included. Comparative data for the 2002-03, 2004 and 2005-06 breeding seasons are from McIntosh *et al.* (2006) and McIntosh (2007a), unless otherwise indicated. Data for the 2007, 2008-09 and 2010 breeding seasons are from Goldsworthy *et al.* (2008b, 2010a, 2011); data from the 2011-12 season is from this report.

	2002-03	**2004**	**2005-06**	**2007**	**2008-09**	**2010**	**2011-12**
Month breeding season (BS) began	Dec-02	Jun-04	Dec-05	May-07	Oct-08	May-10	Oct-11
Duration of breeding season (months)	9	7	6	7	7	9	8
Median pupping date	13-Mar-03	5-Sep-04	28-Feb-06	27-Aug-07	24-Feb-09	28-Aug-10	21-Feb-12
± s.d. (days)	42	39	36	36	41	46	47
90% births (5%- 95%)	2 Jan—21 May[1]	3 Jul -1 Nov	4 Jan-18 Apr	28 Jun-26 Oct	18 Dec-3 May	14 June-11 Nov	5 Dec-9 May
90% births (days)	139[1]	121	104	120	136	150	156
Cumulative births	-	200	207	245	268	259	249
Cumulative pup deaths	73	70	75	51	88	66	104
Maximum live pup count	122	148	125	145	122	128	84
At months since beginning of BS	6	7	6	6	7	6	6
Max live pup count + cumulative dead[2]	185	208	197	198	197	189	167
Total live pups microchipped	148	202	144	203	161	201	118
Minimum pup production[3]	221	272	219	254	249	267	222
AdjŇ	227	288	203	255[4]	267[4]	269	251
(95% CL)	(216-239)	(273-302)	(199-207)	(245-266)	(259-275)	(261-276)	(246-256)
No. recapture estimates	3	2	3	11	7	13	17
Overall estimate of pup production	227	288	219	255[4]	268[4]	269	251
Confidence limit (min est. to +95% CL)	(221-239)	(273-302)		(254-266)	(268-275)	(267-276)	(249-256)
Mortality rate	32.2%	24.3%	34.2%	20.0%	32.8%	24.5%	41.4%

[1]Shaughnessy *et al.* (2006)
[2]at time of maximum live count
[3]total microchipped + cumulative dead
[4]estimates have been slightly modified from previous reports (Goldsworthy *et al.* 2008b, Goldsworthy *et al.* 2010a) to rectify errors in the number of marked pups (M) available for re-sighting during some surveys.

