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Developing population protocols to determine the abundance of Australian sea lions at key subpopulations in South Australia

Photo: S Goldsworthy (SARDI)

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1 EXECUTIVE SUMMARY

The Australian sea lion was listed as a threatened species under the EPBC Act in February 2005. Information on the size and status of most subpopulations is poor and hampers developing appropriate management strategies for the species. Many aspects of the species' breeding biology and ecology are unique among otariids (fur seals and sea lions) and make accurate assessment of pup production challenging. This project aimed to undertake Australian sea lion pup production surveys at Blefuscu, Lilliput and Breakwater Islands and Gliddon Reef in the Nuyts Archipelago using a combination of mark-recapture (Petersen estimate) and cumulative mark and count (CMC) methods. Other breeding and haul-out sites in the Nuyts Archipelago were also surveyed by single ground and aerial surveys undertaken at the end of the breeding season. Surveys of the Dangerous Reef and English Island colonies in southern Spencer Gulf were also undertaken using mark-recapture and CMC methods, respectively.

Three mark-recapture sessions were undertaken at Lilliput and Blefuscu Islands during the 2007-08 breeding season, giving estimates of 64 (95% CL, 62-69) and 99 (95% CL, 92-106) pups, respectively. Due to sea conditions, landing at Breakwater Island and Gliddon Reef was only possible on one out of three occasions, when 15 and 7 pups were surveyed, respectively. Single ground surveys for pups at Lounds (34 pups), Purdie (95), West (39) and Fenelon (40), produced a total minimum pup production estimate for the Nuyts Archipelago of 393.

The 2008 breeding season at Dangerous Reef lasted nine months (early February to November). Four surveys were undertaken roughly corresponding to the first, third, fourth and fifth month of breeding. The maximum mark-recapture estimate (520 pups, 95% CL 509-535) was less than the maximum pup count of 537. This represents a maximum decline of around 24% since the 2006-07 breeding season and a departure following at least four consecutive breeding seasons of sustained increases in pup production. This decline most likely reflects a drop in fecundity rates between seasons, rather than a reduction in female population size, although surveying of subsequent breeding season will be needed to assess this. Even with the reduction in pup production in the 2008 breeding season, the overall trend in pup abundance is still increasing at around 6.9% per season, or 4.5% per year, since 1996.

Estimated mortality rates of pups to the fifth month of breeding at Dangerous Reef were high (43%). A very clear pattern of alternating high (mean ~38%) and low (mean ~18%) pup

mortality between winter and summer breeding seasons has now been established at Dangerous Reef. Based on studies from other sea lion and fur seal populations, we propose that climate and season induced fluctuations in hookworm (*Uncinaria* spp.) infection in combination with enteritis-bacteraemia complexes explains the observed marked inter-seasonal fluctuation in pup mortality. Given these fluctuations could induce a large variance in recruitment and age-structure, there is a critical need to understand the role of disease and parasites on pup survival, and on the broader population structure and demography of Australian sea lion populations.

Surveys undertaken at English Island were compromised by influxes of dispersing pups into the colony from Dangerous Reef (25km away), with an unknown number of untagged pups present by the second survey when pup production to June 2008 was estimated to be 23.

For surveys undertaken during this study, we are confident that mark-recapture methods provide accurate estimates of pup production at Lilliput and Blefuscu Islands, however, those undertaken at Dangerous Reef underestimated total pup production, with the largest estimate being provided by counts of marked, unmarked and cumulative dead pups. The long nine-month breeding season meant that at least one additional survey should have been undertaken there, but limited funds prohibited this. Future surveys should build in some contingency to conduct additional surveys if required due to extended breeding seasons.

For the small colony surveys undertaken at Breakwater Island and Gliddon Reef, and English Island, two major problems were uncounted. Firstly, access at Breakwater Island and Gliddon Reef was difficult, with landings being only possible on one occasion over three attempts. The second major problem was at English Island, where the presence of dispersed Dangerous Reef pups undermined the cumulative count and mark (CMC) method, because an unknown proportion of unmarked pups present were from Dangerous Reef. The only way to eliminate the inclusion of dispersed pups from these surveys is to modify the CMC method to only include new black-coat and brown pups and increase the number of surveys (eg. monthly from the second month of breeding).

A workshop to develop a national survey strategy for monitoring Australian sea lion populations is proposed to occur during 2009. Results from this and previous studies will be important in the selection of appropriate monitoring sites, survey methodology and frequency.

2 INTRODUCTION

Background

The Australian sea lion, *Neophoca cinerea,* is one of five sea lion species in the world. Sea lions form around one-third of species in the Otariidae family of seals that includes all of the fur seals and sea lions. Over recent decades there has been growing concern over the status of all five sea lion species. In the North Pacific Ocean, the Steller sea lion, *Eumetopias jubatus*, has been declared endangered in parts of its range and is considered threatened with extinction in other parts (Trites et al. 2007). Although the total population of Californian sea lions in California and Mexico is increasing (Carretta et al. 2004), the Mexican stock is in decline (Szteren et al. 2006). There have also been reductions in numbers of the Galapagos subspecies of the Californian sea lion, *Zalophus californianus wollebaeki* (Alava & Salazar 2006), and the Japanese subspecies, *Z. c. japonicus,* is probably extinct (Mate 1982). Numbers of South American sea lions, *Otaria flavescens*, have reduced considerably in recent years (Crespo & Pedraza 1991, Reyes et al. 1999, Shiavini et al. 2004), especially in the Falkland Islands (Thompson et al. 2005), and numbers of New Zealand sea lions, *Phocarctos hookeri* (Lalas & Bradshaw 2003), and Australian sea lions (McKenzie et al. 2005) have not recovered from historic sealing. The last two species form the smallest populations of all sea lion species. Australian sea lions were listed as a threatened species under the EPBC Act in February 2005.

The ASL is Australia's only endemic and least-abundant seal species. It is unique among pinnipeds in being the only species that has a non-annual breeding cycle (Gales et al. 1994). Furthermore, breeding is temporally asynchronous across its range (Gales et al. 1994, Gales & Costa 1997). It has the longest gestation period of any pinniped, and a protracted breeding and lactation period (Higgins & Gass 1993, Gales & Costa 1997). The selective factors that have shaped this atypical life-history remain enigmatic. Recent population genetic studies have indicated little or no interchange of females among breeding colonies, even those separated by short (20 km) distances(Campbell 2003, Campbell et al. 2008). The important management implication of extreme levels of female natal site-fidelity (philopatry) is that each colony effectively represents a closed population.

There are 76 known breeding locations for ASL, 58 (76%) of these sites are currently classified as breeding colonies (≥ 5 pups recorded) and 18 (24%) as haul-out sites with occasional pupping (≤ 4 pups recorded) (Goldsworthy et al. in press-a). Of the 76 confirmed breeding sites, 48 (63%) occur in SA, and 28 (37%) in WA (Goldsworthy et al. in press-a). Based on estimates of pup numbers, a minimum of 3,610 pups are born per breeding cycle throughout the species' range, with 86% of these (3,107 pups) in SA and 14% (503 pups) in WA (Goldsworthy et al. in press-a). The species was subject to sealing in the late 18th, the 19th and early 20th centuries, resulting in a reduction in overall population size and extinction of populations in Bass Strait and other localities within its current range.

Although the pre-harvested population size of ASL is unknown, the overall population is believed to be in recovery. Unlike Australian (*Arctocephalus pusillus doriferus*) and New Zealand (*A. forsteri*) fur seal populations, which have been recovering rapidly throughout southern Australia over the last 20 years, there is a general view that recovery of the ASL populations has been limited. One of the most critical issues impeding effective management of ASL is the high uncertainty in estimates of the size and status of sub-populations throughout its range. Most sub-populations are scattered on remote offshore islands and the non-annual, asynchronous and protracted breeding seasons have made it difficult to obtain accurate estimates of pup production.

McKenzie et al. (2005) noted that the quality of data on pup production across the range of ASL was typically poor. Poor data is largely due to the species' protracted breeding season, meaning that by the end of the pupping period some pups may have died, dispersed or moulted (and may go unrecognised). Because of this, researchers have tried to estimate the maximum numbers of pups present from single counts, timed when maximum pup numbers are expected in the colony, or from multiple point counts made throughout the breeding season in order to recognise the maximum number in the colony. Where possible, the cumulative number of dead pups is added to these estimates. These methods are likely to result in underestimates of the true number of pups produced, but to what extent is poorly understood and is likely to vary among sub-populations. These issues make it difficult to accurately estimate the size and trends in abundance of ASL populations.

Further, reliable estimates of pup abundance are available for very few ASL colonies, and time-series data are available for even fewer. Although the methodologies to estimate pup numbers have advanced in recent years in conjunction with an understanding of the timing of breeding seasons at certain colonies, the quality of time-series data is typically poor because early records were based on limited surveys. The apparent high variability in pup numbers recorded between breeding seasons has also made it difficult to interpret trends in population abundance with any level of confidence.

McKenzie et al. (2005) noted that these observations of major shortfalls in the quality of data on pup production, population size and trends in the species are important because they place serious limitations on our capacity to adequately manage the species. At its most basic level, management for the recovery of the ASL will need to be underpinned by an ability to detect changes in the status of populations and the species as a whole. To this end, Goldsworthy et al. (2007c) developed and tested the appropriateness of two new methods for estimating pup production in ASL subpopulations.

