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Maintaining the monitoring of pup production at key Australian sea lion colonies in South Australia (2013/14)

Simon D Goldsworthy, Alice I Mackay, Peter D Shaughnessy, Fred Bailleul and Clive R McMahon

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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

December 2014

Final report to the Australian Marine Mammal Centre

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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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 March 2013 and October 2014. This included direct counts and mark-recapture surveys at Seal Bay and the Seal Slide on Kangaroo Island, Lilliput and Blefuscu Islands in the Nuyts Archipelago, Olive, Jones and Nicolas Baudin Islands off the west Eyre Peninsula, and Dangerous Reef and English Island in Spencer Gulf. The breeding status and pup production were also determined by direct counting for Nuyts Reef and a number of islands off the western and lower Eyre Peninsula including Ward, Pearson, West Waldegrave, Dorothee and Lewis Islands.

Pup production for the 2013 breeding season at Seal Bay was estimated to be 268 (range 259-277), based principally on twice-weekly surveys of new pup births and deaths, and on Petersen (mark-recapture) estimates in most of the colony, as well as direct counts of pups in Pup Cove. This estimate is similar to those from the previous four breeding seasons (2007: 254-256; 2008-09: 268-275; 2010: 267-276; 2011-12: 249-256).

Pup production at the Seal Slide was estimated to be 10 for the 2013 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 eight breeding seasons (since 2002-03), and range between 9 and 15 over this period. No trends are apparent at this stage.

Pup production estimates at Lilliput and Blefuscu Islands in 2013, based on the Petersen estimate and cumulative pup production method, were 79 (95% CL 68-90) and 89 pups (95% CL 85-93) from two mark-recapture sessions, respectively. These are the sixth pup abundance surveys undertaken at these colonies, the fourth using the Petersen method and the first using the Petersen and cumulative pup production method.

Estimated pup production at Olive Island based on the Petersen method with cumulative pup production was 140 (95% CL, 123-156). Estimates of pup production available for six consecutive breeding seasons at Olive Island from 2006 (206) to 2013 (140) suggest a 32% decline (over 7 years, 5 breeding seasons), although this was not statistically significant. A single ground survey was undertaken on Jones Island on 17 June 2013 when a total of 15 pups were sighted. The estimate for the 2013 season is similar to previous surveys between 2001/02 and 2011/12 which have ranged between 7 and 15 pups.

Two mark-recapture sessions were undertaken at Nicolas Baudin Island in June and August 2013. Using the Petersen estimate and cumulative pup production method the total pup production was estimated to be 81 (95% CL 71-91). This estimate falls within the range of other surveys conducted in 2001/02 (72 pups), 2003 (70 pups) 2005/06 (98 pups).

The estimate of pup production for the 2014 breeding season at Dangerous Reef was 485 (95% CL 462-508). Although there has been an apparent ~42% decline in estimates of pup numbers between the 2006/07 (831) and 2014 (485) breeding seasons (5 breeding seasons, ~7.5 years), this decline is not statistically significant. Monitoring at this site continues to present challenges in the enumeration and interpretation pup abundance metrics, and the potential influence of season and other factors influencing re-sight probabilities. Analyses were undertaken to determine if inter-breeding season differences in individual detection heterogeneity (IDH) may contribute to biasing estimates of pup production and trend analyses at Dangerous Reef. Results indicated that resight probabilities were effectively 1 and did not differ between seasons. Furthermore, although pup survival varied between breeding seasons, there was no apparent relationship between survival in summer or winter breeding seasons to account for the difference observed in pup abundance metrics.

A single ground count was undertaken at English Island on 4 July 2014, and a total of 64 pups counted, including one brown pup that had previously been marked on Dangerous Reef during the first mark-recapture trip. This is a substantial increase in pup numbers from previous surveys and is likely to be confounded by an unknown number of pups dispersing to English Island from Dangerous Reef, and the fact that the survey was done well after the end of the breeding season.

Ground surveys were also undertaken at a number of islands in the Great Australian Bight and off western and southern Eyre Peninsula. In March 2013, during a ground survey at Lewis Island 79 pups were counted. In June 2013, 2 pups were counted at Point Labatt. In August 2013, ground counts were undertaken at Ward Island (46 pups), Pearson island (28 pups), Dorothee Island (no evidence of breeding) and West Waldegrave Island (91 pups). In December 2013, a ground and aerial survey of Nuyts Reef counted 54 pups on the two main reefs. A ground survey was undertaken at North Casuarina Island in January 2014 when 11 pups were counted, and an aerial survey of Curta Rocks was undertaken in February 2014 with no evidence of breeding.

2. INTRODUCTION

2.1. Background

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). The species is listed as Vulnerable under the threatened species category of the Commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act), Vulnerable under the South Australian *National Parks and Wildlife Act* (1972) and Endangered by the International Union for the Conservation of Nature (IUCN) Redlist. Recent population genetic studies have indicated little or no interchange of females among breeding colonies, even for those separated by short distances (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.

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 was 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 the 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, 2009c), 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, 2009c). 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.* 2010a). 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, obtaining 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 (southern Spencer Gulf); Olive and Jones Islands (Chain of Bays, western 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.

2.2. Objectives

The aims of this study were to continue to provide data on the status and trends in abundance of ASL by undertaking pup production surveys at key monitoring sites between March 2013 October 2014. This included:

- undertaking surveys of Olive and Jones Islands, Lilliput and Blefuscu Islands, Seal Bay and Sea Slide, Dangerous Reef and English Islands, and the first mark-recapture survey at Nicolas Baudin Island;
- undertaking single surveys at sites where pup numbers have not been surveyed comprehensively for some years, and where breeding status remains uncertain (Nuyts Reef, Ward Island, Pearson and Dorothee Islands, and Curta Rocks);
- analysing existing mark-recapture data to assess the influence of individual detection heterogeneity in biasing estimates of pup production and trend analyses; and
- continuing trials of remote camera systems to monitor breeding chronology to improve survey optimisation and resourcing.

Some changes to the work plan were required. The breeding season at Jones Island was over sooner than expected, so a more comprehensive survey could not be undertaken at this site. Instead a single ground count was conducted in June 2013. A helicopter aerial survey of Dangerous Reef in March 2014 indicated that breeding had just started. As such, results from surveys undertaken up to 4 July 2014 are reported here. An additional survey at North Casuarina Island was conducted during the AMMC funded State-wide census for New Zealand fur seals.

3. METHODS

3.1. Field sites

Olive and Jones Islands

Olive Island (32.719° S, 133.695° E, Figure 1) was accessed by vessel from Streaky Bay, with two visits made in June and July/August 2013. 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 vessel from the settlement at Baird Bay. The island was visited on one occasion during which a ground survey of pups was undertaken (17 June 2013).

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). A ground count and two mark-recapture surveys were undertaken on these islands between August and October 2013.

Dangerous Reef and English Island

Dangerous Reef (34.870° S, 136.217° E) is 35 km south-east of Port Lincoln and forms part of the Sir Joseph Banks Group Conservation Park (Figure 1). It comprises Main Reef with nearby East Reef and West Reef, covering about 12 ha in total. Sea lion pups are born on Main Reef, with some movement to the West Reef several weeks after birth. Dangerous Reef was accessed by vessel from Port Lincoln three times between 14 May and 4 July 2014. Direct counting of live pups and surveying of dead pups was conducted during each visit, and mark-recapture of pups was undertaken during the second and third visit.

English Island (34.638° S, 136.196° E) is a small rocky island that forms part of the Sir Joseph Banks Group Conservation Park. A direct count of ASL pups was conducted on 4 July 2014.

Seal Bay and Seal Slide

Seal Bay is part of the Seal Bay Conservation Park situated on the south coast of Kangaroo Island, centered on 35.996° S, 137.327° E (Figure 2). 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.* 2007a, 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 2) 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 2013 breeding season. The methodology to survey the Seal Slide followed that described by Goldsworthy *et al.* (2007c) for small colonies and is referred to as the cumulative mark and count (CMC) method.

At Seal Bay, three methods were used to estimate pup production during the 2013 breeding season: direct counts of live and dead pups; 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 for these approaches is detailed below.

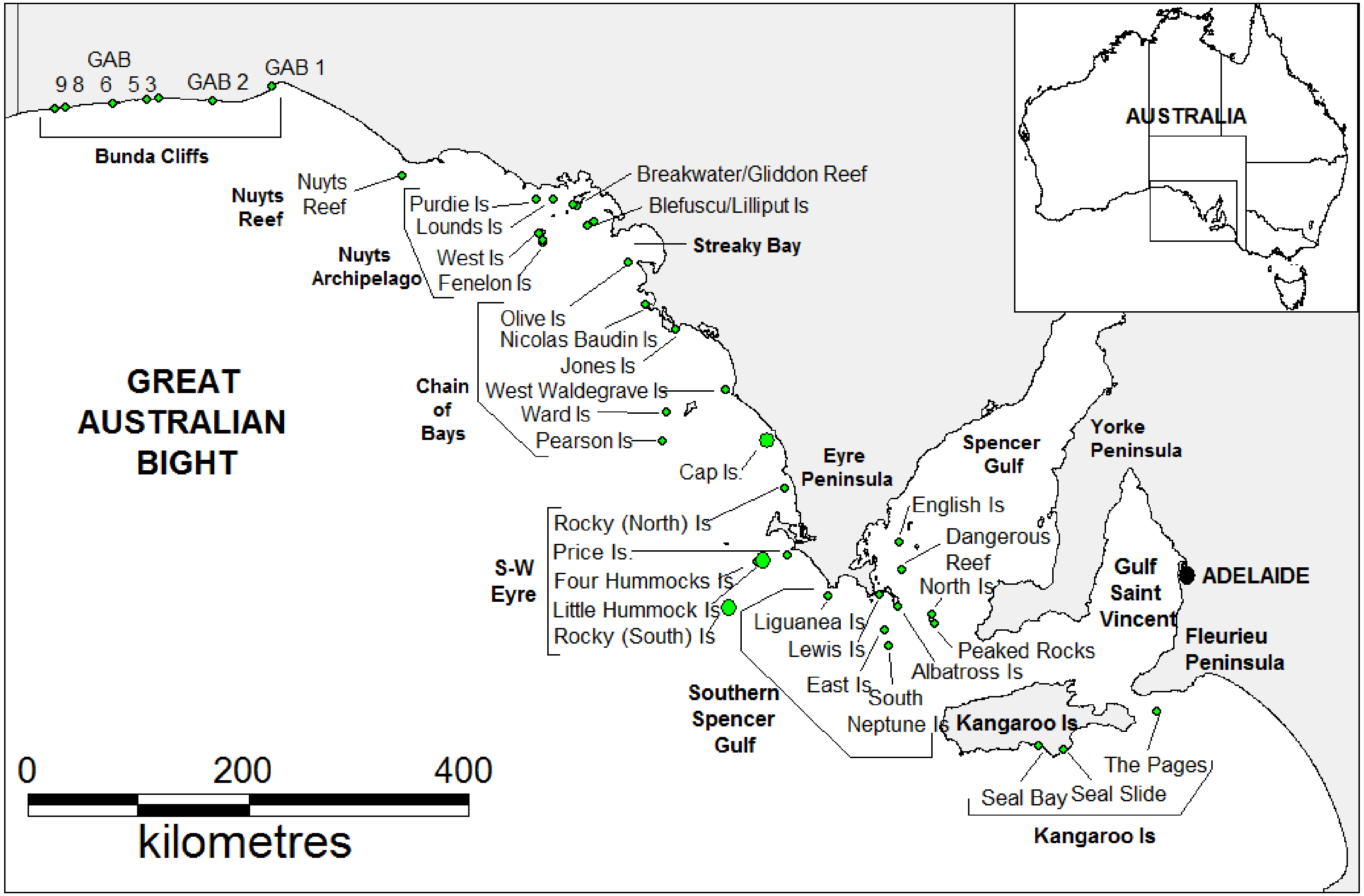


Figure 1. The location of Australian sea lion breeding colonies in SA and the seven metapopulations as described by Goldsworthy *et al*. (2007c).

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.

3.2. 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 were first applied to estimating pup production in ASL populations at Dangerous Reef in July 1999 (Shaughnessy and Dennis 1999). They have since been used at Seal Bay, Dangerous Reef, and Olive, North Page and South Page Islands (McIntosh *et al.* 2006, Shaughnessy *et al.* 2006, Goldsworthy *et al.* 2007c, McIntosh *et al.* 2012, Goldsworthy *et al.* 2013).

A mark-recapture procedure was used to estimate the number of live pups at Seal Bay and Olive, Nicolas Baudin, Lilliput and Blefuscu Islands. At Seal Bay, pups were externally marked by clipping the fur of the rump and also implanted with 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 carcasses 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 and number of recently dead pups that had not been marked was also recorded. Pups sighted in future surveys (i.e., known to be alive) were included as 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:

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

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:

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

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:

$$\hat{B}_{1-2} = (\hat{N}_2 - \hat{N}_1\hat{\phi}_{1-2}) + D_1$$

where, $\hat{N}_1$ is the Petersen estimate of the number of live pups in the colony at Survey 1, and $\hat{N}_2$ is the Petersen estimate of the number of live pups at Survey 2. D_1 is the cumulative number of dead pups recorded up to the end of Survey 1. $\hat{\varphi}_{1-2}$, is the apparent survival of pups between Survey 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).

The variance of the estimated number of pup births between consecutive mark-recapture surveys was calculated from a general formula in Kendall and Stuart (1977):

$$Var(\hat{B}_{1-2}) = Var(\hat{N}_2) + Var(\hat{N}_1)(\hat{\phi}_{1-2})^2 - (\hat{N}_1)^2(\hat{\phi}_{1-2}),$$

where

$$Var(\hat{\varphi}_{1-2}) = \frac{\varphi(1-\varphi)}{M_1}.$$

The ±95% confidence limits are calculated as:

$$\hat{B}_{1-2} \pm (1.96\sqrt{Var(\hat{B}_{1-2})}).$$

This approach was repeated to estimate the number of births that occurred between surveys 2 and 3, and surveys 3 and 4 etc.

Total cumulative pup production (N_c) was hence estimated as:

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

In the case of two consecutive estimates N_1 and N_2, the variance of the estimated total cumulative pup production N_c is:

$$Var(N_c) = Var(\hat{N}_1) + Var(\hat{B}_{1-2}),$$

The ±95% confidence limits of this estimate were calculated from:

$$N_c \pm (1.96\sqrt{Var(N_c)}).$$

Seal Bay pup production estimate

At Seal Bay, more detailed analysis of the pup numbers was possible because a longer time series is available within each breeding season, 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, 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).

Seal Slide pup production estimate

The methodology to survey the Seal Slide followed that described by Goldsworthy *et al.* (2007c) 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 subsequently.

Trends in pup abundnace

To estimate changes in pup production we considered two models fitted to the log of maximum pup counts and pup production in each breeding season. The models tested were: (1) a simple linear regression model; and (2) a multiple linear regression model that included a factor (Period) to allow for the non-annual interval between breeding seasons of the ASL

The model equation for (2) was:

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

where '*Pups*' was either the maximum 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. Models were fitted using the statistical package and environment R version 2.15.1 (R Core Team 2013).

The axes of the plots of pup numbers against breeding season are linear. The fitted curve is based on the logarithm of pup numbers because trends in seal populations are generally exponential in nature (Payne 1977).

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.

Dangerous Reef – survival and capture probabilities

Capture-history matrices were constructed from the resight histories of tagged pups within a season for four breeding seasons at Dangerous Reef. These capture probabilities were used as input files for the capture-mark-recapture (CMR) program MARK (White and Burnham 1999) to estimate survival and capture probabilities after weaning. MARK provides survival (Φ) and recapture (p) estimates under the Cormack-Jolly-Seber (CJS) model (Cormack 1964, Jolly 1965, Seber 1965) and under several models that appear as special cases of the CJS model (Lebreton *et al.* 1992). Parametric goodness-of-fit (GOF) tests within MARK were used to test whether the CJS model assumptions were met (Burnham *et al.* 1987, Lebreton *et al.* 1992). This bootstrap procedure simulates encounter histories that exactly meet the CJS model assumptions. These simulated data were compared to the field data for compliance with the CJS model assumptions (White and Burnham 1999).

Remote camera trials to monitor breeding chronology

Two remote cameras (UV565 8MP “Black Ops”, UoVision Australia) were deployed on Olive Island at the beginning of August 2013. The cameras were set to collect images of breeding activity and breeding chronology in the ASL colony. The camera systems were motion activated (within 20 m) and stated to be capable of transmitting collected images via Multimedia Messaging Service (MMS) and 3G mobile network to email. Each camera contained a 16 MB SD card to record images. The cameras were initially tested in Adelaide to ensure motion activation and transmitting of messages worked. At Olive Island the cameras were unable to join the mobile phone network (although personal mobile phones had reception in the location the cameras were deployed). Further discussion with the company indicated that the cameras were not in fact 3G enabled, and instead worked on the 2G – GSM network. Therefore, no recordings were made.