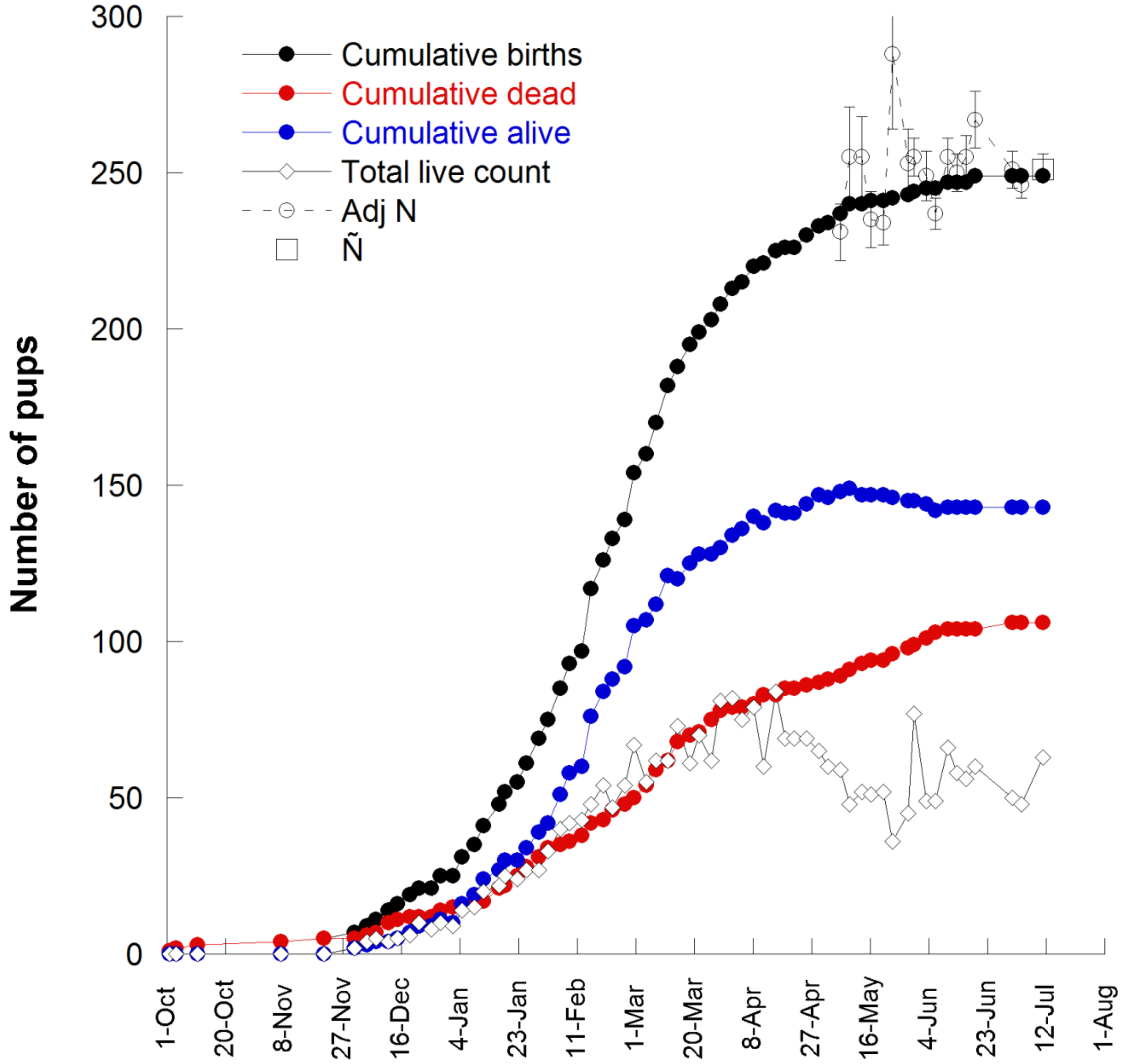

Figure 5. Changes in the number of cumulative pup births, cumulative pup deaths, minimum number of pups alive (cumulative alive), and number of live pups counted during twice weekly surveys of Australian sea lion pups at Seal Bay between 1 October 2011 and 12 July 2012.

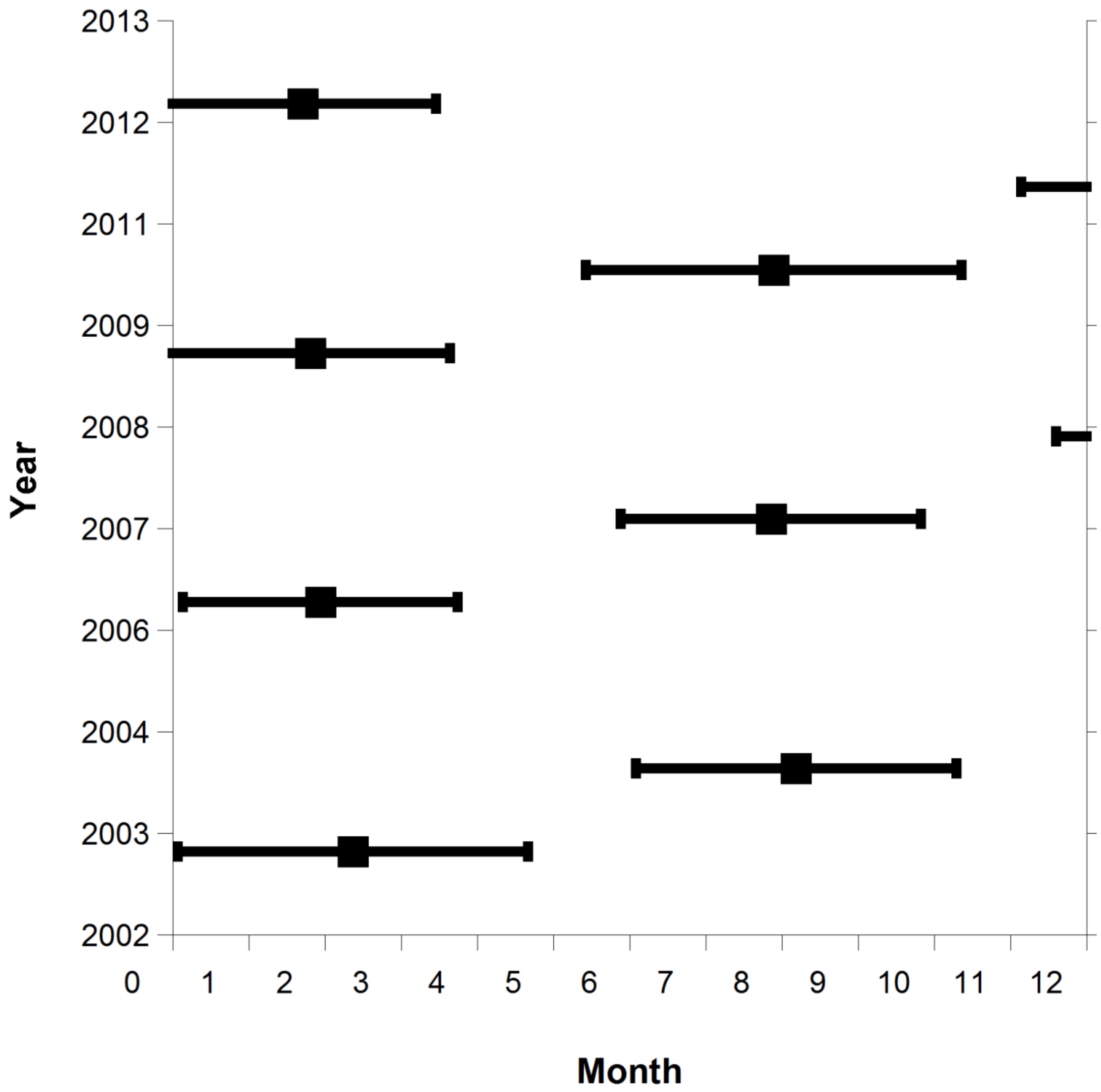

Figure 6. Variation in the breeding season chronology of Australian sea lions at Seal Bay across seven consecutive breeding seasons. Median pupping dates are indicated by squares and error bars represent the spread of 90% of births (5-95%) based on probit analyses of cumulative pup births.