The survey method developed for large ASL subpopulations (>40 pups) utilised individual re-sight histories of tagged pups and Cormack-Jolly-Seber (CJS) models in conjunction with standard mark-recapture methods. The survey method developed for small ASL subpopulations (<40 pups) used a cumulative mark and count (CMC) approach to improve estimates of pup production. The principal reason for developing these methods was to provide a repeatable survey approach, which resulted in precise estimates of pup production with confidence limits.

McKenzie et al. (2005) also noted that because of the large number of ASL breeding sites and their asynchronous breeding patterns, achieving high quality trend data across all breeding sites over time is unlikely to be achievable, especially considering the difficulty and expense in reaching 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 survey, Goldsworthy et al. (2007c) undertook a distance analysis among ASL subpopulations and identified 11 metapopulations in the species, with seven of them in South Australia (SA) (Figure 2.1). Among SA metapopulations, only four included sites where accurate, repeatable, cost effective and logistically feasible surveys could be undertaken. Within each of these, one large (>40 pups) and one small (<40 pups) site were selected (8 in total) as regionally representative sites to form the basis for ongoing surveys. The principal objective was to design a monitoring program that collected high quality census data from a subset of subpopulations, enabling estimates of the status and trends in their abundance to be obtained across the range of the species in the shortest possible time. Such surveys would underpin management of the species across its range. The SA sites identified included The Seal Slide and Seal Bay (Kangaroo Island metapopulation); English Island and Dangerous Reef (Spencer Gulf metapopulation); Jones and Olive Islands (Chain of Bays metapopulation); and Breakwater/Gliddon Reef and Blefuscu Islands (Nuyts Archipelago metapopulation).

Aims & Objectives

The original aims of this study were to undertake ASL surveys at English Island and Dangerous Reef in Spencer Gulf, and Breakwater/Gliddon Reefs and Blefuscu Island (Nuyts Archipelago) over the 2007/08 financial year. However, due to an associated project being undertaken at Lilliput Island, and additional funds being provided through DEWHAs Migratory Marine Section, mark-recapture CJS surveys were also undertaken at Lilliput Island, and a helicopter assisted single ground count survey was undertaken of the remaining Nuyts Archipelago breeding colonies (Lounds, Purdie, West and Fenelon Islands). This included aerial surveys of a number of haul-out sites, and potential new breeding colonies, enabling the most comprehensive survey of ASL abundance in the Nuyts Archipelago to date.

The adjusted aims where therefore to:

1) Survey ASL pup production at Blefuscu and Lilliput Islands using mark-recapture/CJS methods;
2) Survey Breakwater Island and Gliddon Reefs using CMC methods;
3) Survey the remaining Nuyts Archipelago breeding colonies (Lounds, Purdie, West and Fenelon Islands) including aerial surveys of a number of haul-out sites, and potential new breeding colonies; and
4) Survey Dangerous Reef and English Islands using mark-recapture/CJS and CMC methods, respectively.

Format of the report

The report is divided into three main chapters. Chapter 3 presents results from ASL surveys undertaken in the Nuyts Archipelago, while Chapter 4 presents those undertaken in Spencer Gulf. Conclusions are presented in Chapter 5.

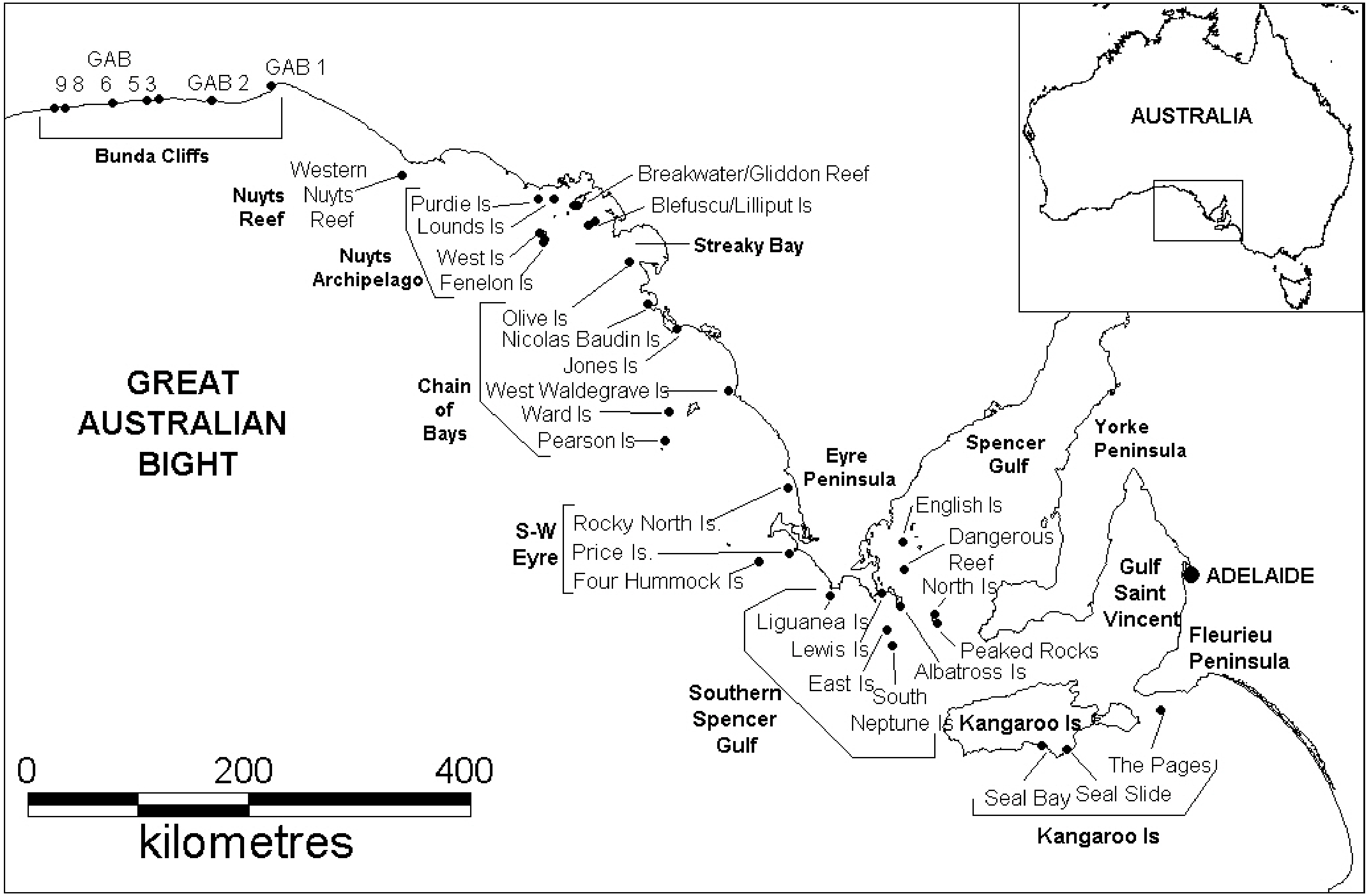


Figure 2.1. Distribution of Australian sea lion breeding sites in South Australia. Seven metapopulations proposed by Goldsworthy et al. (2007c), are also identified.

3 PUP ABUNDANCE IN THE NUYTS ARCHIPELAGO 2007/08

Introduction

The Nuyts Archipelago is located in the eastern Great Australian Bight (Figure 3.1) and contains eight breeding sites (colonies) of Australian sea lions (ASL) that broadly occur in four pairs. Lilliput and Blefuscu Islands occur in the eastern Nuyts Archipelago, and form two small islets off East and West Franklin Islets, respectively. The distance between the two breeding colonies is only about 5km. Breakwater Island and Gliddon Reef form two small islets that are located off the south-east of Goat Island and the south-west of St Peter Island, respectively. The distance between the two colonies is only 2.5km. Lounds and Purdie Islands are located in the western region of the Nuyts Archipelago, about 10 and 7km south of the mainland, respectively, with approximately 7 km separating the two islands. West and Fenelon Islands occur in the southern part of the Nuyts Archipelago, forming part of the Isles of St Francis Group. West Island is west of St Francis Island, and Fenelon Island is the most southern Island in the Nuyts Archipelago. The distance between the two breeding colonies is only about 10km. The Nuyts Archipelago was identified as a key Australian sea lion metapopulation by Goldsworthy et al. (2007c)(Figure 2.1). They sought to identify one large (>40 pups) and one small (<40 pups) colony representative of the metapopulation to form the basis for ongoing surveys where accurate, repeatable, cost effective and logistically feasible surveys could be undertaken. For the Nuyts Archipelago metapopulation, they proposed Blefuscu Island as a representative large colony, and Breakwater/Gliddon as representative small colonies.

The principal aim of this study was to estimate ASL pup production at Blefuscu Island and Breakwater/Gliddon Reef using the mark-recapture/Cormack-Jolly Seber (CJS) and cumulative mark and count (CMC) approach developed by Goldsworthy et al. (2007c). Because of another research study being undertaken at the same time at Lilliput Island, we decided to incorporate a survey of that colony, adding another large colony to the study. Furthermore, because of its close proximity to Blefuscu Island, and the dispersal capabilities of moulted pups, we anticipated that pup movement between Blefuscu and Lilliput Islands during the breeding season was likely, and therefore it was important to survey both colonies simultaneously.