4. RESULTS AND DISCUSSION

4.1. Jones and Olive Islands

Jones Island

New born pups (two) were first sighted at Jones Island on 10 March 2013 (Alan Payne *pers. comm.*). A single ground survey was undertaken on Jones Island on 17 June 2013, when a total of 16 pups were counted; 1 black, 12 brown, 2 moulted and 1 dead. 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.* 2010a). In the 2007/08 season a minimum of 11 pups were sighted (Goldsworthy *et al.* 2010a). In the 2010 season, 28 pups were counted, but given the advanced state of pups (most were 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 that therefore the estimate for that season was inflated (Goldsworthy *et al.* 2012). The estimate for the 2011/12 was 12 pups, and the estimate from this season (2013) is consistent with that and with previous surveys between 2001/02 and 2007/08. Tagged pups that were marked at Nicolas Baudin Island in June 2013 were reported from Jones Island in September 2013 through to March 2014 (Alan Payne *pers comm*.), supporting the idea that high pup counts at Jones Island in the 2010 season were probably a result of the presence of pups from other islands. Trends for pup-count data are presented in Figure 3. The linear and multiple regression model fitted to the log of maximum live-pup counts (excluding the 2010 season count) identified no significant change in pup numbers with breeding season ($F_{1,3}$ = 0.110, P = 0.762, r^2 = 0.0354), or with breeding season and period ($F_{2,3}$ = 1.300, P = 0.435, r^2 = 0.435).

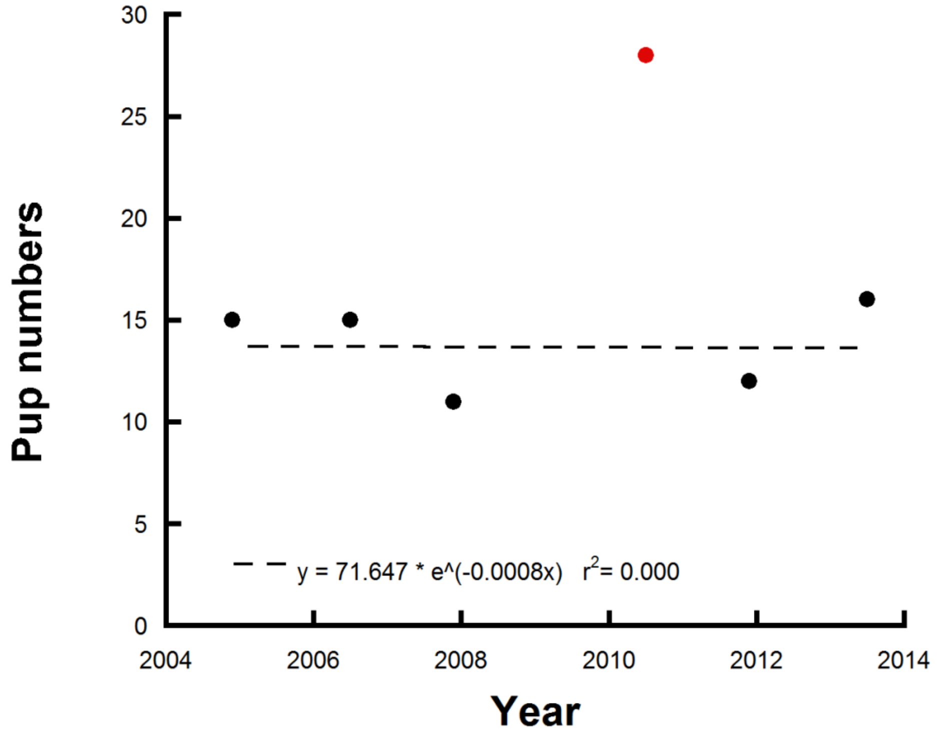


Figure 3. Trends in the estimated ASL pup production at Jones Island over six consecutive breeding seasons (2004/05 to 2013). The inflated number for the 2010 season (red filled circle) is indicated. An exponential curve is fitted to the data (excluding the 2010 breeding season).

Olive Island

An initial ground survey was conducted at Olive Island on 19 June 2013, and a total of 74 pups were counted; 22 black (30%, 2 pups with mate-guarded mothers), 45 brown (61%) and 7 dead (9%). 41 brown pups were then marked as part of the mark-recapture program and two mark-recapture surveys were undertaken on 19 June 2013, and between 31 July and 1 August 2013. Petersen estimates of live pups were greater during the second survey (mean 127, 95% CL 118-137) than the first (mean 99, 95% CL 89-108) (Tables 1 and 2).

Based on tag re-sights between surveys 1 and 2 (Table 1), the apparent survival rate (φ) was 0.976 (sd = 0.024). Based on Petersen estimates and using the cumulative pup production method, the net increase in pup numbers between surveys 1 and 2 is estimated to be 31 (95% CL, 18-45), giving an overall estimate of pup production at Olive Island for the 2013 breeding season of 140 (95% CL, 123-156, Table 1).

Olive Island was recorded as a breeding colony in November 1977 when 52 pups were seen (Dennis 2005). Pups were also seen 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), for the 2011/12 breeding season it was 129 (95% CL 126 – 132), and for the 2013 breeding season it was 140 (95% CL, 130-150) (Goldsworthy *et al.* 2012, this report, Goldsworthy *et al.* 2013) (Figure 4). Although the reduced pup production from 2006 (206) to 2013 (140) suggests a 32% decline (over seven years, and six breeding seasons), linear and multiple regression models fitted to the log of maximum live-pup counts identified no significant change in pup numbers with breeding season ($F_{1,4}$ = 4.306, P = 0.107, r^2 = 0.518), or with breeding season and period ($F_{2,3}$ = 1.768, P = 0.311, r^2 = 0.541).

Table 1. Summary of abundance estimates of ASL pups at Olive Island in the 2013 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture estimates, during two sessions, in June and August 2013.

Survey	**1**	**2**
Date	**19-Jun**	**31 Jul/1-Aug**
Cumulative marked	41	41
Maximum unmarked counted	36	57
Maximum count (live)	67	95
Cumulative dead (unmarked)	10	12
Cumulative dead (marked)	0	0
Total cumulative dead	10	12
Maximum count (live) + cumulative dead	77	107
Cumulative marked + dead (unmarked) + max unmarked	87	110
Petersen Estimate (live)	99	127
Petersen Estimate Lower – Upper CL	89-108	118-137
(No. recapture estimates)	7	8
Petersen Estimate (live) + cumulative dead	109	139
Lower – Upper CL	99-118	130-149
Apparent survival (φ) between sessions		0.976
Estimated pup production between sessions		31
Lower – Upper CL		18-45
Estimated cumulative pup production	109	**140**
Lower – Upper CL	99-118	**123-156**

Table 2. Details of Petersen mark-recapture estimates for Olive Island between June and August 2013. 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 live 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	Est N	sd	V	%	CV	Nlo	Nup
Survey 1		41	63	28	92	7	48	44%			
19-Jun-13	1	41	58	22	107	12	134	38%			
19-Jun-13	2	41	33	13	101	16	272	39%			
19-Jun-13	3	41	48	18	107	14	197	38%			
19-Jun-13	4	41	38	18	85	10	104	47%			
19-Jun-13	5	41	30	11	108	20	396	37%			
19-Jun-13	6	41	43	20	87	10	92	47%			
19-Jun-13	7	41	43	17	102	14	187	40%			
				Mean	**99**	**4.7**		**41%**	**5.1%**	**89**	**108**
Survey 2											
1-Aug-13	1	40	78	21	146	18	315	27%			
1-Aug-13	2	40	82	26	125	11	131	32%			
1-Aug-13	3	40	73	21	137	16	269	29%			
1-Aug-13	4	40	81	27	119	10	104	33%			
1-Aug-13	5	40	74	20	145	19	342	27%			
1-Aug-13	6	40	86	29	118	9	80	34%			
1-Aug-13	7	40	79	27	116	10	98	34%			
1-Aug-13	8	40	77	27	113	10	91	35%			
				Mean	**127**	**4.7**		**31%**	**3.7%**	**118**	**137**

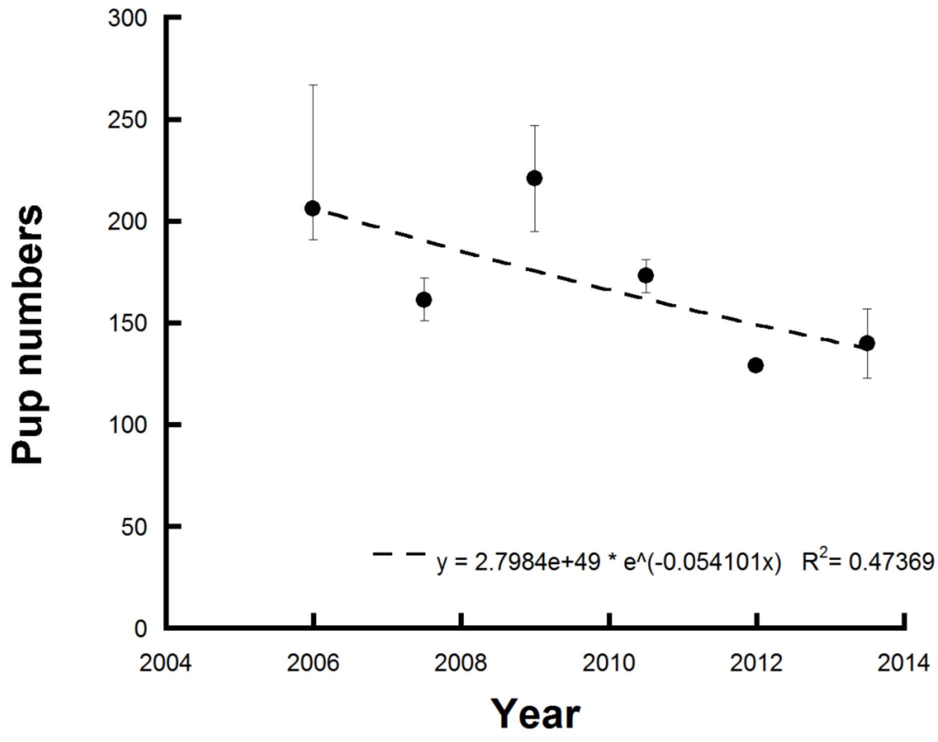


Figure 4. Trends in the estimated ASL pup production at Olive Island over six consecutive breeding seasons (2006 to 2013). Error bars represent upper (95%) and lower (absolute minimum) confidence limits; for the 2011/12 season they are too small to show. An exponential curve is fitted to the data.

4.2. Nicolas Baudin Island

Nicolas Baudin Island

An initial ground survey was conducted at Nicolas Baudin Island on 21 June 2013, and a total of 31 pups were counted; 2 black (6%, both pups with mate-guarded mothers), 27 brown (87%), 0 moulted, and 2 dead (6%). A total of 31 brown pups were then marked as part of the mark-recapture program and two mark-recapture sessions were undertaken on 21 June 2013 and 2-3 August 2013. The Petersen estimate of live pups after the first survey was 57 (95% CL 54-60) (Table 3 and 4), with the addition of two dead pups the estimate of live plus cumulative dead pups up until 21 June 2103 was 59 (95% CL 56-62) (Table 4). The second survey was conducted over a single day and it was not possible to determine the number (*M*) of marked (tagged) pups available for resighting during the survey. Although only 20 tagged individual pups were identified (67% of those originally tagged), the maximum number of tagged pups sighted during a recapture survey was 28. Assuming none of these pups were double-counted, we base our estimate of *M* for the second survey on this value (Table 3). With an *M* of 28, the Petersen estimate of live pups for the second survey was 74 (95% CL 66-81). Based on tag resights between surveys 1 and 2 (Table 3), the apparent survival rate (φ) between surveys was 0.903 (sd = 0.053). From Petersen estimates of live plus cumulative dead pups for the first survey, plus an estimate of the net cumulative pup production between survey 1 and 2 of 22 pups (95% CL, 12-32), the estimated total pup production at Nicolas Baudin Island for the 2013 breeding season is 81 (95% CL 71-91, Table 4).

A number of factors made the 2013 survey of Nicolas Baudin challenging, and may therefore have affected the accuracy of the survey. The island is about 10 ha in area with many pools and low-lying areas that become inundated during high tide (Shaughnessy 2010). During high-tide the island therefore becomes many sub-islands separated by channels, where the water current can be strong. During both surveys, many pups were highly mobile and in the water, making it challenging in many cases to determine whether an individual was tagged or not. Furthermore, seven pups that had been tagged at Nicolas Baudin were reported at Jones Island in late September 2013 (Alan Payne *pers comm*), including one individual which was not re-sighted during the second mark-recapture session. Two of these pups were still at Jones Island in March 2014. Longer periods of time are needed to undertake tag resights to provide confidence around the number of marked pups available for recapture. In addition, it would be better to schedule surveys around neap tides.

The first pup surveys were undertaken at Nicolas Baudin Island during the 2001-02 season when a single ground count estimated 72 pups (Shaughnessy *et al.* 2005). Three ground counts were undertaken in 2003 giving an estimate of 70 pups, and 98 pups were counted in the 2005-06 survey (Shaughnessy 2008, 2010, Shaughnessy *et al.* 2011). The estimate of 81 pups for the 2013 survey falls within the range of other surveys. The next survey should be attempted during summer months in conditions where most of the island is available for survey.

Table 3. Details of Petersen mark-recapture estimates for Nicolas Baudin Island on 21 June 2013. 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 live 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	Est N	sd	V	%	CV	Nlo	Nup
Survey 1											
21-Jun-13	1	31	32	16	61	7	49	50%			
21-Jun-13	2	31	32	16	61	7	49	50%			
21-Jun-13	3	31	29	18	50	4	19	62%			
21-Jun-13	4	31	32	19	52	4	20	59%			
21-Jun-13	5	31	37	20	57	5	23	54%			
21-Jun-13	6	31	27	14	59	7	55	52%			
21-Jun-13	7	31	30	14	65	9	75	47%			
21-Jun-13	8	31	32	18	55	5	27	56%			
21-Jun-13	9	31	32	17	58	6	36	53%			
21-Jun-13	10	31	35	21	51	4	14	60%			
21-Jun-13	11	31	31	16	59	7	44	52%			
21-Jun-13	12	31	35	19	57	5	26	54%			
21-Jun-13	13	31	32	17	58	6	36	53%			
21-Jun-13	14	31	32	19	52	4	20	59%			
				Mean	**57**	**1.6**	**3**	**54%**	**2.8%**	**54**	**60**
Survey 2											
2-Aug-13	1	28	48	28	48	0	0	58%			
2-Aug-13	2	28	41	14	80	11	128	34%			
2-Aug-13	3	28	48	18	74	8	59	38%			
3-Aug-13	4	28	58	21	77	6	40	36%			
3-Aug-13	5	28	41	13	86	13	174	32%			
3-Aug-13	6	28	45	16	77	9	89	36%			
				Mean	**74**	**3.7**		**39%**	**5.0%**	**66**	**81**

Table 4. Summary of abundance estimates of ASL pups at Nicolas Baudin Island in the 2013 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture estimates, during two sessions, in June and August 2013.

Session	**1**	**2**
Date	**21 Jun**	**2-3 Aug**
Cumulative marked	31	31
Maximum unmarked counted	17	37
Maximum count (live)	29	63
Cumulative dead (unmarked)	2	3
Cumulative dead (marked)	0	0
Total accumulative dead	2	3
Maximum count (live) + cumulative dead	30	66
Cumulative marked + dead (unmarked) + max unmarked	49	60
Petersen Estimate (live)	57	74
Petersen Estimate Lower – Upper CL	54-60	66-81
(No. recapture estimates)	14	6
Petersen Estimate (live) + cumulative dead	59	78
Lower – Upper CL	56-62	70-85
Apparent survival (*φ*) between sessions		0.903
Estimated pup production between sessions		22
Lower – Upper CL		12-32
Estimated cumulative pup production	59	**81**
Lower – Upper CL	56-62	**71-91**

4.3. Blefuscu and Lilliput Islands

Blefuscu Island

An initial ground survey was conducted at Blefuscu Island on 20 August 2013, when a total of 53 pups were counted: 13 black (23%, 3 pups with mate-guarded mothers), 38 brown (72%) and 2 dead (4%). On a second ground survey on 26 September 2013, 71 pups were counted: 12 black (17%, 8 pups with mate-guarded mothers), 56 brown pups (79%), 0 moulted pups and 3 dead pups (4%). 30 brown pups were then marked as part of the mark-recapture procedure and two mark-recapture surveys were undertaken on 27 September 2013 and 22 October 2013 (Table 5 and 6). The Petersen estimate of live pups on 27 September 2013 was 73 (95% CL 68 – 79) and including cumulative dead pups it was 78 (95% CL 73 – 84) (Table 5 and 6). The Petersen estimate of live pups on 22 October 2013 was 81 (95% CL 77 – 85) and 89 including cumulative dead pups (95% CL 85 – 93) (Table 5 and 6).