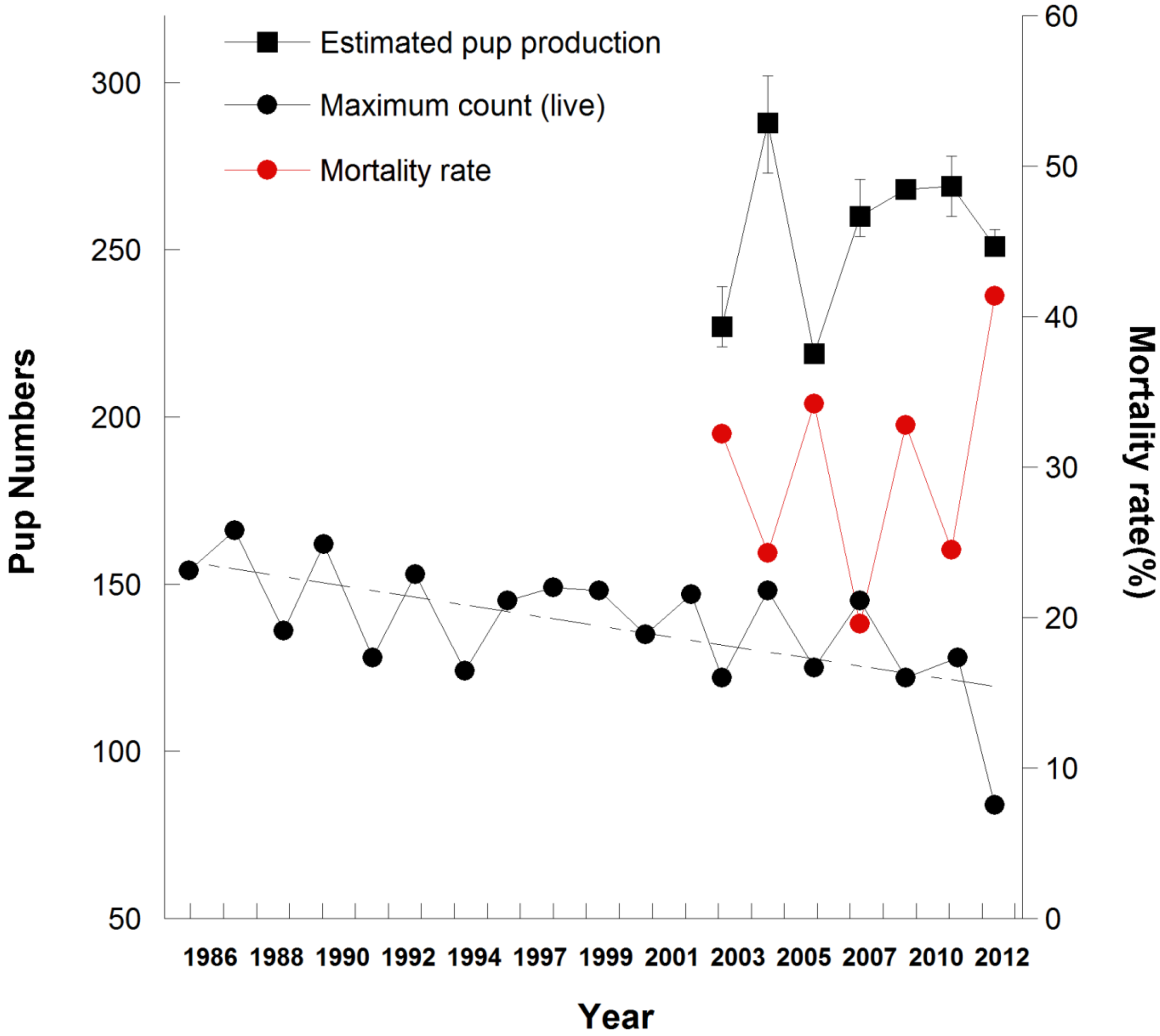

Figure 7. Trends in the abundance of Australian sea lion pups at Seal Bay based on maximum live pup counts for 19 breeding season between 1985 and 2011-12. Trends in the overall estimate of pup production and pup mortality rate are presented for the last 7 breeding seasons. Error bars represent upper and lower 95% confidence limits of estimated pup production.