Shortly into the 2007-08 breeding season, an opportunity to use a helicopter (temporarily based at Ceduna) became available. Additional funds were secured (DEWHAs Migratory

Marine Section) to support helicopter assisted single ground counts of the remaining Nuyts Archipelago breeding colonies (Lounds, Purdie, West and Fenelon Islands) including aerial surveys of a number of haul-out sites, and potential new breeding colonies

This chapter therefore details results from mark-recapture and CJS surveys undertaken at Lilliput and Blefuscu Islands, CMC surveys undertaken at Breakwater Island and Gliddon Reef, single ground counts of pups at Lounds, Purdie, West and Fenelon Islands, and aerial surveys of a number of other islands in the Nuyts Archipelago that may form additional breeding and haul-out sites.

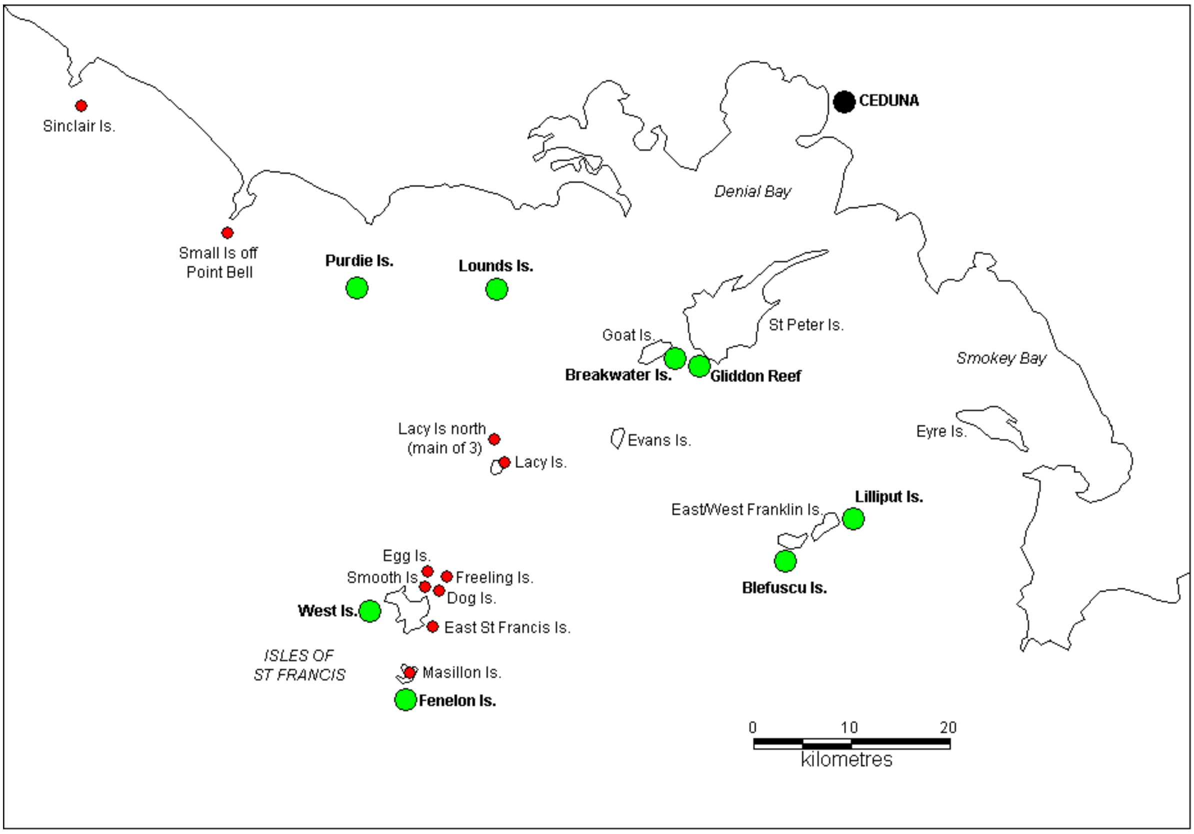


Figure 3.1. Location of Australian sea lion breeding colonies (green circles) and haul-out sites (red circles) in the Nuyts Archipelago, surveyed during 2008.

Methods

Field sites

Lilliput and Blefuscu Islands occur in the eastern Nuyts Archipelago, and are two small islets off East and West Franklin Island, respectively. These Islands were officially named in 2007, and have formerly been referred to as North East and South East Franklin, respectively (Dennis 2005, Shaughnessy et al. 2005).

Pup production

a) *Lilliput and Blefuscu Islands*

The methodological approach to survey pup production followed that developed by Goldsworthy et al. (2007c, 2008b) for large Australian sea lion colonies. The approach was to: 1) undertake live and dead pup surveys based on visual methods to compare with previous surveys; 2) estimate pup production using multiple Petersen estimates throughout the breeding season, adjusting for recovered (cumulative) mortalities; 3) ensure that re-sighting of tagged individual pups did not violate the assumption of equal capture probabilities (Caughley 1977); 4) use individual re-sight data to estimate pup survival and recapture probabilities independently using CJS models. The final estimate of pup production combines the maximum Petersen estimate with survival estimates based upon both recovered cumulative pup mortality and that estimated from re-sight data using CJS models.

During each visit to the islands, sea lion pup numbers were surveyed by direct counting of live pups, surveying of dead pups and by mark-recapture. The methods are summarised below.

Live and dead pup counts

For each visit to Lilliput and Blefuscu Islands, the number of live pups was counted while slowly walking around the islands. The number of dead pups seen was also recorded. The number of dead pups was added to previous counts to give the number of cumulative dead pups. When that number was added to the number of live pups, it gave an estimate of the minimum pup numbers to that date. Pelage patterns of pups were noted to estimate the timing of breeding with black pups considered to be <4 weeks, brown pups approximately 4-20 weeks and moulted >20 weeks age (Shaughnessy et al. 2005).

Petersen estimates

A mark-recapture procedure was used to estimate the number of live pups present during each visit to Lilliput and Blefuscu Islands. During each colony visit a sample of pups was tagged in the trailing edge of each fore-flipper with individually numbered plastic tags (Dalton® Size 1 Supertags). During each field trip, individual re-sight records were collected for marked individuals with the aid of binoculars. All dead pups sighted were recorded and rocks were placed on top of carcases to avoid repeat counting. Records of the total number of tagged, untagged and newly recorded dead pups were noted on each field trip. The numbers of re-sights of individually marked pups on the days prior to recapture surveys were used as the number of ‘marked’ individuals in subsequent recapture events using the Petersen estimate procedure (see below).

During each visit to each island (sessions), individual re-sight records were collected for tagged individuals with the aid of binoculars. Records of the total number of tagged, untagged and newly recorded dead pups were noted on each field trip. Individual re-sights of tagged pups (usually undertaken over a minimum of three days prior to recapture surveys), provided the number of ‘marked’ individuals in the population available for recapture. Pups sighted in subsequent sessions were assumed to be available for sighting in all preceding sessions. During recapture surveys, the individual identity of tagged pups was determined by reading tag numbers with binoculars. The number of untagged pups seen was also recorded as were newly dead pups that had not been marked.

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

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

where *M* is the number of marked pups at risk of being sampled during recapture operations, *n* is the number of pups examined in the recapture sample, and *m* is the number of marked pups in the recapture sample.

The variance of this estimate is calculated as

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

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

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

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

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

Tests for equal catchability

The key assumption of mark-recapture studies is that the probability of capture is the same for all individuals in the population. This was tested within the tagged population by examining the number of times individual pups were re-sighted within each capture session. We used Leslie's test for equal catchability, following methods detailed in Caughley (1977), and for each of the six recapture session examined the number of times known-to-be-alive individuals were re-sighted. We used Leslie's test in favour of the zero truncated Poisson test because it enabled us to use data on zero recaptures (animals known to be alive from subsequent recapture sessions but not sighted). This could be achieved for all but the final recapture session. The assumption in Leslie's test is that if catchability is constant the recapture frequencies will form a binomial distribution. This assumption can be tested as a χ^2 with $(\sum f) - 1$ degrees of freedom, by comparing the observed variance to the expected binomial variance, where

$$\chi^2 = \frac{\sum fi^2 - \frac{(\sum fi)^2}{\sum f}}{\frac{\sum fi}{\sum f} - \frac{\sum n^2}{(\sum f)^2}},$$

and *n* is the number of individually tagged pups re-sighted during each recapture, *i* is the number of times individual pups were re-sighted during recapture sessions and f is the number of individuals re-sighted *i* times (Caughley 1977).