Based on tag re-sights between surveys 1 and 2 (Table 6), the apparent survival rate (φ) was 1.0. Based on Petersen estimates of live pups and cumulative dead pups during the first survey, plus an estimate of the net cumulative pup production between survey 1 and 2 of 8 pups (95% CL, 1-15), the overall estimate of pup production at Blefuscu Island is 86 (95% CL

77-95, Table 6). As this is less than the second Petersen estimate of live plus cumulative dead pups, we take the latter (89 pups, 95% CL 85 – 93) as the best estimate of pup production at Blefuscu Island for the 2013 season including cumulative dead pups (Table 6).

Table 5. Details of Petersen mark-recapture estimates for Blefuscu Islands between September and October 2013 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 live 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	Est N	sd	V	%	CV	Nlo	Nup
Survey 1											
26-Sep-13	1	30	48	22	65	5	25	46%			
26-Sep-13	2	30	51	20	76	7	52	39%			
26-Sep-13	3	30	47	20	70	6	41	43%			
26-Sep-13	4	30	49	17	85	10	105	35%			
26-Sep-13	5	30	52	21	74	6	41	40%			
26-Sep-13	6	30	55	23	71	5	27	42%			
				Mean	**73**	**2.8**		**41%**	**3.9%**	**68**	**79**
Survey 2											
22-Oct-13	1	30	57	21	81	7	52	37%			
22-Oct-13	2	30	53	19	83	9	75	36%			
22-Oct-13	3	30	69	24	86	6	36	35%			
22-Oct-13	4	30	66	23	86	7	43	35%			
22-Oct-13	5	30	65	24	81	6	31	37%			
22-Oct-13	6	30	62	26	71	4	14	42%			
22-Oct-13	7	30	59	22	80	7	43	37%			
22-Oct-13	8	30	62	22	84	7	49	35%			
22-Oct-13	9	30	62	24	77	5	27	39%			
				Mean	**81**	**2.1**		**37%**	**2.6%**	**77**	**85**

Table 6. Summary of abundance estimates of ASL pups at Blefuscu Island in the 2013 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture estimates, during two sessions, in September and October 2013.

Survey	**1**	**2**	**3**
Date	**20 Aug**	**26-Sep**	**22-Oct**
Cumulative marked		30	30
Maximum unmarked counted		32	45
Maximum count (live)	51	68	73
Cumulative dead (unmarked)	2	5	8
Cumulative dead (marked)		0	0
Total accumulative dead		5	8
Maximum count (live) + cumulative dead		73	81
Cumulative marked + dead (unmarked) + max unmarked		67	83
Petersen Estimate (live)		73	81
Petersen Estimate Lower – Upper CL		68-79	77-85
(No. recapture estimates)			
Petersen Estimate (live) + cumulative dead		78	**89**
Lower – Upper CL		73-84	**85-93**
Apparent survival (*φ*) between sessions			1.00
Estimated pup production between sessions			8
Lower – Upper CL			1-15
Estimated cumulative pup production		78	86
Lower – Upper CL		73-84	77-95

Lilliput Island

An initial ground survey was conducted at Lilliput Island on 19 August 2013, and a total of 43 pups were counted; 17 black (40%, 6 with mate-guarded mothers), 25 brown (58%), 0 moulted and 1 dead (2%). On a second ground survey on 26 September 2013, 69 pups were counted; 9 black (13 %, the mother of 1 pup was mate-guarded) 60 brown pups (87 %), 0 moulted pups and 0 dead pups. A third ground survey on 22 October 2013 counted 68 pups; 2 black (3%, both with mate-guarded mothers), 64 brown (90%), 2 moulted (3%) and 3 dead (4%). However, an estimated additional 14 pups were counted from the helicopter on the islet off the southern end of the island which could not be accessed during the ground count due to high tide and swell. A total of 35 brown pups were marked as part of the mark-recapture program and two mark-recapture sessions were undertaken on 27 September 2013 and 23–24 October 2013 (Table 8).

Based on eight recapture estimates, the Petersen estimate of live pups on 28 September 2013 was 69 (95% CL 65-73), and including cumulative dead pups was 70 (95% CL 66-74) (Table 7 and 8). Based on 12 recapture estimates, the Petersen estimate of live pups on 23 October 2013 was 64 (95% CL 60-68), and including cumulative dead pups was 69 (95% CL 65-73) (Table 7 and 8). The lower estimate from the second mark-recapture session is driven by the low estimate for *M* (the number of marked pups at risk of being sampled during recapture operations) which was 28, and a number of marked individuals whose tags could not be read (average 20% of pups sighted with tags), including those on the islet off the southern end of the island and pups in the sea.

Based on tag re-sights (values of *M*) between survey 1 and 2 (Table 7), the apparent survival rate (φ) between surveys was 0.800 (sd = 0.068). Based on Petersen estimates of live plus cumulative dead pups for the first survey, plus an estimate of the net cumulative pup production between survey 1 and 2 of 9 pups (95% CL 0-19), the estimated total pup production at Lilliput Island for the 2013 breeding season is 79 (95% CL 68-90, Table 8). This estimate is the same as that derived from the cumulative marked (tagged) and dead pups, plus the maximum number of unmarked pups observed (Table 8).

The surveys of pup production for Lilliput and Blefuscu Islands represent the sixth survey of pup abundance at these colonies, and the fourth using mark-recapture methods (Table 9). 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.* 2009d). The estimate for pup production for the 2007/08 breeding season using mark-recapture methods was 64 (95% CL 62-69) (Goldsworthy *et al.* 2009c), similar to the estimate for the 2010, (66, 95% CL 64-67) and 2012 (69, 95% CL 64-78), with the 2013 survey representing the largest estimate of pup production (79, 95% CL 68-90) (Goldsworthy *et al.* 2012, 2013, this study) (Table 9). Results from four consecutive breeding seasons using mark-recapture methods suggest a marginal increase in pup production (Figure 5). However, the linear and multiple regression model fitted to the log of maximum live-pup counts identified no significant change in pup numbers with breeding season ($F_{1,2}$ = 15.08, P = 0.0604, r^2 = 0.883), or with breeding season and period ($F_{2,1}$ = 4.235, P = 0.325, r^2 = 0.894).

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.* 2009d). The estimate for pup production for the 2007-08 breeding season using mark-recapture methods was 99 (95% CL, 92-106) (Goldsworthy *et al.* 2009c), 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) was lower than the mark-recapture estimates for the two previous breeding seasons and was likely due to the high proportion of moulted pups counted during this survey, meaning it was possible that some pups were at sea or hauled out on the adjacent islands and were therefore unavailable for survey. The estimate from the 2013 season is in a similar range, although still lower, than the earlier mark-recapture estimates (89, 95% CL, 85-93) (Table 9). Results from four consecutive breeding seasons using mark-recapture methods suggest a marginal decline in pup production, although this is non-significant (Figure 5). The linear and multiple regression model fitted to the log of maximum live-pup counts identified no significant change in pup numbers with breeding season ($F_{1,2}$ = 0.651, P = 0.505, r^2 = 0.246), or with breeding season and period ($F_{2,1}$ = 6.170, P = 0.274, r^2 = 0.925). A generalised least squares model to estimate and adjust for any auto-correlation detected no auto-correlation in the data.

Table 7. Details of Petersen mark-recapture estimates for Lilliput Islands between September and October 2013 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 live 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	Est N	sd	V	%	CV	Nlo	Nup
Survey 1											
27-Sep-13	1	35	52	26	70	5	22	50%			
27-Sep-13	2	35	45	22	71	6	39	49%			
27-Sep-13	3	35	48	25	67	5	22	52%			
27-Sep-13	4	35	46	23	70	6	32	50%			
27-Sep-13	5	35	47	24	68	5	27	51%			
27-Sep-13	6	35	45	23	68	6	30	51%			
27-Sep-13	7	35	51	25	71	5	27	49%			
27-Sep-13	8	35	48	25	67	5	22	52%			
				Mean	**69**	**1.9**		**51%**	**2.7%**	**65**	**73**
Survey 2											
23-Oct-13	1	28	40	20	56	4	20	50%			
23-Oct-13	2	28	41	15	75	10	95	37%			
23-Oct-13	3	28	50	21	66	5	27	42%			
23-Oct-13	4	28	47	19	69	6	42	40%			
23-Oct-13	5	28	35	14	69	9	85	40%			
23-Oct-13	6	28	38	15	70	9	78	39%			
23-Oct-13	7	28	44	19	64	6	35	43%			
23-Oct-13	8	28	43	19	63	6	33	44%			
24-Oct-13	9	28	44	20	61	5	26	45%			
24-Oct-13	10	28	41	19	60	5	29	46%			
24-Oct-13	11	28	41	20	57	5	21	49%			
24-Oct-13	12	28	44	21	58	4	19	48%			
				Mean	**64**	**1.9**		**44%**	**2.9%**	**60**	**68**

Table 8. Summary of abundance estimates of ASL pups at Lilliput Island in the 2013 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture estimates, during two sessions, in September and October 2013.

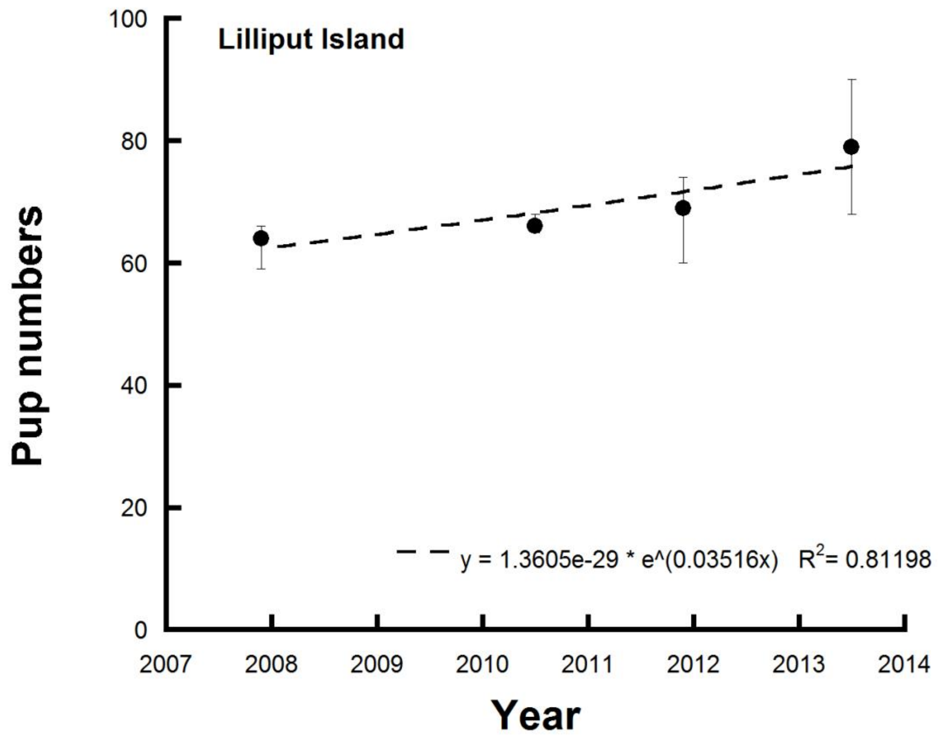
Survey Date	1 19 Aug	2 27-Sep	3 23-24 Oct
Cumulative marked		35	35
Maximum unmarked counted		26	39
Maximum count (live)	42	69	68
Cumulative dead (unmarked)	1	1	5
Cumulative dead (marked)		0	0
Total accumulative dead		1	5
Maximum count (live) + cumulative dead		70	73
Cumulative marked + dead (unmarked) + max unmarked		62	79
Petersen Estimate (live)		69	64
Petersen Estimate Lower – Upper CL		65-73	60-68
(No. recapture estimates)		8	12
Petersen Estimate (live) + cumulative dead		70	69
Lower – Upper CL		66-74	65-73
Apparent survival (φ) between sessions			0.800
Estimated pup production between sessions			9
Lower – Upper CL			0-19
Estimated cumulative pup production		70	**79**
Lower – Upper CL		66-74	**68-90**

Table 9. Numbers of Australian sea lion pups estimated at Lilliput and Blefuscu Islands between 1990 and 2013. 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]	2013[6]
Lilliput Is.	46 [A]	67[B]	64 (62-69)[C]	66 (64-67)[C]	69 (64-78) [C]	79 (74-84)[C]
Blefuscu Is.	75 [A]	84[B]	99 (92-106)[C]	108 (104-111)[C]	67 (60-78) [C]	89 (85-93)[C]

[1]September, November 1990 (Gales *et al.* 1994)
[2]November 2004; January-July 2005 (Goldsworthy *et al.* 2009d)
[3]November 2007, January-April 2008 (Goldsworthy *et al.* 2009c)
[4]October/November 2010 (Goldsworthy *et al.* 2012)
[5]July 2012 (Goldsworthy *et al.* 2013)
[6] September/October 2013 (This study)

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



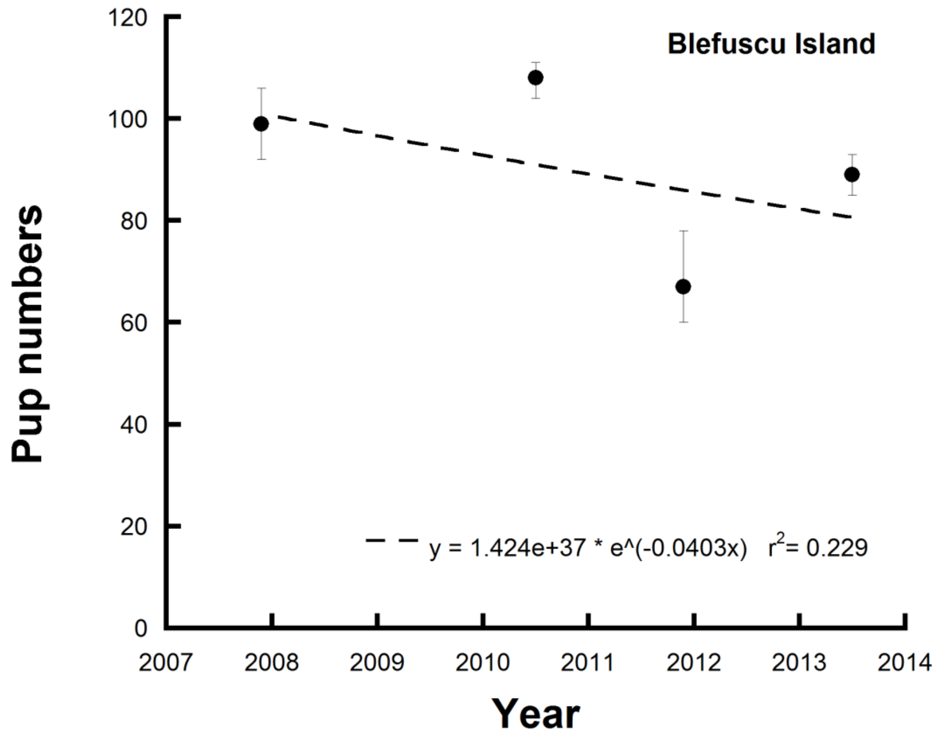


Figure 5. Trends in the estimated ASL pup production at Lilliput and Blefuscu Islands over four consecutive breeding seasons (2007/08 to 2013). Error bars represent upper (95%) and lower (absolute minimum) confidence limits. An exponential curve is fitted to the data.

4.4. Dangerous Reef

Pup counts

The first survey of the 2014 breeding season at Dangerous Reef was conducted on 14 March 2014 by aerial survey, when three black pups were observed indicating that the breeding season had started between 1-3 weeks earlier. Ground surveys were conducted 14 May, 2 June, 2 July and 14 October 2014 (Table 10). A single black pup with a mate-guarded female was sighted in the final survey on 14 October 2014, suggesting that the duration of the breeding season for 2014 was about 7.5 months. Counts of live and dead pups at Dangerous Reef during the 2014 breeding season are presented in Table 10, and the proportion of black, brown and moulted pups observed on each survey are presented in Figure 9. The largest estimate of pups, based on the maximum number of live pups counted (225) plus cumulative dead pups (69) until that date, was 294 on 2 June 2014 (Table 10). A total of 248 pups were individually tagged between 3 June and 3 July 2014. On 18 October 2014 when 248 pups had been tagged, 43 untagged pups had been sighted. Adding 136 untagged pup mortalities gives a minimum estimate of 427 pups (Table 10).