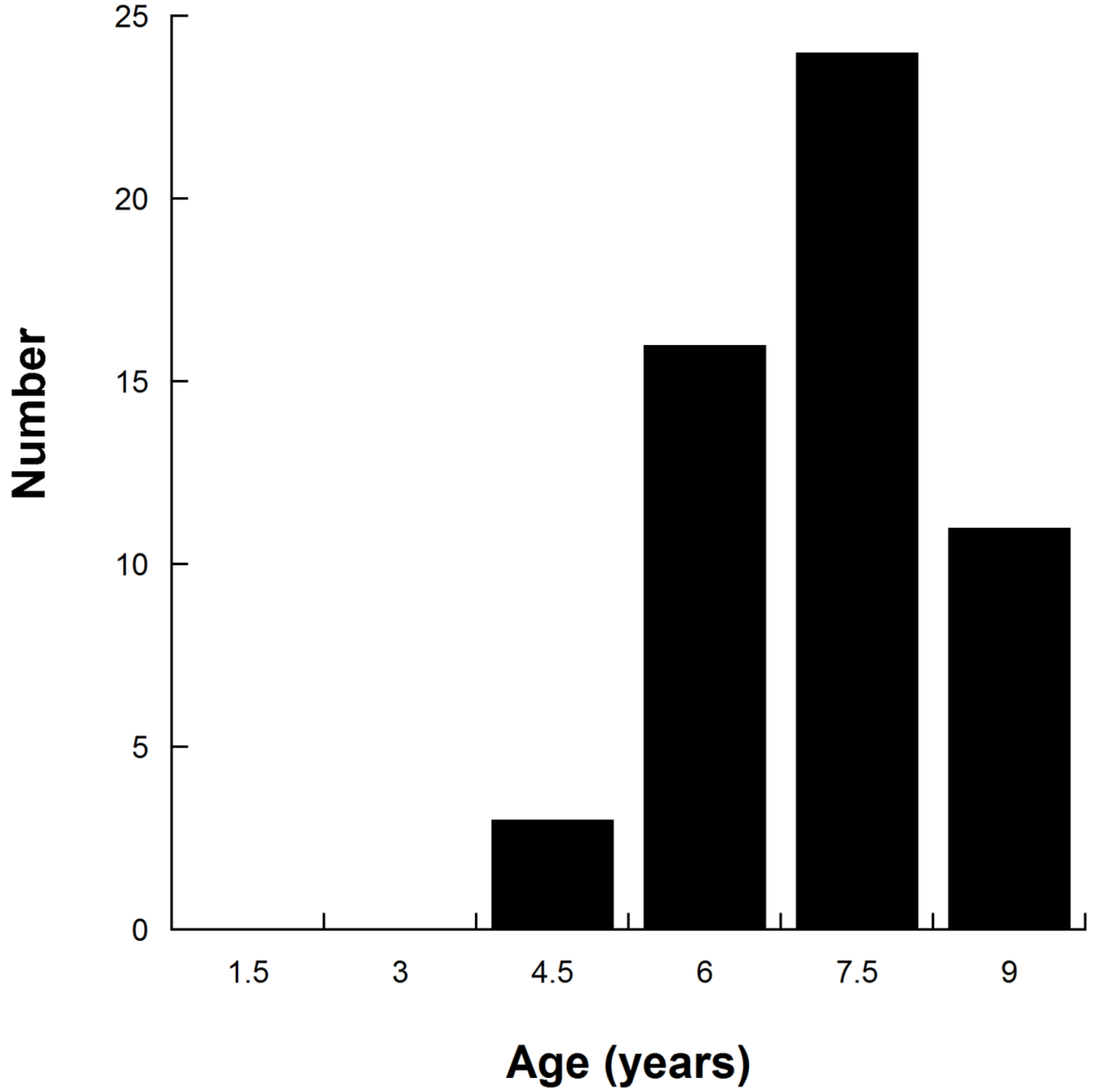

Figure 8. Age distribution of 54 known-age ASL females that pupped at Seal Bay in the 2011-12 breeding season. Note that micro-chipping only commenced 9 years before the 2011-12 breeding season, and thus no data is available for older individuals.

Table 7. Details of pup surveys undertaken at the ASL colony at the Seal Slide (Kangaroo Island) between December 2011 and March 2012. The number of clear (unmarked), marked, dead and total pups seen on each survey is indicated, in addition to the number of new marks applied. The number of marked pups available to be re-sighted at each survey is presented, along with the cumulative number of dead pups recorded. The minimum number of pups at each visit is estimated by summing the number of pups marked, maximum number of unmarked pups and cumulative number of dead pups.

Date	Clear count	Marked count	Dead clear	Dead marked	Total live count	Total live & dead count	New marked	Cum. marked	Min alive	Cum. dead clear	Min. Total
14-Dec-11	4	0	0	0	4	4	3	3	4	0	4
18-Jan-12	3	1	1	0	4	5	1	4	6	1	7
27-Jan-12	3	3	0	0	6	6	1	5	7	1	8
14-Feb-12	5	3	0	0	8	8	0	5	10	1	11
26-Mar-12	7	1	0	0	8	8	0	5	12	1	13