Survival

We used Cormack-Jolly-Seber (CJS) models (Cormack 1964, Jolly 1965, Seber 1970) implemented in program MARK (White & Burnham 1999) to model the survival and recapture (re-sighting) probability (*p*) of pups. Because our surveys identified previously tagged pups that had died during the interval between capture and re-sighting sessions, we employed the joint live-dead modification to the CJS model (Burnham 1993). The classic CJS model only allows for the estimation of apparent survival (ϕ) given that it is confounded by permanent emigration (Burnham 1993). By including information on the confirmed mortality of known individuals (if data is available), the processes of permanent emigration and true mortality can be separated. As such, the joint live-dead CJS model estimates true survival (*S*), the probability of identifying and reporting a dead (marked) individual (*r*), live capture probability (*p*) and the fidelity (*F*) probability (i.e., the probability that a pup remains on the study site for the duration of the mark-recapture program and is available for live recapture given that it is alive). As such, the probability of permanent emigration is 1 – F (Burnham 1993).

Because previous pup production assessments determined that F was approximately equal to 1 (i.e., no permanent emigration, see Goldsworthy et al. (2007c, 2008b), we used the simpler CJS model with live captures only to estimate true survival (ϕ is equivalent to S when F = 1).

b) Breakwater Island and Gliddon Reef

The methodology to survey Breakwater Island and Gliddon Reef followed that described by Goldsworthy et al. (2007c, 2008b) for small colonies, termed the cumulative mark and count (CMC) method. During each visit, attempts were made to mark a number of pups, by clipping a small patch of fur on the rump using scissors. The number of marked, unmarked and dead pups sighted was recorded on each visit to the colony, and where possible, additional pups were marked. Dead pups were covered with rocks to avoid repeat counting on subsequent surveys. Pup numbers were estimated for each visit from the numbers of marked pups and accumulated dead pups, plus the number of live unmarked pups. The last item was estimated in several ways, and the maximum number was used to estimate the number of pups born to date. For the first visit, it was simply the number of unmarked live pups seen. For the latter surveys it was the maximum number of unmarked pups seen in one of the previous surveys, less pups marked since then.

c) Other colonies and haul-out sites in the Nuyts Archipelago

Other breeding colonies, including Lounds, Purdie, West and Fenelon Islands were surveyed once using ground counts, when a helicopter became available for use. Live and dead pup surveys were undertaken, and pups were categorised according to the pelage stage (black, brown and moulted). Haul-out sites and potential new breeding colonies were surveyed from the air during close approach fly-overs. Australian sea lions were counted and categorised either as juveniles, adult females and adult males, and a search was made for pups.

Results

a) *Lilliput Island*

Timing of breeding season

The pupping season at Lilliput Island was already underway during the first visit (session 1) to the Island on 8 November 2007, when 30 live and 1 dead pup were counted (Table 3.1). During that survey, 45% of pups had black pelage (~<4 weeks) and 55% had brown (~4-20 weeks age) and none were fully moulted (Figure 3.2a). On subsequent survey in late January and February, fewer black pelage pups were present, and more pups moved into the brown and moulted stages as they developed. Only 4% of pups were recorded as black on the final survey indicating that the breeding season was essentially over by late February (Figure 3.2).

Marking and absolute counts

A total of 41 pups were marked (tagged) over three sessions (Table 3.1). On each session, the maximum number of unmarked pups counted during surveys of the colony and cumulative mortalities (unmarked and marked) were recorded (Table 3.1, Figure 3.3). This enabled minimum estimates to be calculated for each visit (session) based on: total counted (live), maximum count (total live count plus cumulative dead), and minimum pups (cumulative marked + dead [unmarked] + maximum unmarked counted) (Table 3.1, Figure 3.3). Minimum estimates of pups based on these approaches increased over the three sessions: 34, 56, and 62, respectively (Table 3.1, Figure 3.3). One pup tagged at Blefuscu Island was sighted at Lilliput Island during session two, but none were seen during session one and three (Table 3.1).

Petersen estimates

Results from Petersen estimates of pup abundance undertaken over sessions one, two and three at Lilliput Island are presented in Table 3.1 and 3.3. Estimates suggest that the numbers of pups (including cumulative mortalities) present at Lilliput Island increased from about 35 (95% CL, 33-37) to 58 (95% CL, 55-60) to 64 (95% CL, 60-69) (between sessions one and three (Table 3.1, 3.2, Figure 3.3).

Test for equal catchability

Details from Leslie's test of equal catchability are presented in Table 3.3. Results from all recapture sessions showed no strong evidence that the assumption that the distribution of recaptures was not binomial, therefore supporting the assumption of equal catchability.

Survival

A total of three 'capture' sessions with 41 marked individuals (315 total re-sightings and zero 'marked' dead return) were available for analyses. Given that no tagged dead pups were recovered, and the limited recapture sessions, most parameters including survival (*S*), dead return probability (*r*) and fidelity (*F*) were inestimable. As such the robust design approach could not compute session specific abundances. We therefore chose to use the simpler CJS live-captures only model estimating apparent survival (Ø) and live capture probability (*p*) because when *F* = 1, Ø = *S*. The best-supported models indicated time-invariant Ø (i.e. apparent survival close to 1 for all sessions) and *p* (all sessions). Time-invariant estimates of Ø close to one, suggest that differences in the Petersen estimates between sessions are attributable to new births and/or temporary dispersal of pups, because pup survival was high and there was no support for permanent emigration. It also suggests that estimates of pup production based upon Petersen estimates, and cumulative pup mortality, are likely to provide the best estimates of pup production for the season.

Estimate of pup production

The minimum estimate of pup production at Lilliput Island for the 2007-08 season, based upon the number of marked (tagged) pups, cumulative dead and maximum unmarked pups sighted is 62. The Petersen estimates including cumulative dead pups was 64 (95% CL, 60-69), during the third session (24 February 2008). Based on the number of pups with black (2), brown (18) and moulted pelage (31) in the 24 February survey, the breeding season was essentially over by this date. The minimum estimate of pups based upon the number of marked (tagged) pups, cumulative dead and maximum unmarked pups sighted (62), bound the minimum confidence limits, providing an adjusted Petersen estimate of pup production for Lilliput Island during the 2007-08 breeding season of 64 (95% CL, 62-69).

b) Blefuscu Island

Timing of breeding season

The pupping season at Blefuscu Island was already underway during the first visit (session 1) to the Island on 8 November 2007, when 39 live pups were counted (Table 3.4). The pelage stage of pups was not recorded during this session, but during session two (29 January) most pups were brown (~4-20 weeks age) and moulted (>20 weeks age) suggesting this was the peak in breeding activity, with progressively more moulted pups seen in session three (3 March) and four (2 April) (Figure 3.2). No black pups were sighted during the final session (2 April) indicating the breeding season had ended (Figure 3.2).

Marking and absolute counts

A total of 53 pups were marked (tagged) over four sessions (Table 3.4). On each session, the maximum number of unmarked pups counted during surveys of the colony and cumulative mortalities (unmarked and marked) were recorded (Table 3.4, Figure 3.4). This enabled minimum estimates to be calculated for each visit (session) based on: total counted (live), maximum count (total live count plus cumulative dead), and minimum pups (cumulative marked + dead [unmarked] + maximum unmarked counted) (Table 3.4, Figure 3.2). Minimum estimates of pups based on these approaches over the four sessions were 48, 81, 78 and 51, respectively (Table 3.4), suggesting that the peak in numbers occurred during the second session in late January. Two pups tagged from Lilliput Island were sighted during session three, and three were sighted during session four (Table 3.4)

Petersen estimates

Results from Petersen estimates of pup abundance undertaken over sessions two, three and four at Blefuscu Island are presented in Table 3.4 and 3.5. Estimates of the numbers of pups (including cumulative mortalities) present at Blefuscu Island were 96 (95% CL, 89-103), 82 (95% CL, 74-90) and 55 (95% CL, 50-60), respectively (Table 3.4, 3.5, Figure 3.4). Consistent with the minimum estimates based on cumulative marked, maximum unmarked and cumulative dead pups, the peak in numbers occurred during the second session (late January).

Test for equal catchability

Details from Leslie's test of equal catchability are presented in Table 3.3. Results from all recapture sessions showed no strong evidence that the distribution of recaptures was not binomial, therefore supporting the assumption of equal catchability.