Mark-recapture estimates of pup numbers

Three mark-recapture estimates of the pup numbers were conducted during the third, fourth and fifth surveys. The largest Petersen estimate derived from these was on the fourth survey, 319 pups (95% CL 312 – 326, Table 10 and 11). Including cumulative dead pups this estimate was 408 (95% CL, 401-415) (Table 10). The estimated number of live pups present on Dangerous Reef had declined to 166 (95% CL 156 - 175) by the final session (Table 10 and 11).

Comparisons of Petersen estimates with direct counts at Dangerous Reef have now been made over nine breeding seasons (Table 12). Petersen estimates were between 1.19 and 1.98 times the direct count (95% confidence limits of comparisons ranged from 1.12 to 2.05). This indicates that estimates derived from mark-recapture procedures were similar to but larger than direct counts in the nine breeding seasons. The discrepancy between the direct counts and the Petersen estimates on each occasion results from the difficulty of sighting all pups in the colony. Some pups may not be viewed during counting because they are away from the island, swimming in the shallows or obscured by rocks.

Cumulative pup production estimates

The cumulative pup production method assumes that the sum of the Petersen estimate and cumulative mortalities in the first mark-recapture survey (survey number 3, 2-5 June 2014) are representative of all pups born to that date. Based on tag re-sights between surveys 3 and 4, and 4 and 5, apparent survival rates (φ) were 0.776 (sd = 0.034), and 0.412 (sd = 0.031), respectively (Table 10). Based on Petersen estimates of live pups, the numbers of births between these sessions was 100 (95% CL 79-121), and 34 (95% CL 12-56) (Table 10). With an estimated 351 pups (95% CL 344-358) born up until the third survey, this gives a total pup production estimate for Dangerous Reef for the 2014 breeding season of 485 pups (95% CL 462-508, Table 10). This estimate is 19% greater than the largest Petersen estimate of live pups plus cumulative dead pups, and 14% greater than the minimum estimate based on minimum live and dead pups (cumulative marked plus cumulative dead unmarked pups plus maximum unmarked pups) counted on 18 October 2014 (Table 10).

The cumulative pup production method has now been applied during five breeding seasons at Dangerous Reef (2006/07; 2008, 2009/10, 2011 and 2014) (Table 13). Cumulative pup production estimates range from 1.01 to 1.26 times the Petersen estimate (plus cumulative dead pups).

Assuming the 2014 breeding season at Dangerous Reef commenced about 1 March (about 13 days earlier than the first survey when three black pups were sighted), the estimated cumulative pup production curve based on the estimates of total pups (live and dead) during the first three surveys and the estimated cumulative net pup production between the third and fourth and fourth and fifth surveys, is presented in Figure 10. A probit analysis of the sigmoidal function fitted to these data to determine the season of births (Caughley 1977) identified the median pupping date as 29 May 2014 (on Julian Day 149 in Figure 10), with 90% of births occurring between 6 April and 21 July 2014 (i.e. in 106 days or 3.5 months).

Pup mortality

For the 2014 breeding season at Dangerous Reef, 63 dead pups were recorded by 5 June 2014 when the live count of pups reached a maximum (225) giving a minimum estimate of 288 pups born to that date, and an incidence of pup mortality of 21.9% (Table 14).

For 16 breeding seasons since 1975 at Dangerous Reef, the incidence of pup mortality based on the above calculation has ranged from 9.9% to 44.6% (Table 14). Pup mortality was higher for breeding seasons that occurred predominantly in winter (20.5% in 1975, 21.2% in 1990, 30.3% in 1996, 42.0% in 1999, 44.6% in 2002, 31.1% in 2005, 12.1% in 2008, 38.9 in 2011, and 23.4% in 2014; with un-weighted average 29.4%) and lower for breeding seasons that occurred predominantly in summer (9.9% in 1976/77,15.3% in 1997/98, 22.9% in 2000/01, 18.6% in 2003/04, 13.9% in 2006/07 and 9.9% in 2009/10, with un-weighted average 15.1%). The trend and inter-breeding season oscillation in cumulative dead pups generally mirror that of the maximum direct count of live pups (Figure 11).

Based on cumulative pup production estimates, mortality rates to the last survey of the last five breeding seasons (2006/07, 2008, 2009/10, 2011 and 2014) have been 10.6%, 42.7%, 11.2%, 43.3%, and 32.0%, respectively (Table 13).The un-weighted average winter and summer pup mortality to the end of those breeding seasons is 39.3% and 10.9%, respectively.

Trends in abundance at Dangerous Reef

There are four main metrics of pup abundance and production available for the Dangerous Reef Australian sea lion colony (Figure 11): 1) the maximum count of pups that includes the cumulative dead pups to that survey date; 2) the minimum live and dead pups that includes the cumulative number of tagged pups plus the maximum unmarked pups counted plus cumulative dead (untagged) pups; 3) the maximum Petersen estimate including cumulative dead pups up until that estimate; and 4) the cumulative pup production estimate. Trends analyses of these four metric is detailed below.

<u>Trends in the maximum count of live and cumulative dead pups</u>

Counts of maximum pups (including dead pups up until that survey date) are available for 16 breeding seasons extending back to 1975. However, the reliability of these figures depends largely on the timing and number of surveys undertaken each breeding season, which vary considerably for these data sets. These estimates underestimate total pup production because not all pups were available for re-sighting (alive and dead) at any single point throughout the breeding season. Analyses of trends in pup counts from 13 breeding seasons since 1994-95 using linear and multiple regression models fitted to the log of pup counts identified no significant change in pup numbers with breeding season ($F_{1,11}$ = 0.060, P = 0.812, r^2 = 0.005), or with breeding season and period ($F_{2,10}$ = 0.158, P = 0.856, r^2 = 0306). The 3rd (1997-98) and 13th (2014) breeding seasons counts were identified as statistical outliers (both counts low, 1997/98 survey did not extend beyond the 4th month of breeding; 2014 low count), but their removal did not change the non-significant results found here (linear regression: $F_{1,9}$ = 0.310, P = 0.591, r^2 = 0.033; multiple regression: $F_{2,8}$ = 0. 603, P = 0.

570, r^2 = 0.131). Goldsworthy et al. (2014) determined a significant increase in live and dead pup counts over nine breeding seasons between 1996 and 2009/10, equivalent to and annual increase of 2.6%, or 3.9% per breeding season (also excluding 1997-98 survey).

Trends in minimum live and cumulative dead pups counts

Estimates of pup numbers that include the cumulative number of tagged pups plus the maximum number of unmarked pups counted (minimum alive), plus cumulative dead (untagged) pups are available for five breeding seasons since 2006/07. Analyses of trends in pup counts using linear and multiple regression models fitted to the log of pup counts identified no significant change in pup numbers with breeding season ($F_{1,3}$ = 0.117, P = 0.755, r^2 = 0.038), or with breeding season and period ($F_{2,2}$ = 2.608, P = 0.277, r^2 = 0.723).

Trends in the maximum Petersen estimate

Estimates of live pup numbers based on the maximum values for the individual mark-recapture (Petersen) estimates (including cumulative dead pups up until that estimate) are available for eight breeding seasons since 1999. Analyses of trends in pup estimates from using linear and multiple regression models fitted to the log of pup counts identified no significant change in pup numbers with breeding season ($F_{1,6}$ = 0.380, P = 0.560, r^2 = 0.060), or with breeding season and period ($F_{2,5}$ = 1.135, P = 0.392, r^2 = 0.312).

Trends in cumulative pup production

Cumulative pup production methods have been used to estimate total pup production over five breeding seasons since 2006-07 (Figure 11). Although there has been an apparent ~42% decline in estimates of pup numbers between the 2006/07 (831 pups) and 2014 (485 pups) breeding seasons (5 breeding seasons, ~7.5 years), analyses using linear and multiple regression models fitted to the log of pup counts identified no significant change in pup numbers with breeding season ($F_{1,3}$ = 3.504, P = 0.158, r^2 = 0.539), or with breeding season and period ($F_{2,2}$ = 3.940, P = 0.202, r^2 = 0.798).

The broad pattern of pup abundance across these four metrics is for an apparent increase in pup production between 1995/96 and 2006/07 peaking at 831 pups (based on cumulative pup production), followed by a decline until the recent survey in 2014 (Figure 11). The apparent increase between 1995-96 and 2006/07 is in the order of 38-40% based on changes in counts of maximum live and cumulative dead pups and the maximum Petersen estimate, respectively. The apparent decline between 2006/07and 2014, ranges from -49%, -42% and -42% based on changes in counts of maximum live and cumulative dead pups, the maximum Petersen estimate and the cumulative pup production methods, respectively.

Given the marked variation in pup production estimates between years, and that this is still a relatively short time-series, more information is needed to determine if trends are ongoing.

Trend metric and individual pup detection variability

Goldsworthy et al. (2011) compared three key pup production metrics assessed over four consecutive breeding seasons at Dangerous Reef (2006/07, 2008, 2009/10 and 2011). These were: 1) minimum live and dead pups (cumulative marked [tagged] pups plus cumulative dead [unmarked] pups plus maximum unmarked pups counted); 2) maximum Petersen estimates and 3) cumulative pup production. Comparison of these metrics indicated an apparent alternation between two states in these metrics. In winter breeding seasons, the pup estimates based on all three metrics are very similar to each other (2008, 2011), but in summer breeding seasons, estimates based on all three metrics are very different (2006/07, 2009/10), with cumulative pup production estimates being greater than the Petersen estimates, which are greater than the estimates based on the minimum live and dead pups (Figure 12). The latter (summer) conforming pattern makes intuitive sense, where Petersen estimates provide a greater estimate based marked and counted pups, and where cumulative pup production estimates (which estimate net-pup production between successive Petersen estimates) provide a greater estimate compared to an isolated Petersen estimate. Goldsworthy et al. (2011) questioned why in the summer (non-conforming) breeding seasons these latter two metrics provided no better estimate than the minimum count of live and dead pups. They suggested the difference may relate to changes in pup behaviour and breeding chronology between summer and winter breeding seasons that affect the sightability of pups and impact on the assumptions of the Petersen estimate (including temporary migration, survival and sightability).

To assess this, analyses were undertaken to determine if inter-breeding season differences in individual detection heterogeneity (IDH) may contribute to biasing estimates of pup production and trend analyses at Dangerous Reef. Data from the four seasons were analysed using the capture–mark–recapture (CMR) program MARK to estimate survival and capture probabilities using the Cormack–Jolly–Seber (CJS) model. No significant differences were detected in re-sight probability between breeding seasons (essentially equal to 1 in all breeding seasons); however, survival (across the period of surveys within breeding seasons) varied markedly between breeding seasons, with no apparent relationship between survival in the conforming (2006/07 =0.770, 2009/10 = 0.224) and non-conforming seasons (2008 = 0.348, 2011 = 0.481) (Figure 13). Although no surveys were possible at Dangerous Reef in the 2012/13 (summer) breeding season, the recent 2014 (winter) breeding season departs from the 2008 and 2011 winter pattern in that pup estimates based on cumulative pup production (479) are larger than those based on the maximum Petersen estimate plus cumulative dead (408), although the latter were lower than that based on the minimum live and dead pups (427) (Figure 11, Table 10).

4.5 English Island

A single ground count was undertaken at English Island on 4 July 2014, and a total of 64 pups were counted, 57 brown (89%), 1 moulted pup and 6 dead pups (9%). One of the brown pups had been tagged on Dangerous Reef on 3 June during the first mark-recapture trip; as such it is possible that some of the untagged pups observed also originated from Dangerous Reef. The lack of black pups and/or mate-guarded females indicates that the breeding season had finished, and the count was not made at the optimal time for small colonies (around the fourth month of breeding).

Australian sea lion pup abundance has now been surveyed at English Island over nine breeding seasons. From 1998 to 2002, between 4 and 15 pups were recorded (McKenzie *et al.* 2005), and 18 pups were seen in February 1991 (Gales *et al.* 1994). In the 2005 breeding season, pup production was estimated to be 27 (Goldsworthy *et al.* 2009d), and in 2008, a minimum of 23 pups were reported (Goldsworthy *et al.* 2009b). In the 2009/10 breeding season, 39 pups were counted and in the 2011 breeding season, 34 pups were estimated. In many previous surveys, pups from Dangerous Reef have been sighted. The marked increase in pup numbers in 2014 from previous breeding seasons is likely therefore to be confounded by an unknown number pups dispersing to English Island from Dangerous Reef.

Table 10. Summary of details of abundance estimates of Australian sea lion pups at Dangerous Reef in the 2014 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture and cumulative pup production abundance estimates, during five visits (sessions) between March 2014 and October 2014.

Survey	**1**	**2**	**3**	**4**	**5**
Date	**14 Mar**	**14 May**	**2-5 Jun**	**2-4 Jul**	**14-18 Oct**
Black	3	59	27	13	1
Brown		127	197	190	44
Moulted		0	1	1	15
Maximum count (live)	3	186	225	204	83
Cumulative dead (unmarked)		31	68	88	136
Cumulative dead (marked)			1	1	19
Total cumulative dead		31	69	89	155
Cumulative marked			149	248	248
Maximum unmarked counted			112	53	43
Maximum count (live) + cumulative dead			294	293	238
Cumulative marked + max unmarked + dead (unmarked)			329	389	427
Petersen Estimate (live)			282	319	166
Petersen Estimate Lower – Upper CL			275-289	312-326	156-175
(No. recapture estimates)			12	4	9
Petersen Estimate (live) + cumulative dead			351	408	321
Lower – Upper CL			344-358	401-415	311-330
				3-4	4-5
Apparent survival (φ) between surveys				0.776	0.412
Estimated pup production between surveys				100	34
Lower – Upper CL				79-121	12-56
Estimated cumulative pup production	3	186	351	451	**485**
Lower – Upper CL			344-358	429-473	**462-508**

Table 11. Details of Petersen mark-recapture estimates for Dangerous Reef between June and October 2014. 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
Survey 3											
4-Jun-14	1	149	209	114	273	8	68	55%			
4-Jun-14	2	149	223	111	299	10	101	50%			
4-Jun-14	3	149	177	122	216	5	21	69%			
4-Jun-14	4	149	208	112	276	9	76	54%			
5-Jun-14	5	149	154	81	283	14	207	53%			
5-Jun-14	6	149	195	99	293	12	140	51%			
5-Jun-14	7	149	130	70	276	16	257	54%			
5-Jun-14	8	149	201	101	296	12	136	50%			
5-Jun-14	9	149	180	89	301	14	201	49%			
5-Jun-14	10	149	194	94	307	14	186	48%			
5-Jun-14	11	149	125	69	269	16	243	55%			
5-Jun-14	12	149	188	95	294	13	159	51%			
				Mean	**282**	**3.5**		**53%**	**1.3**	**275**	**289**
Survey 4											
4-July-14	1	247	189	143	326	9	75	76%			
4-July-14	2	247	183	142	318	8	67	78%			
4-July-14	3	247	243	190	316	5	26	78%			
4-July-14	4	247	202	158	316	7	49	78%			
				Mean	**319**	**3.7**		**77%**	**1.2**	**312**	**326**
Survey 5											
17-Oct-14	1	87	83	43	167	12	149	52%			
17-Oct-14	2	87	62	32	167	16	247	52%			
17-Oct-14	3	87	66	42	136	9	78	64%			
17-Oct-14	4	87	76	39	168	14	183	51%			
17-Oct-14	5	87	63	32	170	16	259	51%			
17-Oct-14	6	87	66	36	158	13	173	55%			
18-Oct-14	7	87	73	30	209	23	519	41%			
18-Oct-14	8	87	70	38	159	13	161	54%			
18-Oct-14	9	87	67	37	156	13	159	55%			
				Mean	**166**	**4.9**		**53%**	**2.9**	**156**	**175**

Table 12. Summary of mark-recapture estimates of the abundance of Australian sea lion pups at Dangerous Reef over nine breeding seasons, highlighting comparison between mark-recapture estimates and direct counts of live pups. For the 2006/07 season comparisons between methods can be made for two of the three mark-recapture estimates.