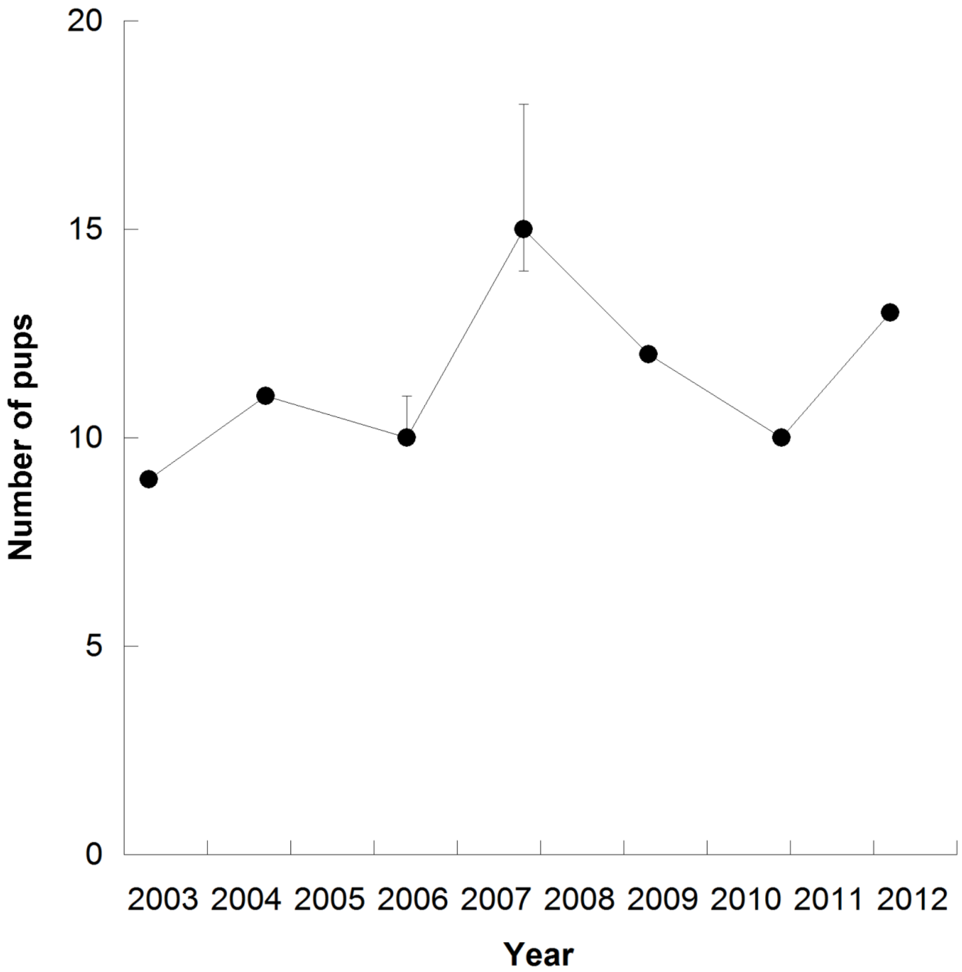

Figure 9. Trends in the estimated Australian sea lion pup production at the Seal Slide (Kangaroo Island), over seven consecutive breeding seasons (2002-03 and 2011-12). Upper (95%) and lower (absolute minimum) confidence limits are available for the 2005-06 and 2007 breeding seasons.

Additional colony surveys

Four additional helicopter-assisted surveys (combining aerial and ground count surveys) were undertaken between November 2011 and February 2013. First, a survey of islands off south-western and southern Eyre Peninsula (19 – 21 November 2011), including Rocky (North), Cap, Rocky (South), Greenly, Four Hummocks, Little Hummock, Price and Golden Islands, and Curta Rocks. The second and third surveys both covered Nuyts Reef (22 March 2012 and 2 August 2012). Fourth was a survey of some islands in the Nuyts Archipelago, western Eyre Peninsula, as well as repeat surveys of Rocky (North) Island and Curta Rocks (27 and 28 February 2013). Details of individual island surveys are given below and in Table 8.

Rocky (North) Island

Rocky (North) Island was visited on 19 November 2011, when 44 pups were counted, 30 brown (70%), 13 moulted (30%) and 1 dead (Table 8). The Island was also visited on 27 February 2013 (~15.3 months later) when a total of 47 pups were counted, 5 black (11%, 2 of those pups had mothers being mate-guarded), 35 brown (78%), 5 moulted (11%) and 2 dead (Table 8). Both surveys were undertaken at a similar stage of the breeding season, although the 2013 survey was slightly earlier based on the presence of black pups and two mate-guarded females, and a smaller percentage of moulted pups. An earlier survey was undertaken on 26 November 2010 (~11.8 months prior to the 2011 survey) when 34 fully moulted pups were counted (Goldsworthy *et al.* 2012). This survey was undertaken well after the breeding season had finished (based on absence of brown pups). The first and only other breeding records for Rocky (North) Island come from a survey undertaken on 14 January 1996, when a total of 16 pups were counted (15 brown, 1 dead) and the breeding season was noted as still being underway (Shaughnessy *et al.* 2005).

Cap Island

There is little historical information on the presence of ASL on Cap Island. Six animals (unclassed) were counted from an aerial survey undertaken in May 1945, and 15 (unclassed) were counted from an aerial survey undertaken on 7 March 1976 (Dennis 2005). A boat based survey saw no animals on 25 January 1990 (Gales 1990). Cap Island was visited by helicopter on 19 November 2011 and identified as a breeding colony for the first time. A total of 38 pups were counted, 2 black (6%), 29 brown (81%), 5 moulted (14%) and 2 dead (Table 8). No mate-guarded females were seen, suggesting the breeding season had just finished.

Rocky (South) Island

There is limited historic data on the presence of ASL on Rocky (South) Island. A number of aerial surveys were conducted in 1976, 1977, 1978 and 1995. All of them indicated small numbers of ASL (between 0 and 22 animals), but no pups or breeding activity were observed (Dennis 2005). The first ground survey for ASL was undertaken on 15 January 1996 when a total of 26 animals were counted, including one dead pup of unspecified age (an older, moulted pup that may well have swum in from a nearby breeding colony) (Shaughnessy *et al.* 2005). Rocky (South) Island was considered a possible breeding site by Gales *et al.* (1994) and Shaughnessy *et al*. (2005). Rocky (South) Island was visited by helicopter on 20 November 2011 and identified as a breeding colony for the first time. A total of 12 pups were counted, 8 brown (78%), 3 moulted (27%) and 1 dead (Table 8). No mate-guarded females or small (black) pups were seen suggesting the breeding season had been completed within the last 4-6 weeks.

Greenly Island

An aerial survey was undertaken of Greenly Island on 20 November 2011 to look for evidence of breeding because breeding had been observed nearby at Cap, Rocky (North), and Rocky (South), Four Hummock, Little Hummock and Price Islands (see below). On the aerial survey 15 adult males and 5 juvenile ASL were counted, but no signs of breeding activity or pups were seen (Table 8). There have been a number of previous ground surveys (in 1947, 1974, 1976, 1984, 1990, 1996, 2004) and aerial surveys (in 1976, 1978, 1995) of Greenly Island (Gales *et al.* 1994, Dennis 2005, Shaughnessy *et al.* 2005). On only one of them, a ground count on 15 January 1996, was a pup (moulted) observed, and it may have swum in from a neighbouring colony (Shaughnessy *et al.* 2005).