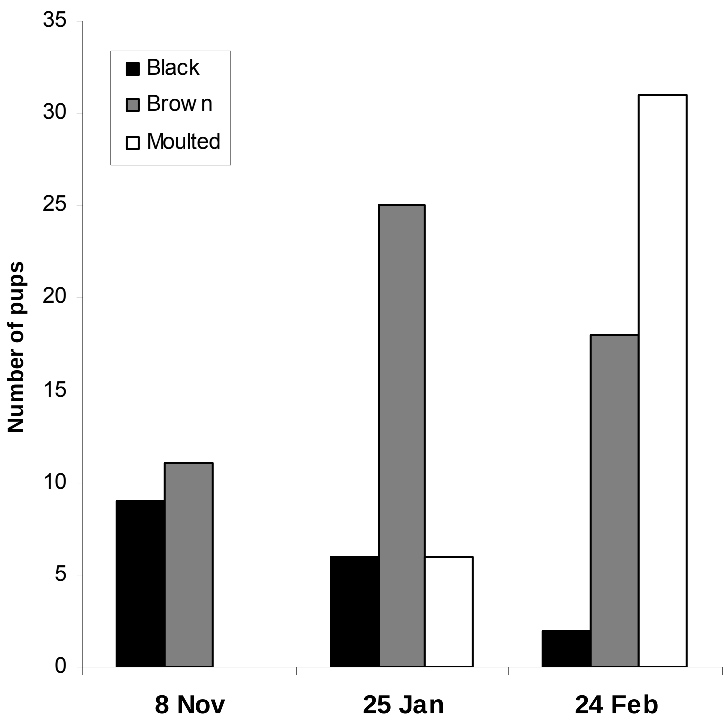
Survival

A total of four 'capture' sessions with 53 marked individuals (379 total re-sightings and one 'marked' dead return) were available for analysis. Given the low number of tagged dead pups recovered, and limited recapture sessions, most parameters including survival (S), dead return probability (r) and fidelity (F) were inestimable. As such the robust design approach could not compute session specific abundances. We therefore chose to use the simpler CJS live-captures only model estimating apparent survival (Ø) and live capture probability (p) because when $F = 1$, Ø = S. The best-supported models indicated time-invariant Ø (i.e. apparent survival close to 1 for all sessions) and p (all sessions). Given time-invariant estimates of Ø were close to one, this suggests that differences in the Petersen estimates between sessions are attributable to new births and/or potential dispersal of pups, because pup survival was high and there was no support for permanent emigration. It also suggests that estimates of pup production based upon Petersen estimates, and cumulative pup mortality are likely to provide the best estimates of pup production for the season.

Estimate of pup production

The minimum estimate of pup production at Blefuscu Island for the 2007-08 season, based upon the number of marked (tagged) pups, cumulative dead and maximum unmarked pups sighted is 81. Petersen estimates, including cumulative dead pups provides an estimate of 96 (95% CL, 89-103), during the second session (29 January 2008). Based on the percentage of pups with black, brown and moulted pelage in the January survey, most pups had been born by this date. However, surveys undertaken on 3 March 2008, noted a three black pups (<4 weeks old), suggesting these were born subsequent to the January surveys. Adding these pups to the final Petersen estimate, gives the best estimate of pup production for Blefuscu Island during the 2007-08 breeding season as 99 (95% CL, 92-106).

A.



B.

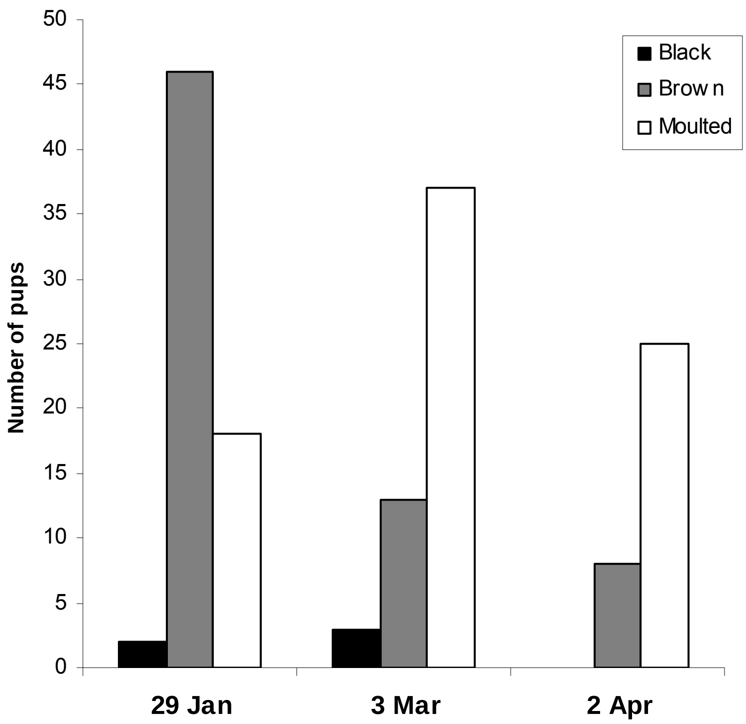


Figure 3.2 The number of Australian sea lion pups recorded with black, brown or moulted pelage during ground surveys at (A) Lilliput and (B) Blefuscu Islands during the 2007-08 surveys.

Table 3.1 Summary of details of Australian sea lion pup marking, counts, known (cumulative) mortalities and various direct counts and Petersen estimates during four visits (sessions) to Lilliput Island between November 2007 and February 2008.

Session	**1**	**2**	**3**
Date	**8-Nov**	**25-Jan**	**24-Feb**
Cumulative marked	20	38	41
Maximum unmarked counted	12	14	18
Maximum count (live)	30	42	51
Tagged pups from Blefuscu Island	0	1	0
Cumulative dead (unmarked)	1	2	2
Cumulative dead (marked)	0	0	0
Total accumulative dead	1	2	2
Maximum count (live) + cumulative dead	31	44	53
Cumulative marked + dead (unmarked) + max unmarked	33	54	61
Petersen Estimate (live)	34	56	62
Petersen Estimate Lower – Upper CL	32-36	53-58	58-67
(No. recapture estimates)	6	6	6
Petersen Estimate (live) + cumulative dead	35	58	64
Lower – Upper CL	33-37	55-60	60-69

Table 3.2 Details of Petersen mark-recapture procedures undertaken at Lilliput Island between November 2007 and February 2008 to estimate the number of live pups present in the population. M = number of marked (tagged) pups in the population, n = the total number of pups sampled and m = the number of marked pups in each recapture sample. N = the estimated pup population size (live only), sd = standard deviation and V = variance. % = the percentage of marked pups in each sample, CV = the coefficient of variance, and Nup and Nlo are the upper and lower 95% confidence limits of each estimate, respectively.

Date	Recapture No.	Marked M	Examined n	M-R m	N	sd	V	%	CV	Nlo	Nup
Session 1											
8-Nov	1	20	25	15	33	2.5	6	60%			
8-Nov	2	20	27	15	36	2.8	8	56%			
8-Nov	3	20	30	18	33	1.5	2	60%			
8-Nov	4	20	27	16	34	2.2	5	59%			
8-Nov	5	20	28	17	33	1.8	3	61%			
8-Nov	6	20	27	15	36	2.8	8	56%			
				Mean	**34**	**1.0**		**59%**	**2.8%**	**32**	**36**
Session 2											
25-Jan	1	38	40	26	58	3.6	13	65%			
25-Jan	2	38	37	25	56	3.6	13	68%			
25-Jan	3	38	39	27	55	3.0	9	69%			
26-Jan	4	38	39	27	55	3.0	9	69%			
26-Jan	5	38	42	28	57	3.1	9	67%			
26-Jan	6	38	42	29	55	2.7	7	69%			
				Mean	**56**	**1.3**		68%	**2.3%**	**53**	**58**
Session 3											
24-Feb	1	37	32	18	65	7	46	56%			
25-Feb	2	37	39	23	62	5	24	59%			
25-Feb	3	37	43	25	63	4	20	58%			
25-Feb	4	37	33	20	61	5	29	61%			
25-Feb	5	37	34	20	62	6	33	59%			
25-Feb	6	37	36	22	60	5	23	61%			
				Mean	**62**	**2**		**59%**	**3.5%**	**58**	**67**

Table 3.3 Leslie's test for equal catchability across each recapture session at Lilliput Island. *m* is the number of individually tagged pups re-sighted during each recapture, *i* is the number of times individual pups were re-sighted during recapture session and *f* is the number of individuals re-sighted *i* times. Chi-squared (χ^2) and degrees of freedom (df) values are also given. High probabilities (*P*) indicate equal catchability.

Session No.	Recapture No.	*m*	m^2	*i*	*f*	*fi*	fi^2	χ^2	df	*P*
2	1	25	625	0	0	0	0			
	2	27	729	1	4	4	4			
	3	27	729	2	5	10	20			
	4	28	784	3	5	15	45			
	5	29	841	4	13	52	208			
				5	11	55	275			
	∑	136	3708		38	136	552	0.076	37	>0.05
3	1	30	900	0	4	0	0			
	2	19	361	1	2	2	2			
	3	24	576	2	3	6	12			
	4	26	676	3	7	21	63			
	5	22	484	4	6	24	96			
	6	21	441	5	5	25	125			
	7	24	576	6	10	60	360			
				7	4	28	196			
	∑	166	4014		41	166	854	0.045	40	>0.05