Date (breeding season)	Max. Direct count (inc. dead pups)	Direct count of pups	Petersen estimate of pups	Comparison[1]	95% confidence interval	No. month since pupping commenced to: Max count	No. month since pupping commenced to: Mark-recapture estimate	Source
Jul 1999 (1999)	383	240	285	1.19	1.12 - 1.25	4	4	(Shaughnessy and Dennis 1999)
Jan 2004 (2003/04)	499	333	423	1.27	1.21 - 1.31	5.5	5	(Shaughnessy 2004)
July 2005 (2005)	585	272	326	1.2	1.15 to 1.25	6	6	(Shaughnessy 2005a)
Nov 2006 (2006/07)	397	330	436	1.32	1.26 - 1.38	4	4	(Goldsworthy et al. 2007c)
Jan 2007 (2006/07)	575	495	629	1.27	1.12 - 1.42	6	6	(Goldsworthy et al. 2007c)
Aug 2008 (2008)	537	210	289	1.38	1.31 - 1.45	6-7	6-7	(Goldsworthy et al. 2009b)
Dec 2009 (2009/10)	435	392	488	1.24	1.19-1.30	6	6	Goldsworthy et al. 2010a)
Jul 2011 (2011)	329	201	399	1.98	1.87-2.05	4	4	(Goldsworthy et al. 2012)
June 2014 (2014)	294	225	351	1.56	1.53-1.59	3	5	This report

[1] Mark-recapture estimate divided by Direct count

Table 13. Comparison of the estimated number of births of Australian sea lions at Dangerous Reef, South Australia for five breeding seasons between 2006/07 and 2014 based on Petersen estimates and cumulative pup production methods. Estimates of pup mortality based on cumulative pup production methods are also presented for these breeding seasons.

Breeding Season	Petersen estimate plus cumulative dead (±CL)	Cumulative pup production (±CL)	Pup mortality based on cumulative pup production estimates	Comparison[1]	Source
2006/07	709 (636-783)	831 (751-912)	10.6%	1.17	(Goldsworthy *et al.* 2007c)
2008	520 (506-535)	541 (518-563)	42.7%	1.04	(Goldsworthy *et al.* 2009b)
2009/10	488 (465-511)	615 (586-669)	11.2%	1.26	(Goldsworthy *et al.* 2010a) [2]
2011	339 (376-413)	402 (376-444)	43.3%	1.01	(Goldsworthy *et al.* 2012)
2014	408 (401-415)	485 (462-508)	32.0%	1.19	This report

[1] Cumulative pup production divided by Petersen estimate plus cumulative dead

[2] Data presented here have been modified to those in Goldsworthy *et al*. (2010a). Cumulative pup production method presented in Goldsworthy et al. (2010b) applied apparent survival values to Petersen estimates including pup mortality, instead of Petersen estimates excluding pup mortality.

Table 14. Estimated number of births of Australian sea lions at Dangerous Reef, South Australia for 16 pupping seasons between 1975 and 2014. Data are collated from Dennis (2005), Shaughnessy and Dennis (2001) and (2003), Shaughnessy (2004) and (2005b), Goldsworthy *et al.* (2007c), Goldsworthy *et al.* (2009b), Goldsworthy *et al.* (2010b), Goldsworthy *et al.* (2011) and this report. The data for 1994/95 includes an adjustment to account for pup mortality because only live pups (295) were counted in that season, following Shaughnessy (2005a).

Pupping season	Cumulative dead pups at max. pup count [a]	Max. pup count [b]	Pup mortality (%)	Month of max. live count since pupping began	Max. cumulative dead pup
1975	73	356	20.5	5	73
1976/77	26	262	9.9	4	26
1990	55	260	21.2	4	55
1994/95	-	354 [c]	not estimated	6.5	
1996	110	363	30.3	-	110
1997/98	38	248	15.3	4	43
1999	161	383 [d]	42.0	4	165
2000/01	90	393	22.9	7	90
2002	190	426 [e]	44.6	6	190
2003/04	93	499 [f]	18.6	5	100
2005	182	585 [g]	31.1	5	274
2006/07	80	575 [h]	13.9	6	88
2008	65	537	12.1	6-7	231
2009/10	43	435	9.9	6	69
2011	128	329	38.9	4	174
2014	69	294	23.5	3	155

[a] 'Cumulative dead pups' refers to the number of dead pups counted through to the maximum pup count.
[b] 'Max. pup count' refers to the maximum live pup count plus cumulative dead pups up until the date of the maximum live pup count.
[c] Adjusted for pup mortality using: "Maximum pup count" x 1.19954, where 0.19954 is the un-weighted average proportion of dead pups in three summer pupping seasons, 1997/98, 2000/01 and 2003/04.
[d] In addition, 23 newly-born pups were recorded on the last two visits; that number plus the previous estimate (of 383) leads to an estimate of pup numbers for the season of 406.
[e] In addition, 29 newly-born pups were recorded on the last visit; that number plus the previous estimate (of 426) leads to an estimate of pup numbers for the season of 453.
[f] In addition, 27 newly-born pups were recorded on the last visit; that number plus the previous estimate (of 499) leads to an estimate of pup numbers for the season of 526.
[g] In addition, 32 newly-born pups were recorded on the last three visits; that number plus the previous estimate (of 585) leads to an estimate of pup numbers for the season of 617.
[h] In addition, 4 newly-born pups were recorded on the last visit; that number plus the previous estimate (of 575) leads to pup count for the season of 579.

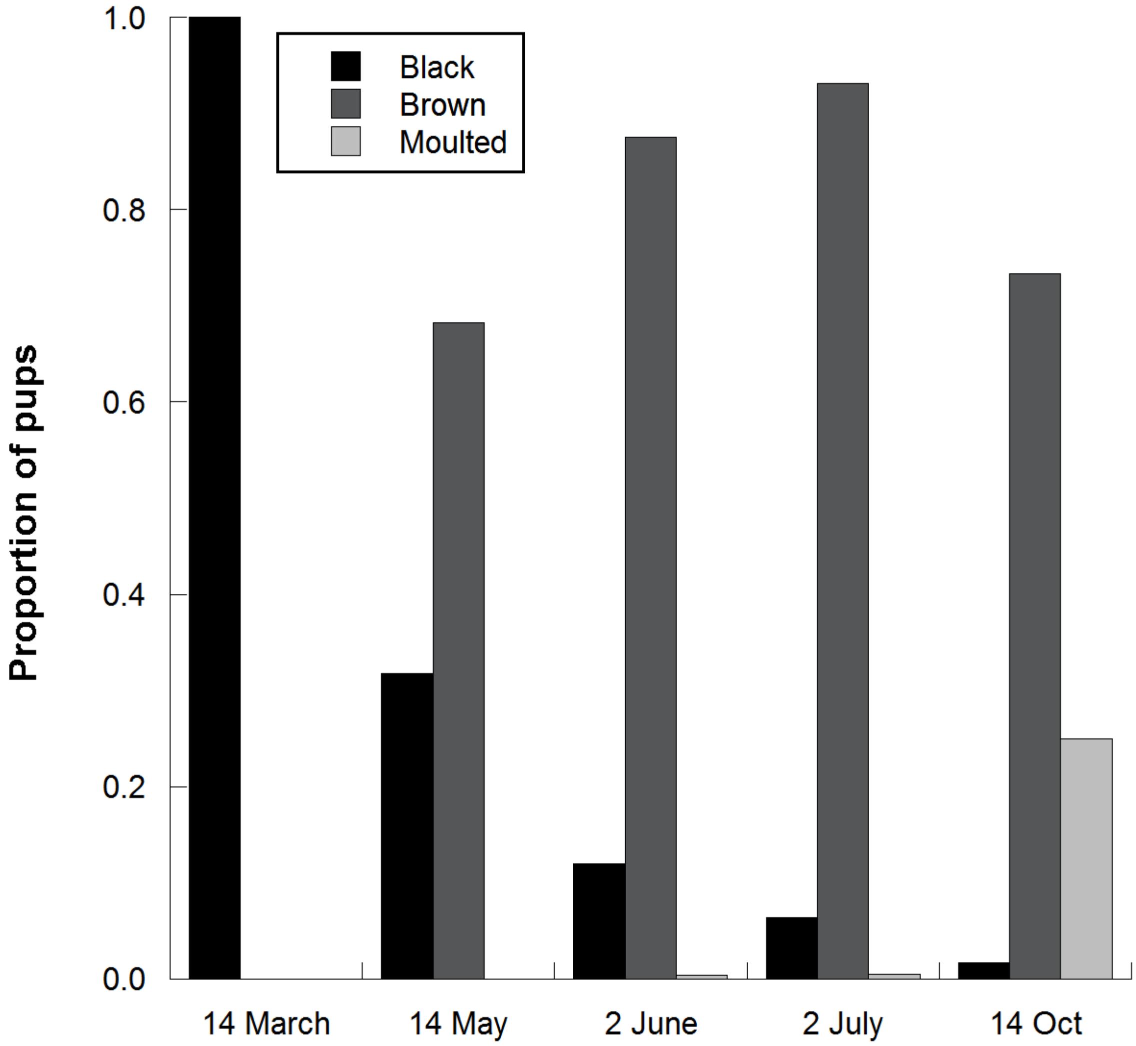


Figure 9. Proportion of Australian sea lion pups classified in three categories (black, brown and moulted) counted during five surveys at Dangerous Reef in the 2014 breeding season.

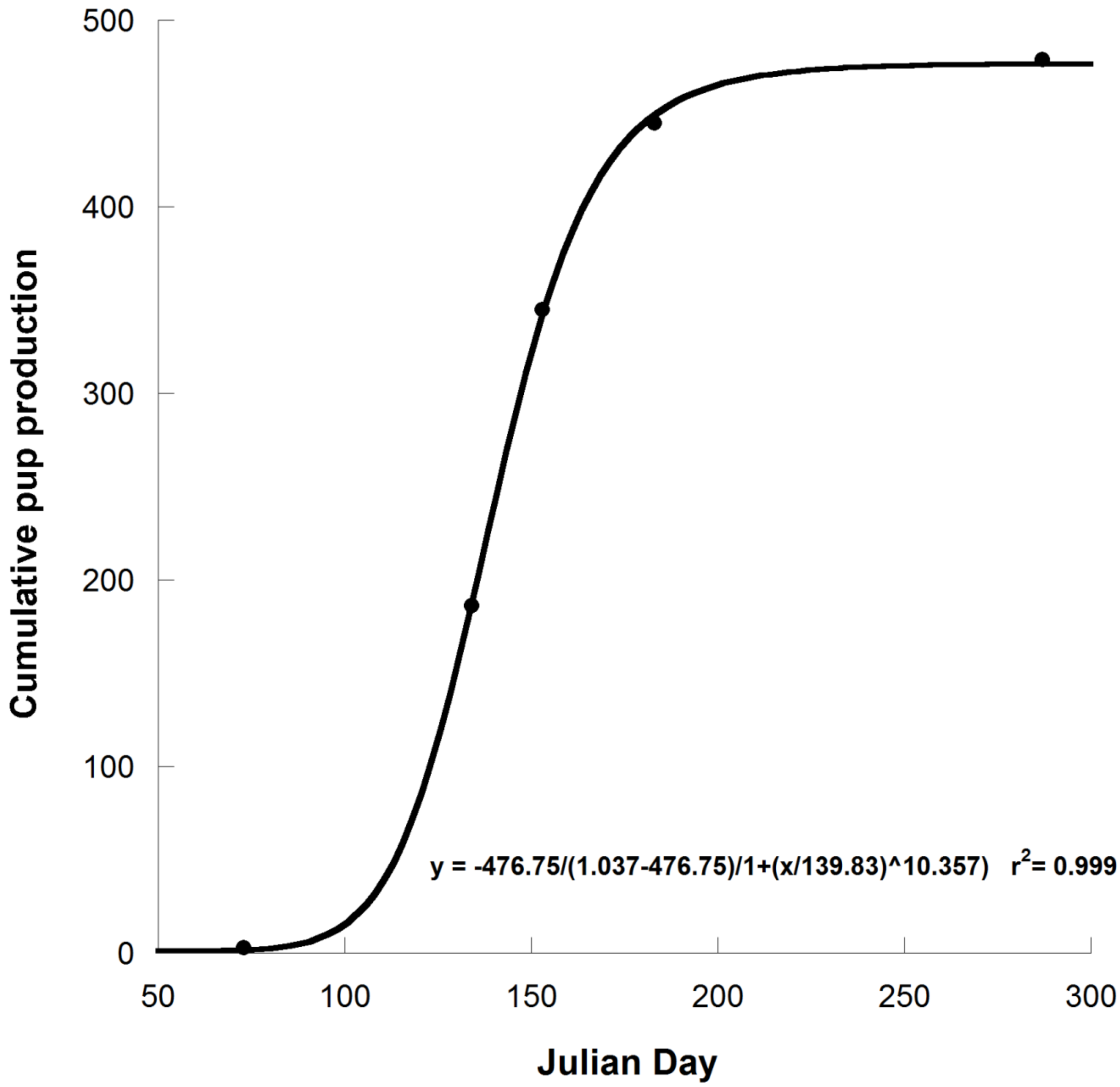


Figure 10. Estimated cumulative pup production of Australian sea lions during the 2014 breeding season at Dangerous Reef based on estimates of pup production up until 14 March 2014, and pup production on the next four surveys (14 May, 2-5 June, 2-4 July, and 14-18 October 2014). The sigmoidal curve fitted to the data assumes that the breeding season commenced on 1 March 2014.

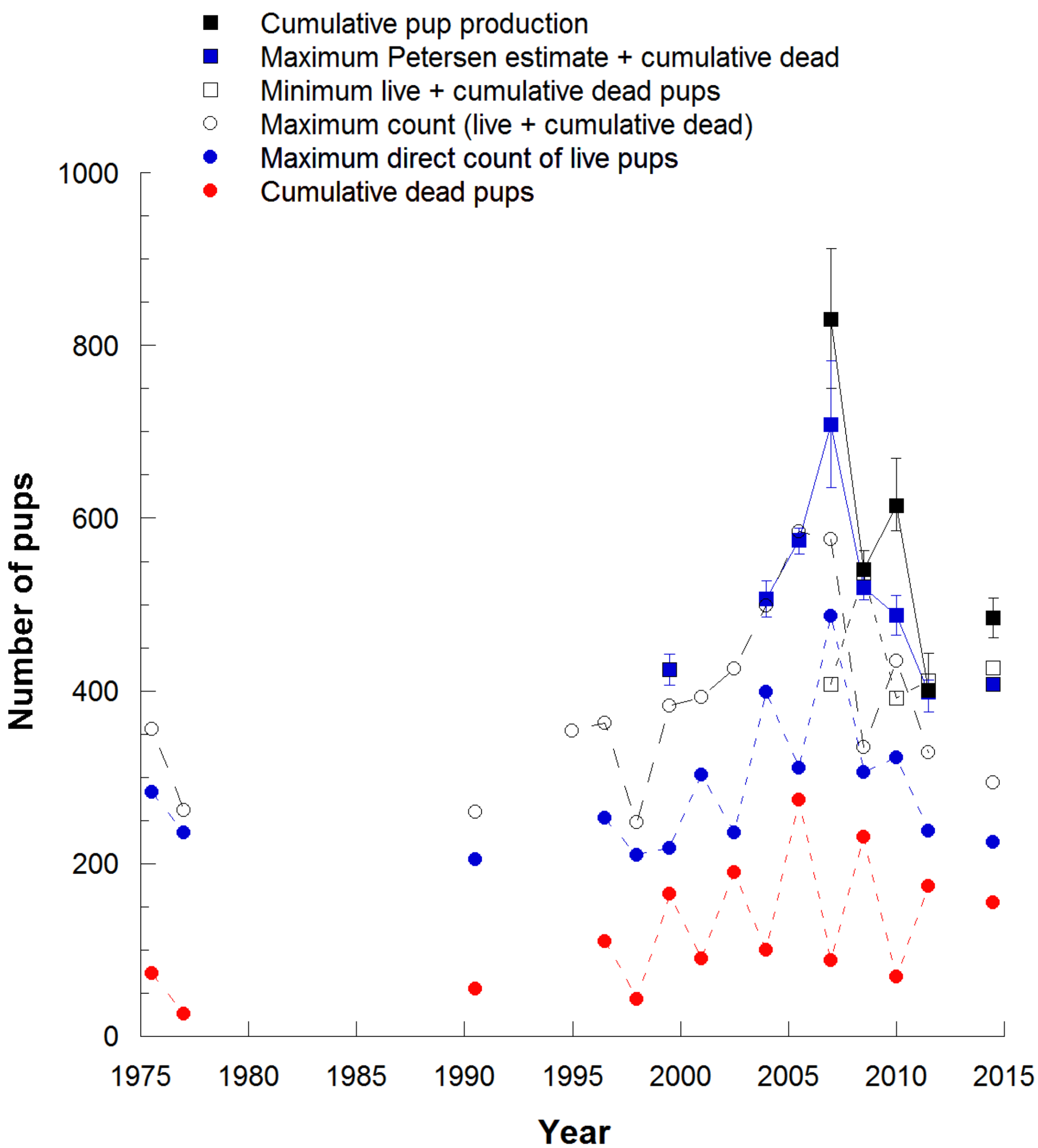


Figure 11. Trends in the abundance of Australian sea lion pups at Dangerous Reef for 15 breeding season between 1975 and 2014, including cumulative pup production (five breeding seasons), Petersen estimates (eight breeding seasons), minimum live and cumulative dead pup counts, maximum direct count of live pups and cumulative dead pups. Error bars around estimates are ± 95% CL. The value for the maximum Petersen estimate (plus cumulative dead pups) for 2011season is obscured behind the value for cumulative pup production.