Four Hummocks Islands

An aerial survey of the Four Hummocks Islands was undertaken on 20 November 2011, when small numbers of ASL (adult males, females and juveniles) were observed on the northern, middle, minor rock (between middle and south) and southern islands (Table 8).

Pups were only observed on the middle island, where the helicopter landed to enable a thorough ground count. A total of 10 pups were counted, 5 brown (50%) and 5 moulted (50%). No mate-guarded females or small (black) pups were seen suggesting the breeding season had been completed within the last 4-8 weeks. Three previous pup counts have been made on Four Hummocks Islands. In January 1996, 12 pups were found on a ground count (5 brown, 6 moulted on the north island, 1 moulted pup on the south island, Shaughnessy *et al.* 2005). In January 1997, one moulted pup was seen on the northern island from an aerial survey (presumably from the previous 1995/96 breeding season, Shaughnessy *et al.* 2005). In November 2010, aerial surveys were undertaken of the southern and middle Four Hummock Islands, and a ground count was undertaken of the northern Island, where nine fully moulted pups were counted (Goldsworthy *et al.* 2012). On the two occasions when brown pups were found, they were sighted on different islands in the group (northern island in 1996 and middle island in 2011).

Little Hummock Island

Between the northern Four Hummock Island and Perforated Island lies a small unnamed low-lying island, here termed Little Hummock Island. Two aerial surveys of Little Hummock occurred in 1976 and 1978 when 12 and 6 ASL (unclassed) were counted. The first ground survey occurred on 29 January 1990 when 9 ASL were counted (Dennis 2005). On 20 November 2011, 4 ASL (2 adult females, and 2 juveniles) were counted on an aerial survey, plus a number of brown pups (Table 8). The helicopter was landed to enable a thorough ground survey, which resulted in a count of 10 brown pups. This survey has identified Little Hummock as a breeding colony for the first time (Table 8).

Price Island

A ground survey of Price Island was undertaken on 20 November 2011, when 17 pups were counted, 5 black (29%) and 12 brown (71%) (Table 8). A number of aggressive adult males were encountered, including one mate-guarding a female. This and the lack of moulted pups suggest the breeding season was only a third to halfway through. On the previous ground survey in November 2010, 17 pups (10 brown and 7 moulted) were counted, and it is thought to have been undertaken 2-3 months following the end of the breeding season. The timing of the breeding season at Price Island appears to be 2-3 months later than Rocky (North), Rocky (South), Cap, and Four Hummocks Island. A pup survey at Price Island in January 1996 was shortly after the end of the breeding season, when 25 (5 brown, 20 moulted) pups were recorded (McKenzie *et al.* 2005).

Golden Island

An aerial survey of Golden Island was undertaken on 20 November 2011, with no evidence of breeding observed (25 unclassed ASL counted, but no pups, Table 8).

Curta Rocks

Curta Rocks has had limited historic surveys. One aerial survey in November 1982 recorded 16 (unclassed) ASL, and a survey from a boat in January 1990 recorded 4 (Dennis 2005). Two aerial surveys were undertaken as part of this project, one on 21 November 2011, recorded six adult males, 11 adult females, 24 juveniles and one large brown pup spread across the four islets and reefs (Table 8). The second survey was undertaken on 28 February 2013 (~15.3 month later), when only five juveniles were counted (Table 8). The presence of the large brown pup and large number of animals and trackways on the slopes of the various islands that make up Curta Rocks identify it as a potential new breeding site.

Nuyts Reef

Nuyts Reef was visited on 22 March 2012, when an aerial survey indicated large numbers of ASL on the eastern (83 unclassed) and western (101 unclassed) reefs (Table 8). The helicopter landed on the western reef, and a single small black pup was sighted, suggesting the breeding season had just commenced. The southern reef was completely wave washed and not surveyed. A follow up survey was undertaken on 2 August 2012 (~4.4 months later) when a total of 44 pups were counted based on ground surveys conducted on the two main reef groups (8 on the eastern reef and 36 on the western reef) (Table 8). Most pups were judged to be 3-4 months old. Although there have been numerous aerial and boat-based surveys (1945, 1976, 1977, 1995, 1996, 2004) of Nuyts Reef (Dennis 2005), the counts undertaken in this study (2012) represent only the third ground counts undertaken. Gales (1990) recorded no pups on the eastern reef and three dead pups on the middle reef (middle reef is adjacent to eastern reef) and no pups on the western reef on a survey undertaken on 3 March 1990. Shaughnessy *et al.* (2005) recorded 12 pups on the western reef (6 brown, 2 moulted and 4 dead) and no pups on the eastern reef based on ground surveys undertaken on 13 April 2004. Boat-based surveys of the other reefs then found no additional pups. The 2012 pup survey represent the most comprehensive to date, confirming breeding on both the eastern and western reefs, and increasing pup production estimates by more than a factor of three. Based on the age of pups and the time since the beginning of the breeding season, the

22 March 2012 survey was only about four months into the breeding season, hence the pup production for the Nuyts Reef is likely greater than the number observed on this survey.