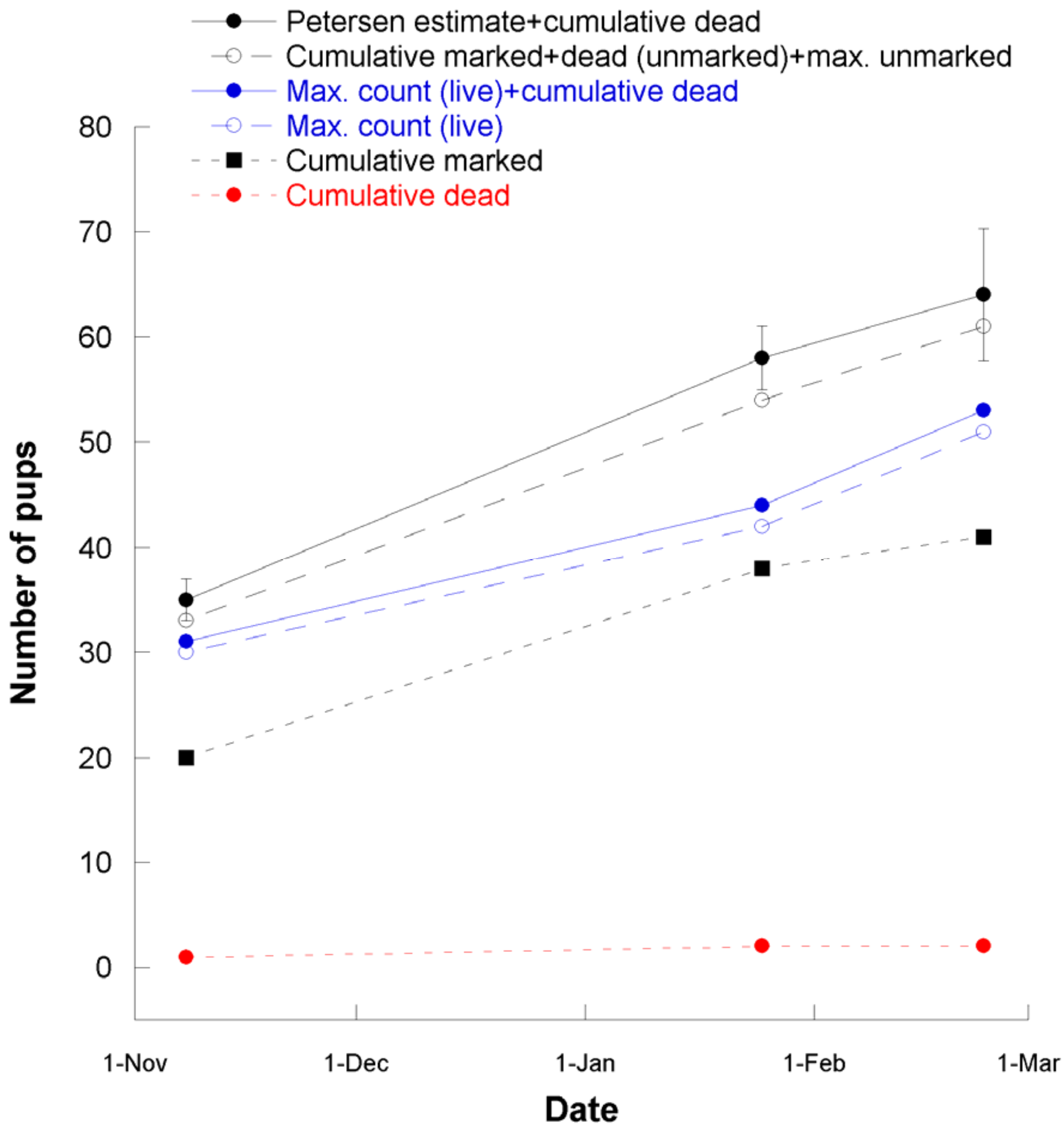


Figure 3.3 Trends in pup numbers at Lilliput Island between November 2007 and March 2008, including cumulative dead, cumulative marked (tagged), maximum counted, and estimated pup production (± 95% CL) from Petersen estimates.

Table 3.4 Summary of details of Australian sea lion pup marking, counts, recovered mortalities and various direct counting abundance and Petersen estimates during five sessions at Blefuscu Island between November 2007 and April 2008.

Session	**1**	**2**	**3**	**4**
Date	**8-Nov**	**29-Jan**	**3-Mar**	**2-Apr**
Cumulative marked	20	53	53	53
Maximum unmarked counted	28	27	18	14
Maximum count (live)	39	66	53	33
Tagged pups from Lilliput Island	0	0	2	3
Cumulative dead (unmarked)	0	1	3	3
Cumulative dead (marked)	0	1	1	1
Total accumulative dead	0	2	4	4
Maximum count (live) + cumulative dead	39	68	57	37
Cumulative marked + dead (unmarked) + max unmarked	48	81	74	70
Petersen Estimate (live)		94	78	51
Petersen Estimate Lower – Upper CL		87-101	70-86	46-56
(No. recapture estimates)		6	6	6
Petersen Estimate (live) + cumulative dead		96	82	55
Lower – Upper CL		89-103	74-90	50-60

Table 3.5 Details of Petersen mark-recapture procedures undertaken at Blefuscu Island between January and April 2008. M = number of marked (tagged) pups in the population, n = the total number of pups sampled and m = the number of marked pups in each recapture sample. N = the estimated pup population size, sd = standard deviation and V = variance. % = the percentage of marked pups in each sample, CV = the coefficient of variance, and Nup and Nlo are the upper and lower 95% confidence limits of each estimate, respectively.

Date	Recapture No.	Marked M	Examined n	M-R m	N	sd	V	%	CV	Nlo	Nup
Session 2											
29-Jan	1	48	52	29	86	6	41	56%			
29-Jan	2	48	46	24	91	9	75	52%			
29-Jan	3	48	48	23	99	10	104	48%			
29-Jan	4	48	47	20	111	14	183	43%			
29-Jan	5	48	51	29	84	6	38	57%			
30-Jan	6	48	55	28	94	8	59	51%			
				Mean	**94**	**7.7**		**51%**	**4.0%**	**87**	**101**
Session 3											
3-Mar	1	43	35	17	87	11	120	0%			
3-Mar	2	43	34	18	80	9	85	49%			
3-Mar	3	43	28	15	79	10	107	53%			
3-Mar	4	43	25	14	75	10	101	54%			
4-Mar	5	43	33	19	74	8	60	56%			
4-Mar	6	43	26	15	73	9	84	58%			
				Mean	**78**	**3.9**		54%	**5.0%**	**70**	**86**
Session 4											
2-Apr	1	34	29	15	65	8	64	52%			
2-Apr	2	34	29	16	61	7	47	55%			
2-Apr	3	34	27	14	64	8	71	52%			
3-Apr	4	34	12	11	37	2	6	92%			
3-Apr	5	34	12	12	34	0	0	100%			
3-Apr	6	34	22	16	46	4	17	73%			
				Mean	**51**	**2**		**71%**	**4.7%**	**46**	**56**

Table 3.6 Leslie's test for equal catchability across each recapture session at Blefuscu Island. *m* is the number of individually tagged pups re-sighted during each recapture, *i* is the number of times individual pups were re-sighted during recapture session and *f* is the number of individuals re-sighted *i* times. Chi-squared (χ^2) and degrees of freedom (df) values are also given. High probabilities (*P*) indicate equal catchability.

Session No.	Recapture No.	*m*	m^2	*i*	*f*	*fi*	fi^2	χ^2	df	*P*
2	1	28	784	0	7	0	0			
	2	23	529	1	10	10	10			
	3	23	529	2	12	24	48			
	4	20	400	3	6	18	54			
	5	16	256	4	8	32	128			
	6	17	289	5	5	25	125			
				6	3	18	108			
	∑	127	2787		51	127	473	0.056	50	>0.05
3	1	24	576	0	0	0	0			
	2	17	289	1	3	3	3			
	3	18	324	2	9	18	36			
	4	15	225	3	7	21	63			
	5	14	196	4	4	16	64			
	6	19	361	5	3	15	75			
	7	15	225	6	7	42	252			
				7	1	7	49			
	∑	122	2196		34	122	542	0.048	33	>0.05
4	1	19	361	0	0	0	0			
	2	12	144	1	5	5	5			
	3	7	49	2	6	12	24			
	4	15	225	3	6	18	54			
	5	16	256	4	6	24	96			
	6	14	196	5	7	35	175			
	7	11	121	6	1	6	36			
	8	12	144	7	2	14	98			
	9	16	256	8	1	8	64			
				9	0	0	0			
	∑	122	1752		34	122	552	0.065	33	>0.05