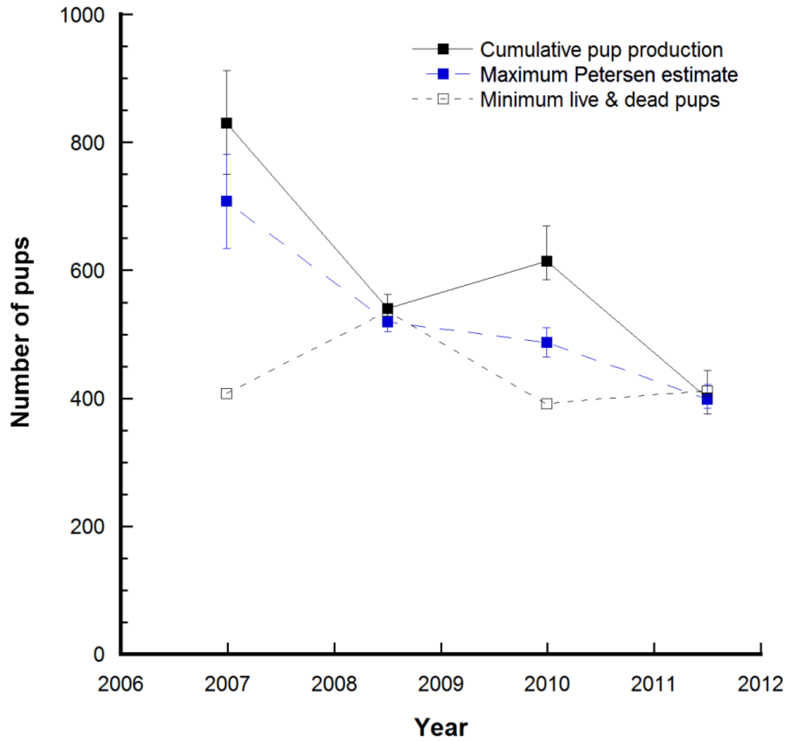


Figure 12. Comparison of three pup production metrics to estimate the abundance of Australian sea lion pups at Dangerous Reef over four consecutive breeding seasons (2006-07, 2008, 2009-10 and 2011). Error bars around estimates are ± 95% CL. Some points are obscured in 2008 and 2011.

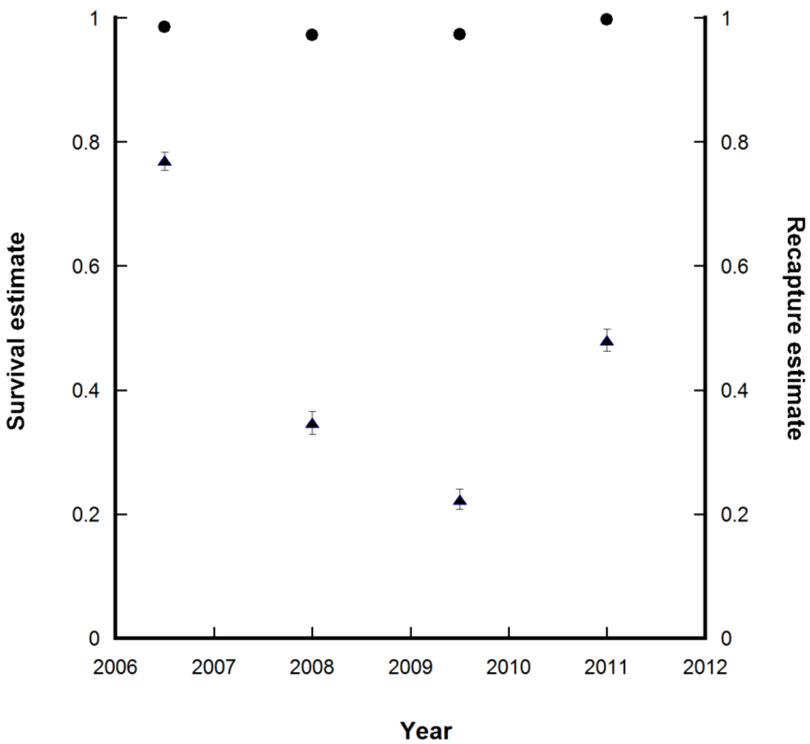


Figure 13. The survival (closed circles - above) and recapture probability (closed triangles-below)) estimates for Australian sea lions in 2006-07, 2008, 2009-10 and 2011. There are differences between the recapture rates and these show considerable inter-annual variation. The vertical bars are the 95% confidence intervals, where these are not visible they are enclosed within the marker.

4.6 Seal Bay

Pup production and population growth

Results of the surveys for pup births and deaths undertaken during the 2013 breeding season at Seal Bay are presented in Table 15 and Figure 14. The breeding season commenced with the first pup birth on 31 March 2013. The last pup birth of the breeding season occurred on 16 December 2013, apart from one very late birth on 30 March 2014, 104 days (3.4 months) later. The duration of the breeding season was approximately 9 months (12 months including the pup born in March 2014).

Based on probit analyses of the cumulative number of births, the median pupping date was 25 August 2013 (sd = 47 days), with 90% of births occurring over 156 days (5.1 months), between 8 June and 11 November 2013 (Table 16). Variation in the chronology of breeding across the last eight breeding seasons is presented in Figure 16.

The mean breeding interval (period between successive median pupping dates) for the eight consecutive breeding seasons was 545 days (range 541-551, sd = 4.0) or 17.9 months (range 17.8-18.1, sd = 0.1) (from data in Table 16, Figure 15).

The cumulative number of births recorded for the 2013 breeding season at Seal Bay was 259 (Table 15, Figure 14). Most pups were born in the Main Beach (MB) area west of the area accessed by the public (89 pups, 34.4%) and in the EPA (75 pups, 29.0%), with 51 pups (19.7%) reported for the WPA and 44 pups (17.0%) for Pup Cove. As Pup Cove could only be surveyed from along the cliff-line at various vantage points, the number of cumulative births for this area may be an under-estimate.

The maximum direct count of live pups was 99 on 12 September 2013 when the cumulative number of dead pups was 27. The cumulative number of pup deaths to the end of the breeding season was 54 on 30 March 2014 when the last pup birth was recorded.

Details of 16 mark-recapture estimates are provided in Table 15. As the most accurate mark-recapture surveys are obtained towards the end of the breeding season, we have only used the nine surveys undertaken after 90% 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 268 with 95% CL 258-277; (Table 15, Figure 14). This is 9 more than estimated from the cumulative survey of new births (259), and 53 more than the minimum estimate of pup production, which is 215 (total live pups microchipped [161] plus cumulative dead pups at the end of the breeding season [54]) (Table 13).

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 2013 season at Seal Bay was 268 (range 259-277), with the lower bound set at the cumulative number of births and the upper bound set as the +95% CL of the adjusted (*AdjN*) Petersen estimate (Tables 12 and 13).

Trends in maximum live pup counts, pup production and mortality

Trends in live pup counts 1985 to 2013

Trends in direct counts of live pups extend over 20 consecutive breeding seasons between 1985 and 2013 (27 years) (Figure 14). A linear regression model fitted to the log of maximum live-pup counts shows a significant decline of 1.9% per breeding season ($F_{1,18}$ = 14.350, P = 0.001, r^2 = 0.4435. The multiple regression model also indicates a significant 2% decline per season with '*Period'* a significant factor, improving the model fit ($F_{2,17}$ = 14.350, P < 0.0002, r^2 = 0.6253).

Trends in estimated pup production and mortality

Estimates of pup production (based on cumulative pup births or mark-recapture estimate) and mortality rates of pups are available for eight consecutive breeding seasons between 2002-03 and 2013 (Figure 16). The linear regression model fitted to the log of estimated pup production showed no evidence of a trend ($F_{1,6}$ = 0.8948, P = 0.3807, r^2 = 0.1298). Including the '*Period'* term in a multiple regression model did not change this result ($F_{2,5}$ = 2.686, P = 0.1613, r^2 = 0.5179). Pup production estimates for the eight consecutive breeding seasons since 2002-03 (Figure 16) 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 16). However, the pattern is absent between 2007 and 2010 breeding seasons, but is apparent between the 2010 and 2013 breeding seasons. After the 2005-06 breeding season, fluctuations in estimated pup production are much less marked; this is likely due to improvements in survey methodologies mid-way through the 2007 breeding season, when access to the Eastern Prohibited Area (EPA) was approved for pup surveys.

Based on a pup production estimate of 268 pups for the 2013 breeding season at Seal Bay, and a total of 54 cumulative pup deaths at the end of the breeding season, the mortality rate for the breeding season is estimated to be 20.1% (Table 16, Figure 14). The average pup mortality rate over the last eight breeding seasons is 28.8% (sd = 7.8); it has varied between about 20% and 41%, and oscillated between the low and high end of that range in consecutive seasons (Goldsworthy *et al.* 2011), with 2013 being a low mortality season (Figure 16). Pup mortality in the low mortality breeding seasons has averaged 22.2% (sd = 2.5), while in the high mortality breeding seasons it averaged 35.4% (sd = 4.7) (from Table 16). There has been no apparent trend in pup mortality between 2002-03 and 2013.

Micro-chipping and demography program

Micro-chipping

In the 2013 breeding season, 268 pups were estimated to have been born at Seal Bay. Of these, at least 54 (20.1%) died before the end of the breeding season. Of the estimated 214 pups that survived, 161 (75%) were microchipped at the time this report was completed (Table 16), representing 60% of all pups estimated to have been born in the 2013 breeding season.

Birth rates and age distribution of females

During the 2013 breeding season, attempts were made 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 140 adult females associated with 54% of the 259 pups recorded in the cumulative survey of new births. Of these 140 adult females, 60 (43%) had a microchips. An additional 14 females were scanned outside of the peri-natal period while nursing pups and were microchipped, giving a total of 74 microchipped females, of which 70 were of known age. The youngest breeding females were ~4.5 years old (born in the 2008-09 breeding season), while the oldest known-age females were ~10 years old (born in the 2002-03 breeding season), coinciding with the beginning of the microchipping program. Only one 4.5 year-old female (1.4% of the 70 known-age females) gave birth, compared to 23 (32.9%) 6 year-olds, 14 (20.0%) 7.5 year-olds, 22 (31.4%) 9 year-olds and 10 (14.3%) 10 year-olds (Figure 17).

Between 1991 and 2001-02, approximately 50 pups were micro-chipped each season (Goldsworthy *et al.* 2007a). A greater microchipping effort was introduced by McIntosh (2007a) in the 2002-03 and 2004 breeding seasons, when Destron microchips (12mm length, with lower read-range) were replaced with TIRIS microchips (23mm length, with greater read-range). Effort will be increased in future seasons to scan as many breeding females as possible.

Table 15. Summary of surveys undertaken for new births and for dead pups, cumulative births and deaths, and direct counts of brown (BP), moulted (MP) and total live Australian sea lion pups at Seal Bay during the 2013 breeding season. Shaded area highlights those surveys when Petersen estimates were calculated.

	Date	New	New	Cumulative			Counts			Petersen M-R estimates					
No.		Births	Dead	Born	Dead	Alive	BP	MP	Total live	M	n	m	*N*	*Adj N*	SE
1	31-Mar	1	1	1	1	0	0	0	0						
2	17-Apr	2	2	3	3	0	0	0	0						
3	23-Apr	1	1	4	4	0	0	0	0						
4	29-Apr	1	1	5	5	0	0	0	0						
5	07-May	0	0	5	5	0	0	0	0						
5	13-May	0	0	5	5	0	0	0	0						
6	21-May	0	0	5	5	0	0	0	0						
7	23-May	0	0	5	5	0	0	0	0						
8	26-May	0	0	5	5	0	0	0	0						
9	28-May	0	0	5	5	0	0	0	0						
10	04-Jun	2	0	7	5	2	2	0	2						
11	11-Jun	2	0	9	5	4	4	0	4						
12	13-Jun	1	0	10	5	5	1	0	1						
13	18-Jun	2	0	12	5	7	5	0	5						
14	25-Jun	5	1	17	6	11	13	0	13						
15	02-Jul	1	0	18	6	12	13	0	13						
16	03-Jul	2	1	20	7	13	3	0	3						
17	08-Jul	4	1	24	8	16	18	0	18						
18	11-Jul	5	1	29	9	20	21	0	21						
19	15-Jul	3	0	32	9	23	22	0	22						
20	18-Jul	4	0	36	9	27	26	0	26						
21	23-Jul	12	1	48	10	38	29	0	29						
22	25-Jul	11	3	59	13	46	31	0	31						
23	29-Jul	13	0	72	13	59	40	0	40						
24	01-Aug	8	0	80	13	67	46	0	46						
25	05-Aug	6	1	86	14	72	48	0	48						
26	08-Aug	9	0	95	14	81	43	0	43						
27	12-Aug	10	2	105	16	89	53	0	53						
28	15-Aug	6	2	111	18	93	55	0	55						
29	19-Aug	13	2	124	20	104	45	0	45						
30	20-Aug	2	2	126	22	104	58	0	58						
31	22-Aug	5	0	131	22	109	44	0	44						
32	26-Aug	5	0	136	22	114	47	0	47						
33	29-Aug	10	1	146	23	123	62	0	62						
34	02-Sep	10	2	156	25	131	64	0	64						
35	05-Sep	9	1	165	26	139	77	0	77						
36	09-Sep	14	1	179	27	152	81	0	81						
37	12-Sep	4	0	183	27	156	99	0	99						
38	16-Sep	9	0	192	27	165	71	0	71						
39	19-Sep	3	0	195	27	168	91	0	91						
40	23-Sep	4	1	199	28	171	86	0	86						
41	26-Sep	4	1	203	29	174	64	0	64						
42	30-Sep	5	1	208	30	178	84	0	84						
43	03-Oct	2	1	210	31	179	71	0	71						
44	08-Oct	8	2	218	33	185	73	0	73						
45	10-Oct	3	1	221	34	187	75	0	75						
46	14-Oct	3	0	224	34	190	95	0	95						
47	17-Oct	0	2	224	36	188	69	0	69	56	69	21	230	264	25
48	22-Oct	7	4	231	40	191	54	0	54	59	54	16	248	275	32
49	28-Oct	4	1	235	41	194	85	1	86	66	86	28	257	280	23
50	31-Oct	2	0	237	41	196	78	1	79	75	79	34	231	252	16
51	04-Nov	4	1	241	42	199	80	1	81	75	81	36	227	244	14
52	07-Nov	3	0	244	42	202	86	0	86	85	86	47	216	230	10
53	11-Nov	3	0	247	42	205	90	2	92	85	92	50	218	230	9
54	12-Nov	1	1	248	43	205									
55	14-Nov	1	0	249	43	206	80	1	81	85	81	43	224	234	11
56	21-Nov	1	0	250	43	207	85	1	86	85	86	44	231	240	12
57	26-Nov	2	3	252	46	206	78	0	78	89	78	40	242	249	14
58	02-Dec	1	3	253	49	204	62	3	65	89	65	28	278	284	23
59	08-Dec	1	1	254	50	204	81	5	86	89	86	31	320	325	27
60	11-Dec	3	1	257	51	206	59	0	59	110	59	34	267	269	17
61	16-Dec	1	0	258	51	207	85	7	92	110	92	45	302	303	18
62	31-Dec	0	0	258	51	207	46	7	53	110	53	26	301	302	26
63	09-Jan	0	0	258	51	207	68	17	85	110	85	44	292	293	17
64	28-Jan	0	1	258	52	206									
65	05-Feb	0	1	258	53	205									
66	13-Feb	0	1	258	54	204									
67	30-Mar	1	0	259	54	205									
				259	54	205							**AdjŇ =**	**268**	**4.9**
														±95% CL (259 – 277)	

Table 16. Summary of the timing and spread of eight consecutive breeding seasons of the Australian sea lion 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 (Ň); 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 (2007b), unless otherwise indicated. Data for the 2007, 2008-09, 2010 and 2011-12 breeding seasons are from Goldsworthy *et al.*(2008a, 2010a, 2011); data from the 2013 season is from this report.