Chronology of western Eyre ASL breeding colonies

On 27 February 2013, a helicopter was used to deploy Satellite Relay Data Loggers with Conductivity, Temperature, Depth (CTD) and Fluorescence sensors on adult male ASL on a number of colonies off the western Eyre Peninsula as part of an Integrated Marine Observing System (IMOS) supported project. This enabled opportunistic aerial surveys of some ASL breeding colonies to determine if breeding had commenced, as some of these colonies were scheduled to be surveyed in 2013 as part of the next AMMC supported ASL survey program. No signs of breeding activity or brown pups were observed on Blefuscu and Lilliput Islands. A single brown pup was seen at Olive Island, indicating commencement of the breeding season there (Table 8). At Nicolas Baudin Island, 4 small brown pups were observed with attending females, and some females were mate-guarded by large adult males, also indicating the early stages of the breeding season (Table 8). No signs of pups or breeding activity were observed at West Waldegrave, Pearson or Dorothee Islands (Table 8). At Rocky (North) Island, many pups were seen, and a detailed ground survey was undertaken (see above).

Table 8. Details of Australian sea lion surveys undertaken at islands in the Great Australian Bight and off lower Eyre Peninsula. Numbers of adult females (AF), adult males (AM), sub-adult males (SAM) and juvenile (Juv) are noted, and the pelage stage of pups. MG denotes pups with mothers being mate guarded.

Island	Date	Pups (Ground surveys)						Aerial surveys				
		Black (MG)	Black	Brown	Moulted	Dead	Total	AF	AM	Juv	Brown Pups	Unclassed (non-pups)
Rocky (North) Island	19-Nov-11			30	13	1	44					
Cap Island	19-Nov-11		2	29	5	2	38					
Rocky (South) Island	20-Nov-11			8	3	1	12					
Greenly Island	20-Nov-11								15	5		
Four Hummocks Islands												
- Nth Is.	20-Nov-11							2	2	4		
- Middle Is.	20-Nov-11			5	5		10					
- Rock b/w Mid and South	20-Nov-11							2	2			
- South Is.	20-Nov-11							5	2	3		
Little Hummock Island	20-Nov-11			10			10	2		2		
Price Island	20-Nov-11	1	4	12			17					
Golden Island	20-Nov-11											25
Curta Rocks												
- Nth Reef.	21-Nov-11							2		2		
- Nth Is.	21-Nov-11							1	4	9	1	
- Middle (main) Is.	21-Nov-11							6		10		
- Sth Rock.	21-Nov-11							2	2	3		
Nuyts Reef												
- Eastern Reef	22-Mar-12											83
- Western Reef	22-Mar-12		1				1					101
Nuyts Reef												
- Eastern Reef	2-Aug-12						8*					
- Western Reef	2-Aug-12						36*					
Blefuscu Island	27-Feb-13										0	
Lilliput Island†	27-Feb-13										0	
Olive Island†	27-Feb-13										1	
Nicholas Bauidin Island†	27-Feb-13										4	
West Waldegrave Island†	27-Feb-13										0	
Pearson Island†	27-Feb-13										0	
Dorothee Island†	27-Feb-13										0	
Rocky (North) Island	27-Feb-13	2	3	35	5	2	47					
Curta Rocks	28-Feb-13									5		

*unclassed pup counts; † pup counts only

Remote camera trials to monitor breeding chronology

Three remote camera systems were trialled as part of this study. Two in SA were installed on Dangerous Reef (one on the north coast, one on the south coast). The third is currently in operation on an island in the Recherche Archipelago and no data were available when this report was prepared. The two remote camera systems were installed on Dangerous Reef on 25 August 2012, at the beginning of the breeding season (a small number of pups were observed at this time), and were removed on 5 January 2013 (133 days later). Camera 1 recorded 196 pictures averaging 1.5 per day. ASL were clearly identifiable in 99 images (51%). A total of 133 individual animals were seen, about 1.3 per image, adult females were identifiable in 43% of images, adult and sub-adult males in 32% of images and juveniles in 8% of images. Pups were apparent in 26 images (13%), and a total of 27 individual pups were identifiable, a little over one per picture (range 0-2). Camera 2 recorded 186 pictures averaging 1.4 per day. ASL were clearly seen in 116 images (62%). A total of 210 individual animals were seen, about 1.3 per image. Adult females were identifiable in 57% of images, adult and sub-adult males in 22% of images and juveniles in 6% of images. Pups were identifiable in 51 images (27%), a total of 56 individual pups were identifiable, a little over one per picture (range 0-5).

The image quality was sufficient to zoom in on animals at least 40 m away and, in most instances, to determine their approximate age and sex (Figure 10). Most importantly, pups were easily recognisable. In addition, their pelage stage could be identified and so pups could be aged approximately based on their appearance. Images of pups were obtainable at weekly intervals or shorter, demonstrating that the remote camera systems can provide an effective tool in obtaining good information on the timing and stage of breeding. The camera systems trialled had built in 3G mobile phones and were programmed to transmit images via MMS to email. Unfortunately, over the 4+ months the cameras were in operation, only four images were successfully transmitted by the mobile network to email. Since this trial was conducted, at least one camera system company licensed to sell in Australia has placed NextG enabled camera systems on the market and hence considerable potential exists for pursuing this monitoring method.

Camera 1: Two brown pups and two adult females, 25 October 2012.

Camera 2: Black pup with adult female, 3 October 2012.

Figure 10. Examples of Remote Camera images of ASL pups at Dangerous Reef

Camera 1: Black pup with adult male and female in distance, 16 October 2012.