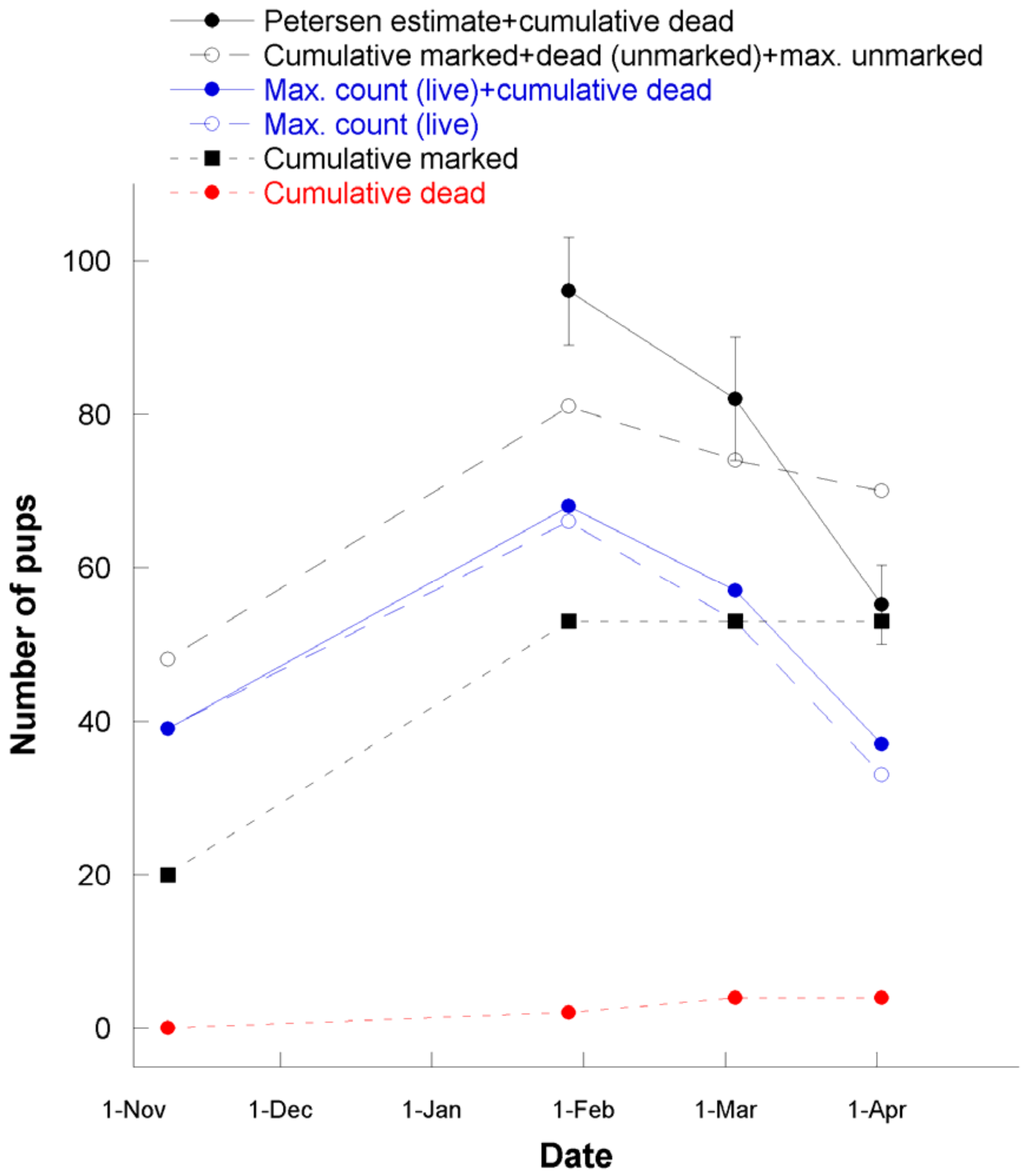


Figure 3.4 Trends in pup numbers at Blefuscu Island between November 2007 and April 2008 2007, including cumulative dead, cumulative marked (tagged), maximum counted, and estimated pup production (± 95% CL) from Petersen estimates.

Table 3.7 Details of Australian sea lion pup surveys undertaken at Breakwater Island and Gliddon Reef 5 March 2008.

	Pup pelage stage				
	Black	Brown	Moulted	Dead	Total
Breakwater Island	3	10	2	0	15
Gliddon Reef	2	2	3	0	7
Total	5	12	5	0	22

Table 3.8 Details of Australian sea lion pup surveys undertaken at Lounds, West, Fenelon and Purdie Islands in the Nuyts Archipelago on 7 April 2008. Pelage stage of pups is also noted.

	Pup Pelage Stage				
	Black	Brown	Moulted	Dead	Total Pups
Lounds Island		18	16		34
West Island	3	19	15	2	39
Fenelon Island[1]	1	19	20		40
Purdie Island	2	23	63	7	95

[1] 6 New Zealand fur seals pups also sighted.

Table 3.9 The numbers of juvenile (Juv), adult female (AF), subadult male (SAM), adult male (AM) and unclassed (Unclass) Australian sea lions counted during aerial surveys of haul-out sites in the Nuyts Archipelago on 7 April 2008. The numbers of New Zealand fur seals seen is also noted.

	Australian sea lion						New Zealand
	Juv	AF	SAM	AM	Unclass	Total	Fur seals
East St Francis	2	2				4	
Dog Is	10	4	1	2		17	5
Freeling Island	3	2		1		6	12
Smooth Is	1					1	
Egg Is	1					1	
Lacy Is	18			1		19	2
Lacy Is north (main of 3)	4					4	
Sinclair Is	27	6		11		44	
Small Is off Pt Bell	0	0	0	0		0	
Masillon Is					15	15	*

* small numbers of New Zealand fur seals hauled-out, but numbers not determined.

c) Breakwater Island/Gliddon Reef

Three attempts were made to land at Breakwater Island and Gliddon Reef and undertake Australian sea lion pup surveys (30 January, 5 March and 4 April 2008). Due to sea conditions, landing on these small islets was only possible on one of these occasions (5 March 2008). A total of 15 pups were counted on Breakwater Island, and seven on Gliddon Reef (Table 3.7). Given mostly brown pups and similar numbers of black and moulted pups, suggest the survey was undertaken approximately mid-way through the breeding season. One pup tagged at Blefuscu was sighted at Gliddon Reef on 5 March, and was not included in the survey results for Gliddon Reef.

d) Other colonies and haul-out sites in the Nuyts Archipelago

A helicopter survey of other Australian sea lion islands in the Nuyts Archipelago was undertaken on 7 April 2008. Ground surveys where pups were counted were undertaken at four breeding colonies (Lounds, West, Purdie and Fenelon islands). Details are presented in Table 3.8. Based on the pelage stage of pups the breeding season had recently ended on all islands surveyed. Aerial surveys of a number of haul-out sites were also undertaken (Table 3.9); no pups were sighted on any of the islands.

Discussion

a) Lilliput and Blefuscu Islands

The results presented in this report provide the most complete pup production estimates for Lilliput and Blefuscu Islands to date, and the first estimates bounded by confidence limits. The estimates for pup production for the 2007-08 breeding season were 64 (95% CL, 62-69) for Lilliput Island, and 99 (95% CL, 92-106) for Blefuscu Island. There is very limited data available on the numbers of pups at these colonies (Dennis 2005). Surveys (ground counts) were undertaken on three occasions on each island during the 2005 breeding season (10 January, 10 March and 6 April), with a maximum of 67 and 84 pups counted for Lilliput and Blefuscu Islands, respectively (Goldsworthy et al. in press-b). The only other estimates of pup numbers for these islands are from a single visit to each in October 1990 when 46 and 75 pups, respectively, were counted (Gales et al. 1994). Comparison of maximum counts plus cumulative dead pups for the 2007-08 pupping season, with those for 2005, are 67 (in 2007-

08) and 53 (in 2005) for Lilliput Island, and 84 and 68 for Blefuscu Island, a decline of 20.9% and 19.0%, respectively.

Given the proximity of Lilliput and Blefuscu islands to each other (~5.6km), movement of pups between islands is expected, especially as the breeding season progresses, and pups moult. Such movement between colonies has the potential to undermine assumptions of the Petersen estimate, namely that no animal immigrates into the study area between marking and recapturing (Caughley 1977). Given that a total of 94 pups were tagged on both islands, and that only four individuals were sighted on the other island during surveys, and none during those surveys when maximum numbers of pups were reported, suggests that movement between islands during the breeding season by pups is limited, and based on the 200708 survey, unlikely to have invalidated the survey method or affected the accuracy of the results.

b) Breakwater Island and Gliddon Reef

Single surveys were undertaken at Breakwater and Gliddon Reefs during the 2007-08 breeding season. Despite three attempts to land on each island, only one shore visit and ground survey was possible, indicating a minimum of 15 and 7 pups, respectively. Previous ground surveys undertaken at Breakwater Island in February 2004 and June 2005, recorded 7 and 17 pups, respectively (Shaughnessy 2004, Goldsworthy et al. in press-b). Gliddon Reef was only identified as a breeding colony in February 2005, a shore visit then counted 7 pups (Goldsworthy et al. in press-b). Given these colonies are <3 km apart, it is unclear if they represent discrete subpopulations, or if breeding females move between them forming a single subpopulation.

c) Other colonies and haul-out sites in the Nuyts Archipelago

The 2007-08 breeding season represents the first time in which all colonies within the Nuyts Archipelago have been surveyed at least once within a breeding season (Table 3.10). Furthermore, ten other location have been confirmed as haul-outs, and one previously suspected breeding colony (Masillon Island) has been confirmed as a haul-out site only. Comparison of the 2007-08 pup count data with previous surveys are presented in Table 3.10. Information is sporadic, with the most comprehensive surveys undertaken in 1990 (Gales et al. 1994), 2005 (Goldsworthy et al. in press-b), and 2007-08 (this study)(Table 3.10). Breakwater Island and Gliddon Reefs were only confirmed as breeding colonies in 2005 by the presence of brown pups (Goldsworthy et al. in press-b), and as such do not appear in any previous surveys. Given that most surveys undertaken represent ground counts that are subject to biases and may not have been timed optimally relative to the breeding season; numbers of pups listed in Table 3.10 represent minimum numbers (with the exception of Lilliput and Blefuscu Island estimates 2007-08 season), and trends in abundances are not able to be assessed. Based on the most recent survey (393 pups), pup production for the entire Nuyts Archipelago is likely to exceed 400 pups.

Table 3.10 Numbers of Australian sea lion pups estimated at the eight breeding colonies within the Nuyts Archipelago from surveys undertaken between 1977 and 2008. Timing of the surveys and the data sources are given as footnotes. Unless otherwise indicated, all surveys represent single visit ground surveys; dashes indicate no survey was undertaken. Totals among colonies are only presented for the three most complete surveys.