	2002-03	2004	2005-06	2007	2008-09	2010	2011-12	2013
Month breeding season commenced	Dec-02	Jun-04	Dec-05	May-07	Oct-08	May-10	Oct-11	Mar-13
Duration of breeding season (months)	9	7	6	7	7	9	8	12
Median pupping date	13-Mar-03	5-Sep-04	28-Feb-06	27-Aug-07	24-Feb-09	28-Aug-10	21-Feb-12	25-Aug-13
± s.d. (days)	42	39	36	36	41	46	47	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	8 June - 11 Nov
90% births (days)	139[1]	121	104	120	136	150	156	156
Cumulative births	-	200	207	245	268	259	249	259
Cumulative pup deaths	73	70	75	51	88	66	104	54
Maximum live pup count	122	148	125	145	122	128	84	99
At months since beginning of BS	6	7	6	6	7	6	6	4
Max live pup count + cumulative dead[2]	185	208	197	198	197	189	167	126
Total live pups microchipped	148	202	144	203	161	201	118	161
Minimum pup production[3]	221	272	219	254	249	267	222	215
Ň	227	288	203	255[4]	267[4]	269	251	268
(95% CL)	(216-239)	(273-302)	(199-207)	(245-266)	(259-275)	(261-276)	(246-256)	(258-277)
No. recapture estimates	3	2	3	11	7	13	17	16
Overall estimate of pup production	227	288	219	255[4]	268[4]	269	251	268
Confidence limit (min est. to +95% CL)	(221-239)	(273-302)		(254-266)	(268-275)	(267-276)	(249-256)	(259-277)
Mortality rate	32.2%	24.3%	34.2%	20.0%	32.8%	24.5%	41.4%	20.1%

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

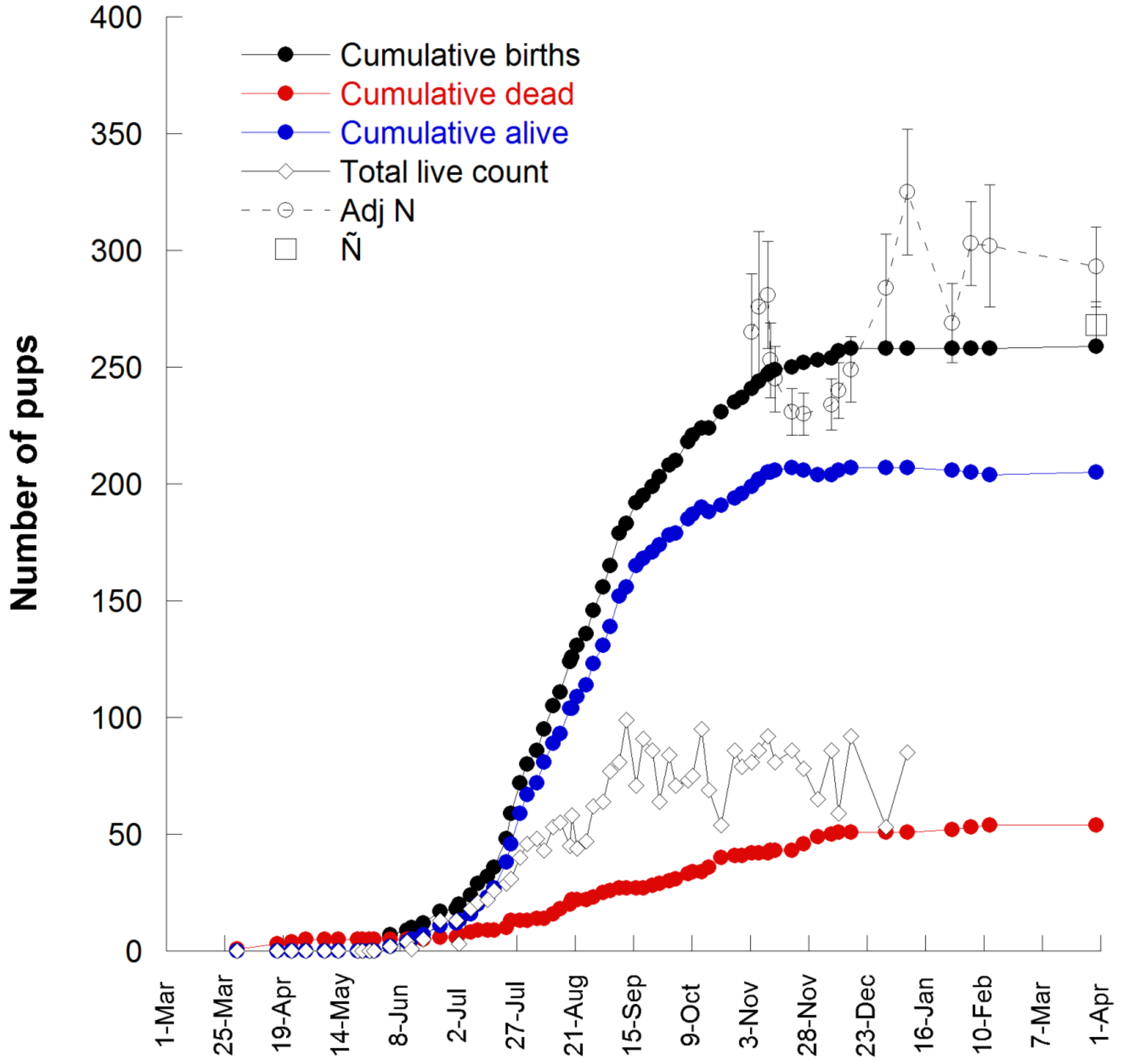


Figure 14. Changes in the number of cumulative pup births, cumulative pup deaths, minimum number of pups alive (cumulative alive), and number of live pups counted during surveys of Australian sea lion pups at Seal Bay conducted between 31 March 2013 and 30 March 2014.

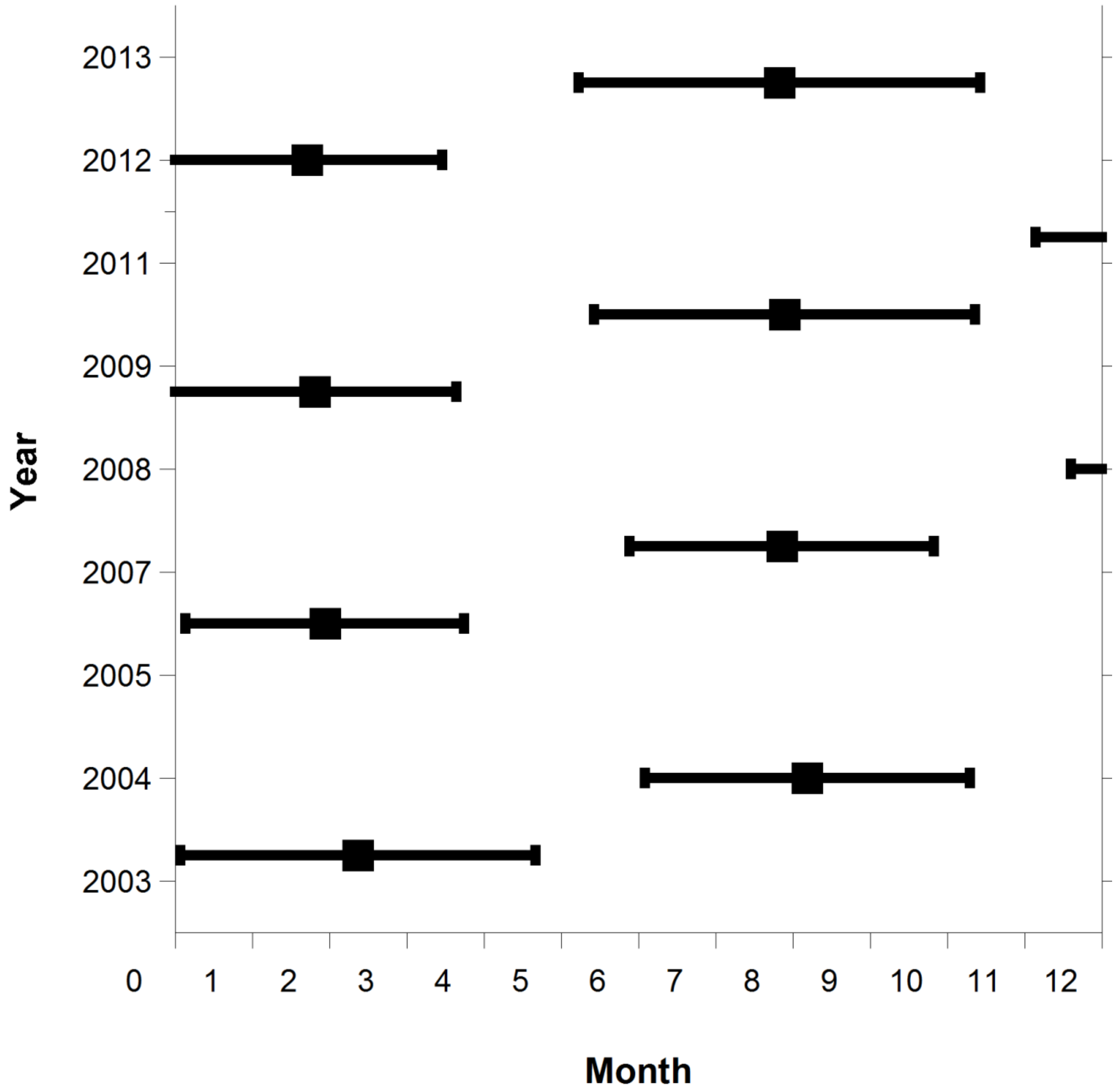


Figure 15. Variation in the breeding season chronology of Australian sea lions at Seal Bay across eight consecutive breeding seasons. Median pupping dates are indicated by squares and error bars represent the spread of 90% of births (5-95%) based on probit analyses of cumulative pup births.

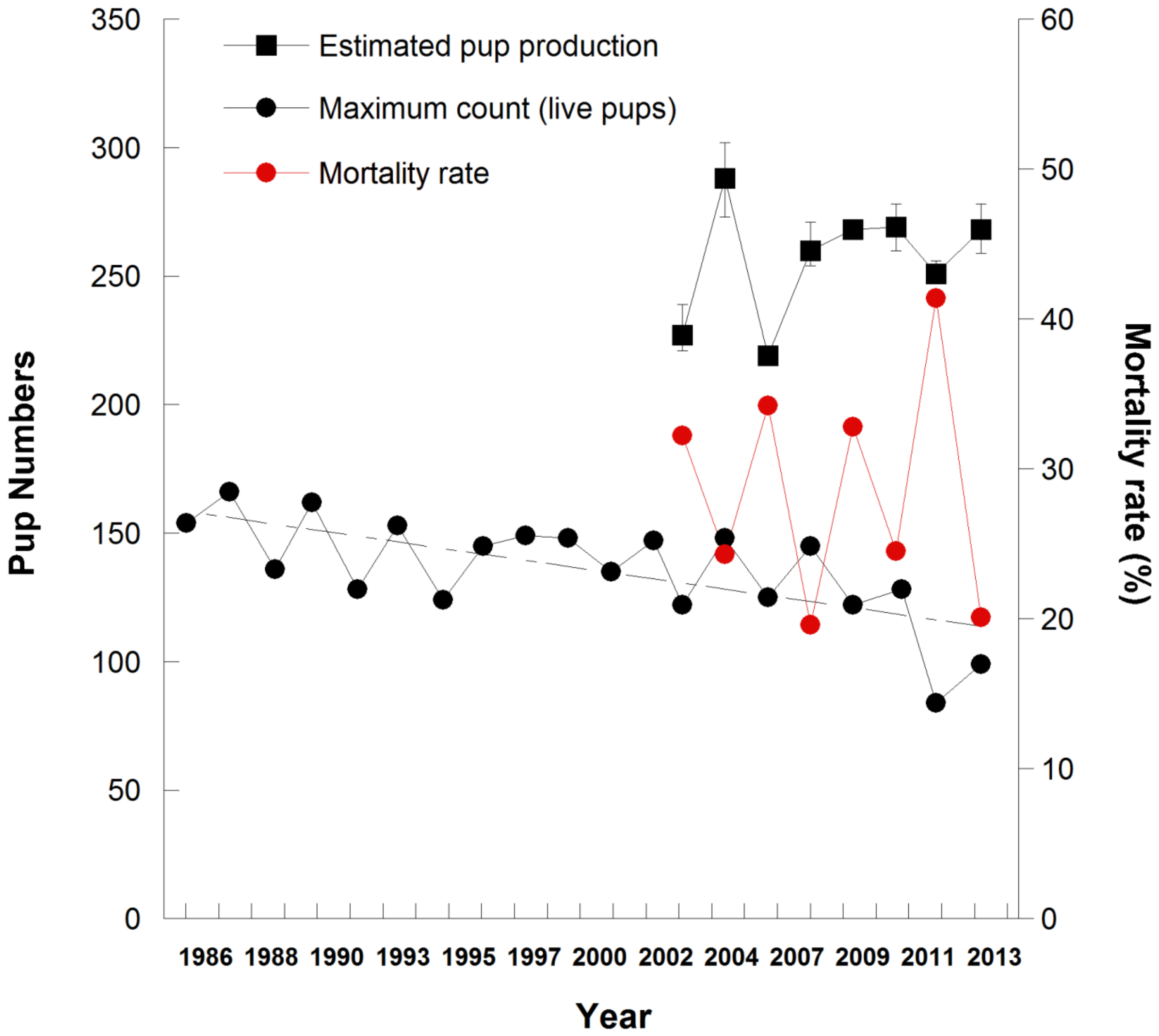


Figure 16. Trends in the abundance of Australian sea lion pups at Seal Bay based on maximum live pup counts for 20 breeding seasons between 1985 and 2013 (with fitted exponential curve). The overall estimate of pup production and pup mortality rate are presented for the last 8 breeding seasons.

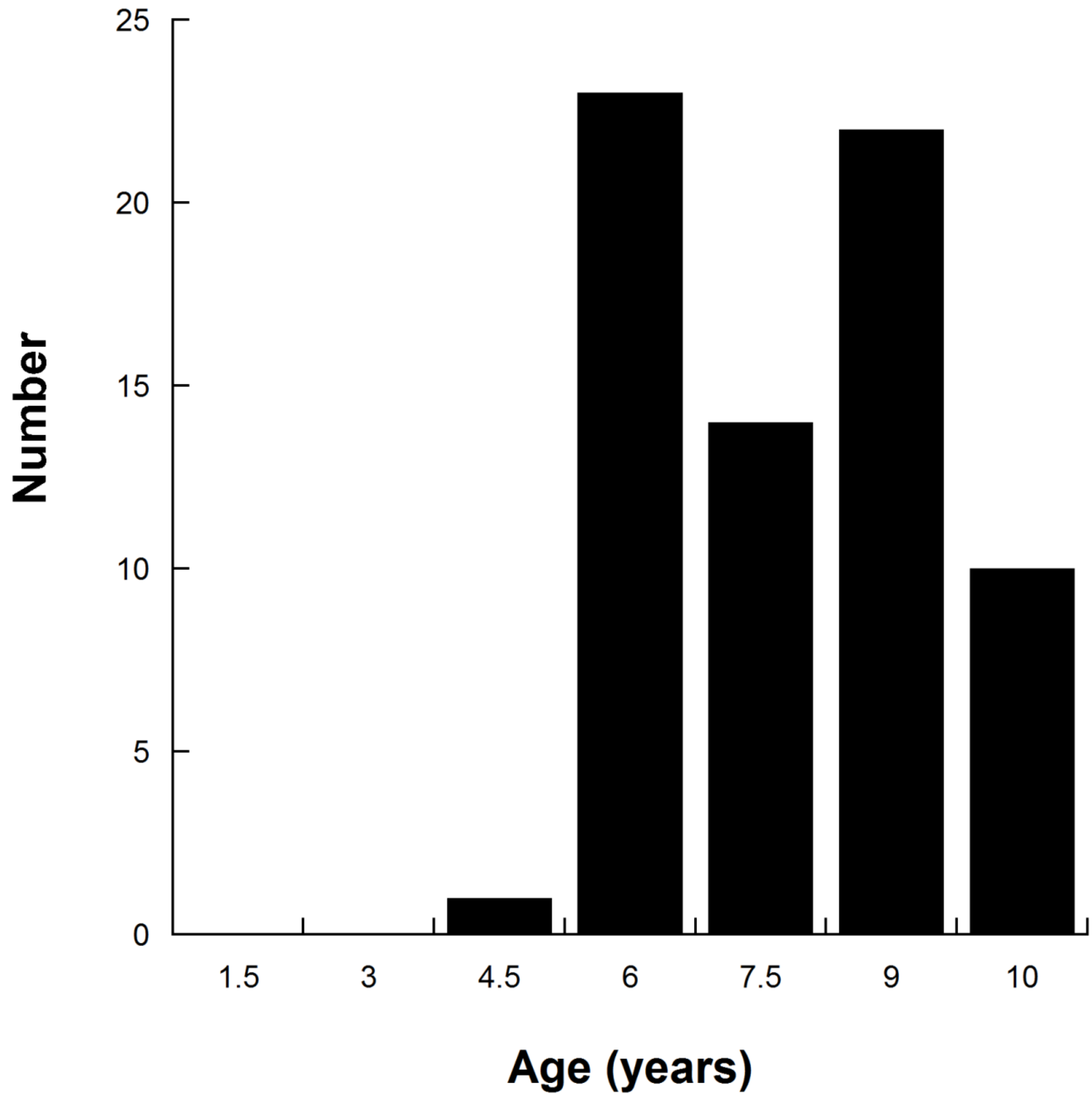


Figure 17. Age distribution of 70 known-age Australian sea lion females that pupped at Seal Bay in the 2013 breeding season. Note that microchipping only commenced ~10 years before the 2013 breeding season, and thus no data is available for females >10 years of age.