Camera 2: Black pup with adult female (left), 1 November 2012.

Figure 10. Continued

Camera 1: Black pup with adult female, 24 November 2012.

Camera 2: Brown pup alone, 11 November 2012.

Figure 10. Continued

Camera 1: Black pup with adult female, 24 November 2012

Camera 2: Brown pup on own, 11 November 2012.

Figure 10. Continued

5 CONCLUSIONS

This study has provided additional estimates of pup abundance and production for a number of key ASL monitoring sites in South Australia between November 2011 and February 2013. It also provides confirmation of breeding, information on breeding season chronology, and estimates of pup abundance at a number of sites in the Great Australian Bight and off the western and southern Eyre Peninsula that have not been surveyed since the early to mid 1990s. Key findings include the discovery of three previously unrecorded breeding sites for ASL, Cap Island, Rocky (South) Island and Little Hummock Island off lower Eyre Peninsula. This has already had important management implications for the Commonwealth managed Gillnet, Hook and Trap Fishery (GHAT). The Australian Fisheries Management Authority (AFMA) were notified of the new ASL colonies, and on 22 May 2013, they implemented a new 4 nautical mile gillnet closure around Cap and Rocky (South) Islands as part of the Southern and Eastern Scalefish and Shark Fishery Closure Direction No. 7 2013 (AFMA 2013) (Figure 11). No new closure was implemented around Little Hummock Island because it already lies within a gillnet closure established for Four Hummock and Price Islands (Figure 11). With the addition of three new ASL colonies, the total number of known colonies (>5 pups) in South Australia has increased from 39 to 42, and the total breeding locations from 48 to 51 (Shaughnessy *et al.* 2011).

The remote field camera trials were successful, despite only being able to test 3G network cameras. As part of the 2013 ASL surveys, we will test recently available Next G mobile network cameras that have recently become available which should be able to relay images through MMS to email more reliably. If this is successful, we will have a useful tool that will enable us to better monitor breeding chronology, optimise survey timing and quality, and improve logistic planning and resourcing for future ASL surveys.

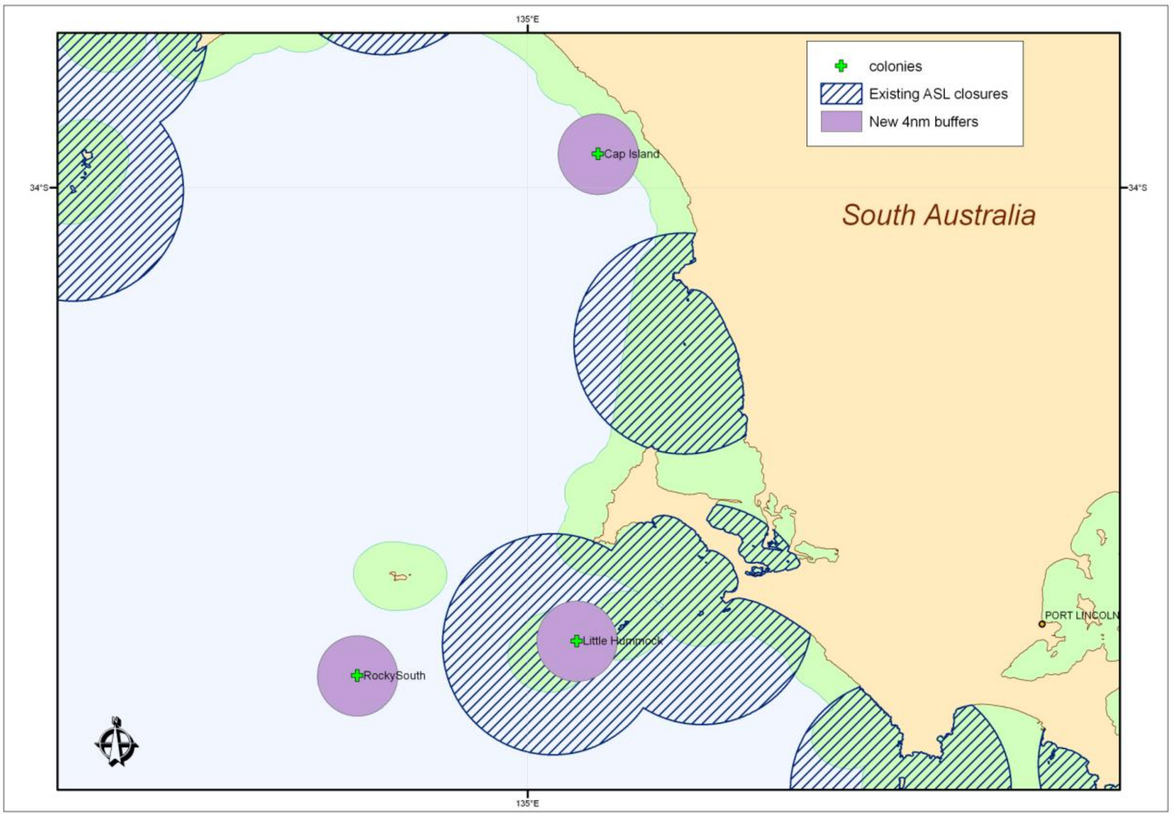

Figure 11. New 4 nautical mile fishery closures for Cap and Rocky (South) Islands introduced into the GHAT fishery as part of the Southern and Eastern Scalefish and Shark Fishery Closure Direction No. 7 2013 (source, AFMA 2013).

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