4.7 Seal Slide

Three pups were marked over three surveys during the Seal Slide breeding season between July and December 2013. Details of the number of unmarked, marked and dead pups sighted on each survey are presented in Table 17. The minimum number of marked, dead and unmarked pups in the population, based on the resight and marking history is also presented. Based on these data, the minimum estimate of pups born in the subpopulation was 10 (Table 17). No mark-recapture estimates were undertaken, so there are no confidence limits around these estimates.

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 some 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. The cumulative number of pups <1 month old was used to estimate the number of pups born during those seasons, resulting in more accurate and reliable estimates of pup production.

Estimates of pup abundance at the Seal Slide with a higher degree of confidence are now available for the last eight breeding seasons since 2002-03 (Figure 18). The first two are from Shaughnessy *et al.* (2009): 9 pups in 2002/03 and 11 pups in 2004. The next six 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.* 2007c, 2008b, 2010a), 10 pups in 2010, 13 pups in 2011-12, and 10 pups in 2013 (Figure 18). Analyses of trends in pup counts from eight breeding seasons since 2002/03 using linear and multiple regression models fitted to the log of pup counts identified no significant change in pup numbers with breeding season ($F_{1,6}$ = 0.347, P = 0.577, r^2 = 0.055), or with breeding season and period ($F_{2,5}$ = 0.162, P = 0.8552, r^2 = 0.061).

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Table 17. Details of pup surveys undertaken at the Australian sea lion colony at the Seal Slide (Kangaroo Island) between July and December 2013. 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 count of clear pups and cumulative number of clear dead pups, plus the number of pups marked up to the previous survey.

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
24 Jul 13	3	0	0	0	3	3	0	0	3	0	3
2 Sept 13	6	0	3	0	6	9	2	2	6	3	9
17 Dec 13	5	1	0	0	6	6	1	3	7	3	10

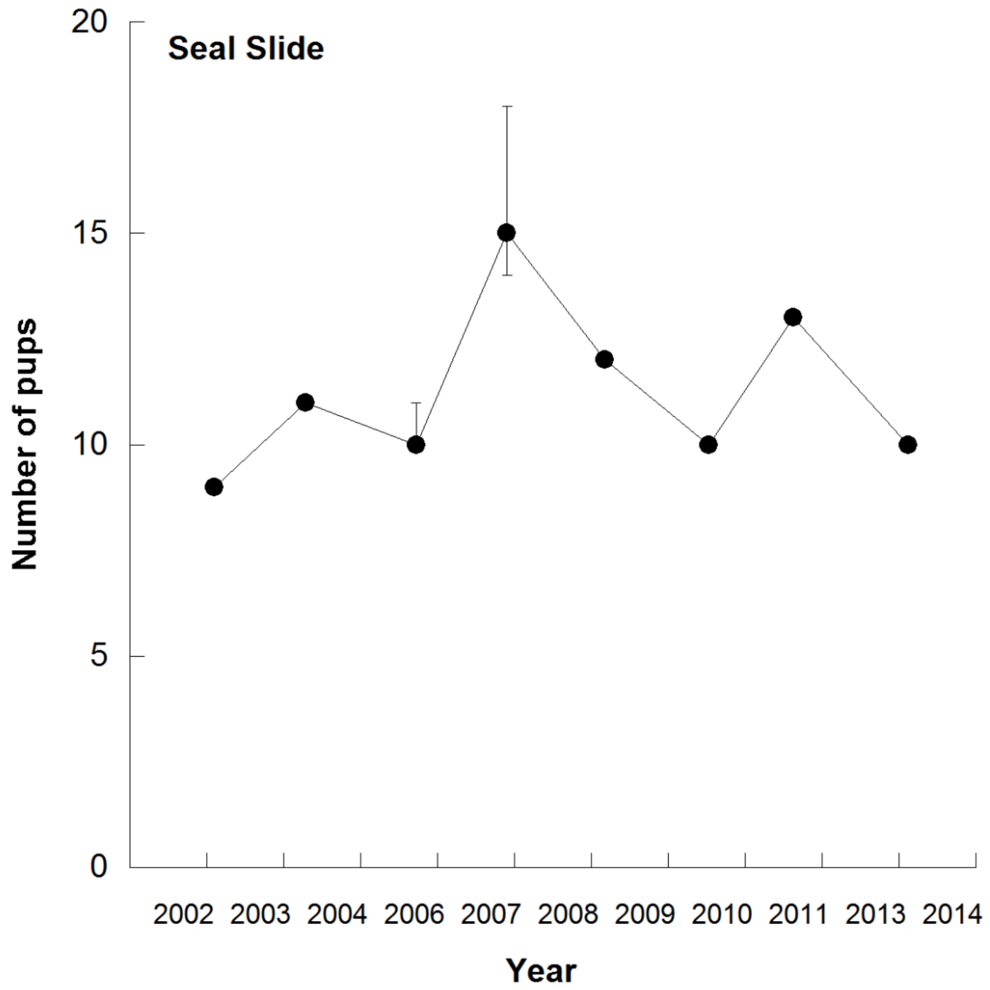

Figure 18. Estimated Australian sea lion pup production at the Seal Slide (Kangaroo Island) over eight consecutive breeding seasons (2002-03 and 2013). Upper (95%) and lower (absolute minimum) confidence limits are available for the 2005-06 and 2007 breeding seasons.

4.8 Additional colony surveys

Helicopter assisted surveys were conducted at a number of colonies between March 2013 and February 2014.

Lewis Island

A single ground survey of Lewis Island was conducted on Lewis Island on 14 March 2013. A total of 79 pups were counted; 23 black (29%, 6 pups with mate-guarded mothers), 53 brown pups (67%) and 3 dead pups (4%) (Table 18). Lewis Island was confirmed as a breeding colony in 2005, and in 2007 a mark-recapture survey was undertaken providing a Petersen estimate of pup production of 131 (95% CL, 116-146), however estimates were confounded by the immigration of pups from Dangerous Reef (Goldsworthy *et al.* 2008b).

Point Labatt

A single cliff-top survey was undertaken at Point Labatt on 18 June 2013 when 2 brown pups were counted. A previous cliff-top survey in 2005 counted a total of 6 pups (Shaughnessy *et al.* 2011). Point Labatt is located approximately 20 km south-east of Nicolas Baudin Island and besides the Bunda Cliffs, is the only mainland breeding colony. Small numbers of pups have been reported sporadically from Point Labatt: four in February 1979 (Ling and Walker 1979), four in July 1986, two in September 1990, two in March 1991 and four in June 1992 (Dennis 2005), and one brown pup in July 2003 (Shaughnessy *et al.* 2005).

Ward Island

A ground survey of Ward Island was conducted on 21 August 2013. A total of 46 pups were counted; 11 black (24%, 3 pups had mothers being mate guarded), 34 brown (74%), and 1 dead pup (2%) (Table 18). Given the absence of moulted pups and the proportion of brown and black pups counted, it is estimated that the survey occurred about 3-4 months into the breeding season, likely underestimating total pup production for the breeding season. Ward Island has rarely been surveyed for Australian sea lions. It was first recognised as a breeding sites by Gales et al. (1994) in January 1990 when two dead pups were found there. Eight large moulted pups were seen there in ground surveys in November 1995, and three moulted pups were seen during ground surveys in January 1996 (Shaughnessy *et al.* 2005). A ground survey undertaken in May 2006 recorded 45 pups (D. Armstrong, in Robinson *et al.* 2008). The 2013 survey is similar to the 2006 survey, although it is not clear at what stage of the breeding season the 2006 survey was undertaken.

Pearson Island

A ground survey of Pearson Island was conducted on 21 August 2013. A total of 27 pups were counted; 5 black (19%, 4 of those pups had mothers being mate-guarded), 21 brown (74%), and 2 dead (7%) (Table 18). Given the absence of moulted pups and the proportion of brown and black pups counted it is estimated that the survey occurred about 3-4 months into the breeding season. All but one pup were counted on the South Island, with a single pup counted on the middle island. During an additional survey on 25 August 2013 a new black pup with a mate-guarded mother, and a single brown pup which was beyond the area originally surveyed on 21 August 2013 were counted. Thus the total number of pups recorded for August 2013 is 30.

Pearson Island was recognised as a breeding site on the basis of 26 moulted pups and three brown pups counted in February 1991 (Gales *et al.* 1994). In February 1994 20 pups (18 moulted and two brown) were counted, and in November 1997 24 brown pups (2 dead) were counted (Dennis 2005, Shaughnessy *et al.* 2005). In July 2005, 35 pups were counted (K. Peters and B. Page, in Goldsworthy *et al.* 2009a)

West Waldegrave Island

A very thorough ground survey of West Waldegrave Island was conducted on 22 August 2013 that involved a full coastal survey and a search on top of the island. A total of 91 pups were counted; 1 black, 85 brown (93%), 4 moulted (4%) and 1 dead (Table 18). The breeding season was over with most brown pups in pre-moult or just commencing to moult. West Waldegrave was recognised as a breeding site in August 1995 when brown pups were sighted during an aerial survey (Shaughnessy *et al.* 1997). In February 2002, 79 pups were counted (68 brown, six moulted and five dead). Three surveys were undertaken in 2003, with the maximum pups numbers obtained in July when 157 pups (145 brown, four moulted and five dead) were counted (Shaughnessy *et al.* 2005). The 2013 survey represents about a 42% decline from the 2003 survey, which was also a winter breeding season. Further surveys are needed at this site to determine if there has been a major reduction in pup numbers.

Dorothee Island

A ground survey of Dorothee was conducted on 21 August 2013 with no evidence of breeding (20 ASL counted but no pups were seen). There is limited access from the water onto the island and therefore is considered to be poor breeding habitat. A single pup was previously counted at Dorothee in January 1996 (Shaughnessy *et al.* 2005).

Nuyts Reef

A ground survey of Nuyts Reef was conducted on 3 December 2013 when 28 pups were counted on the southern main reef; 2 black (7%, both with mate-guarded mothers), 23 brown

(82%) and 3 dead (11%) (Table 18). A further 26 pups were counted on the north-eastern reef during an aerial survey (low hover over the reef) when 11 black (42%), 13 brown (50%) and 2 dead (8%) were counted (Table 18). It was not possible to accurately assess how may black pups had mate-guarded mothers. The total count of pups at Nuyts Reef in 2013 was therefore 54. 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 (2013) represent only the fourth ground count 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. In August 2012, 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). The 2013 survey therefore represents the largest pup count for this site.

North Casuarina Island

A single ground survey was conducted at North Casuarina Island on 29 January 2014 when a total of 11 pups were counted of which 6 were brown (55%), 4 moulting (36%), 1 moulted (9%) and zero dead. ASL pups have been previously sighted at North Casuarina Island on three occasions; in February 1990 (one brown pup), in February 1996 (three brown pups) and in August 2000 (3 pups seen from Cape du Couedic with the aid of binoculars) (Shaughnessy *et al.* 2009). The survey conducted January 2014 represents the most comprehensive survey of the site and the largest pup production.

Curta Rocks

An aerial survey of Curta Rocks was undertaken on 13 February 2014, and no pups or signs of breeding ASL were detected. This surveys follows two recent surveys undertaken in November 2011 (when one large brown pup was sighted) and February 2013 (no pups sighted) (Goldsworthy *et al.* 2013). 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. 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 animals (non pups, Dennis 2005). Further opportunistic surveys should be undertaken at Curta Rocks to resolve its breeding status.

Table 18. Details of Australian sea lion pup surveys undertaken at islands in the Great Australian Bight and off lower Eyre Peninsula. Live pups are categorised by their pelage stage. MG denotes pups with mate-guarded mothers**.** All surveys were ground surveys, with the exception of NE reef – Nuyts Reef and Curta Rocks, which were aerial surveys.

Island	Date	Numbers of pups					
		Black (MG)	Black	Brown	Moulted	Dead	Total
Lewis Island	14-Mar-13	6	17	53	0	3	79
Point Labatt	18-Jun-13			2			2
Ward Island	21-Aug-13	3	8	34	0	1	46
Dorothee Island	21-Aug-13	0	0	0	0	0	0
Pearson Island	21-25 Aug 13	5	1	22	0	2	30
West Waldegrave Island	22-Aug-13		1	85	4	1	91
Nuyts Reef							
Southern main reef	3-Dec-13	2	0	23	0	3	28
NE reef (aerial survey)	3-Dec-13		11	13	0	2	26
North Casuarina Island	29-Jan-14	0	0	10	1	0	11
Curta Rocks (aerial survey)	13-Feb-14	0	0	0	0	0	0

5. CONCLUSIONS

This study continues to provide important information on the status of the ASL population in South Australia. A commitment to establish a range of key monitoring sites across the State is now providing important time series that were unavailable a decade ago. With four and six consecutive breeding seasons monitored at Lilliput and Blefuscu Islands and Olive and Jones Islands, respectively, these sites are now providing some insight into trends in abundance for the species on the western Eyre Peninsula. The project was also able to undertake the first mark-recapture survey at Nicolas Baudin Island, although the method may not be suitable there, especially during winter months when large tides and heavy seas result in islands becoming a series of exposed reefs. The survey of Dangerous Reef has been important given the size of this population and the apparent (>40%) decline in pup production from a high of 831 in 2006/07 to 485 in 2014. Monitoring at this site continues to present challenges in the enumeration and interpretation of pup abundance metrics, and the potential influence of season and factors influencing re-sight probabilities. Analyses were undertaken to determine if inter-breeding season differences in individual detection heterogeneity (IDH) may contribute to biasing estimates of pup production and trend analyses at Dangerous Reef. Results indicated that resight probabilities were effectively 1 and did not differ between seasons, and although pup survival varied markedly between breeding seasons, there was no apparent relationship between survival in summer or winter breeding seasons to account for the difference observed in pup abundance metrics. Results from other sites indicate that other factors, including the timing of surveys (e.g. English Island) and movement of pups between breeding sites (e.g. Nicolas Baudin) continue to present challenges in survey design, enumeration and interpretation of data at all ASL breeding sites. The inherent variability in data (at all sites) makes it hard to determine if trends are significant, and long-term data are needed (e.g Seal Bay).

Unfortunately, the remote field camera trials were unsuccessful as the cameras were not able to transmit images through the Next G network. We will continue to pursue this approach and hope that suitable camera systems will be available in the near future; as we believe the use of remote cameras to monitor the breeding chronology of ASL would greatly improve our ability to optimise survey timing and improvise the logistic planning and resourcing of surveys. Ongoing monitoring of the Seal Bay population where the timing and duration of breeding, pup production and mortality and demographic processes can be monitored in detail will be essential for informing and interpreting the breeding ecology and survey design at other sites.

The study was also able to undertake a number of single surveys at sites where pup numbers have not been surveyed comprehensively for some years, and where breeding status remains uncertain. These included Nuyts Reef, Ward Island, Pearson and Dorothee Islands, and Lewis Island. A survey was also undertaken at North Casuarina Island off Kangaroo Island. Curta Rocks was surveyed as a possible breeding site, but as yet we are unable to determine its breeding status.

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