Breeding colony	1977[1,2]	1982[2]	1990[3]	1992[4]	1995[5]	2002[6]	2004-05[7]	2007-08[8]
Lilliput Is.	-	-	46	-	-	-	67[A]	64[A,B]
Blefuscu Is.	-	-	75	-	-	-	84[A]	99[A,B]
Breakwater Is.	-	-	-	-	-	-	17 [A]	15
Gliddon Reef	-	-	-	-	-	-	7	7
Lounds Is.	5	-	26	16	4	-	-	34
Purdie Is.	-	-	112	65	34	-	132	95
West Is.	-	-	14	-	18	-	56[A]	39
Fenelon Is.	-	8	21	-	9	19	10	40
Totals			294				373	393

[1]October 1977 (Ling & Walker 1979, Dennis 2005)
[2]April 1992 (Robinson et al. 1996)
[3]September, November 1990 (Gales et al. 1994)
[4]February 1992 (Dennis 2005)
[5]August 1995 (Shaughnessy et al. 2005)
[6]September 2002 (Robinson et al. 2003)
[7]November 2004; January-July 2005 (Goldsworthy et al. in press-b)
[8]November 2007, January-April 2008 (This study)
[A]Multiple (2-4) ground surveys within one breeding season
[B]Estimates based on mark-recapture procedures.

4 PUP PRODUCTION AT DANGEROUS REEF AND ENGLISH ISLAND, SOUTHERN SPENCER GULF

Introduction

The population of Australian sea lions at Dangerous Reef is the largest for the species. Pup abundances have been estimated at Dangerous Reef since 1994. Between 1994 and 1999 pup abundances have been monitored by counting pups. Since 1999, monthly counts through the breeding season in conjunction with mark-recapture methods have used to estimate pup production. Mark-recapture provides a more robust means to obtain estimates of pup production because the method enables the calculation of confidence intervals around each estimate. This method has now been used for four breeding seasons at Dangerous Reef. During the 2006-07 breeding season, pup production was estimated to be 708 (95% CL 632-779) (Goldsworthy et al. 2007a). The exponential rate of increase in pup production from 1999 until 2006-07, based on maximum live-pup counts plus cumulative mortality and mark-recapture methods, ranged between 6.7-9.9% per breeding season, or 4.4-6.4% per year (Goldsworthy et al. 2007a). This provides further evidence of strong positive growth in the population, which has been occurring since 2000.

Australian sea lion pup abundances have been surveyed at English Island over six breeding seasons. Between 1998 and 2002, between four and 15 pups were recorded (Shaughnessy 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. in press-b).

Methods

a) Field sites

Dangerous Reef (34.870 S, 136.2170 E) is 35 km south-east of Port Lincoln and forms part of the Sir Joseph Banks Group Conservation Park (Figure 3.1). It comprises Main Reef with nearby East Reef and West Reef. They cover about 12 ha in area (Robinson et al. 1996). Sea lion pups are born on Main Reef, and some of them move to West Reef several weeks after birth. Dangerous Reef was accessed by vessel from Port Lincoln, between 2 February 2008 and 28 August 2008. Four trips to the island were made over this period. During each visit to the island, sea lion pup numbers were surveyed by direct counting of live pups, surveying of dead pups and for three of the visits to the island by mark-recapture. Methodology for these approaches is detailed below.

English Island (34.638 S, 136.196 E) is a small rocky island that forms part of the Sir Joseph Banks Group and is 1.2 km east-north-east of Sibsey Island. Australian sea lion pups were surveyed on two occasions, 21 May and 23 June 2008.

b) Live and dead pup counts

The number of live pups was counted while slowing walking around the island, taking care not to disturb animals on the top of the island, to reduce the chance of double counting. After counting around the periphery of the island, the counters walked through the centre of the island to count the pups.

We recorded the number of pups that had died since the previous visit. To avoid double counting, dead pups were sprayed with paint or covered with rocks when they were counted. The number of dead pups was added to give the number of ‘accumulated dead pups’. When that number was added to the number of live pups, it gave the best available estimate of pup production to that date.

c) Mark-recapture/Equal catchability and CJS

Mark-recapture, test for equal catchability and CJS analyses followed those detailed in Chapter 3.

d) Survival

Details of calculating survival, fidelity and recapture probability using Comack-Jolly-Seber methods are detail in Chapter 3.

e) Cumulative Mark and Count

The methodology to survey English Island followed that described by Goldsworthy et al. (2007c) for small colonies, termed the cumulative mark and count (CMC) method. During each visit, attempts were made to mark a number of pups, by clipping a small patch of fur on the rump using scissors. The number of marked, unmarked and dead pups sighted was recorded on each visit to the colony, and where possible, additional pups were marked. Dead pups were covered with rocks to avoid repeat counting on subsequent surveys. Pup numbers were estimated for each visit from the numbers of marked pups and accumulated dead pups, plus the number of live unmarked pups. The last item was estimated in several ways, and the maximum number was used to estimate the number of pups born to date. For the first visit, it was simply the number of unmarked live pups seen. For the latter surveys it was the maximum number of unmarked pups seen in one of the previous surveys, less pups marked since then.

f) Trends in abundance

The rate of change in pup numbers was calculated using linear regression of the natural logarithm of the mean estimate of pup numbers against year or breeding season (~1.5 years). The exponential rate of increase (*r*) is the slope of the regression line. An exponential rate of increase has been demonstrated for other seal species, for example the New Zealand fur seal on Kangaroo Island (Shaughnessy et al. 1995). It can be expressed as a percentage increase using the following formula $(e^r-1) * 100$.

Results

a) Dangerous Reef

Pup counts

On the first visit to Dangerous Reef on 2 February 2008, 3 live pups were recorded, indicating that the breeding season had commenced by the beginning of February. On 21 November 2008, approximately 6 young brown pups were sighted (A. Lowther pers. comm.), although no systematic counts were undertaken. These observations suggest that the duration of the breeding season for 2008 was at least 9 months. Counts of live and dead pups surveyed at Dangerous Reef during the 2008 pupping season are presented in Table 4.1 and Figure 4.1. The largest estimate of pups based on counts of cumulative tagged (201), cumulative dead untagged pups (201) and maximum untagged pups (135) was 537 on 26 August 2008. This does not include an unknown number of pups that would have been born after 26 August 2008.

Mark-recapture estimates of pup numbers

The mark-recapture estimate procedure utilised 201 tagged pups. Re-sights of these tagged pups over several days prior to recapture surveys were used to provide a pool of tagged pups for each recapture session. Pups sighted in future surveys (known to be alive) were included as being available for re-sighting in previous recapture sessions. The number of tagged pups available to be re-sighted varied considerably between surveys (109-170, Table 4.2). Mark-recapture estimates of the number of live pups were the greatest during the first session (mean 334, 95% CL 322-346), and then progressively declined in the second (mean

331, 95% CL 315-347) and third recapture sessions (mean 289, 95%CI 275-304, Table 4.2, Figure 4.1). Adding accumulative dead pups to these values provided the reverse pattern of increasing estimates of 399 (95% CL 387-411), 493 (95% CL 447-509) and 520 pups (95% CL 509-535), respectively, highlight the significant pup mortality during this breeding season (Table 4.1, Figure 4.1).

Comparisons of mark-recapture estimates with direct counts at Dangerous Reef have now been made over five breeding seasons (Table 4.3). Mark-recapture estimates were between 1.19 and 1.38 times the direct count of pups (95% confidence limits of comparisons range from 1.12 to 1.45). This indicates the comparison of mark-recapture estimates with direct counts of pups were similar in the five pupping seasons. The discrepancy between the direct counts and the mark-recapture 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.

Equal catchability

Results from Leslie's test of equal catchability are presented in Table 4.4. Results from the second and third recapture sessions were non-significant, indicating that the assumption that the distribution of recaptures was binomial and that catchability of tagged pups was equal is supported.

Survival

A total of three 'capture' sessions with 201 marked individuals (901 total re-sightings and 30 'marked' dead return) were available for analyses. Given the limited recapture sessions, most parameters were inestimable. As such the robust design approach could not compute session specific abundances. We therefore chose to use the simpler CJS live-captures only model estimating apparent survival (*Ø*) and live capture probability (*p*) because when $F = 1$, $Ø = S$. The best-supported models indicated support for time dependency in survival (session 1: 0.897; session 2: 0.821; session 3: not inestimable), essentially because the final session estimate was very low, but inestimable. The estimated constant mean survival was 0.823 (95% CL 0.802 – 0.843) per 30 day period. Fidelity (F) was 1.000, indicating that all animals were available for re-sighting from one session to the next, if alive. This suggests that differences in the Petersen estimates between sessions are attributable to new births and deaths, and temporary dispersal of pups, as there was no support for permanent emigration. It also suggests that estimates of pup production based upon Petersen estimates, and cumulative pup mortality are likely to provide the best estimates of pup production for the season.

Estimate of pup production

The minimum estimate of pup production at Dangerous Reef for the 2008 season, based upon the number of marked (tagged) pups, cumulative dead and maximum unmarked pups sighted is 537 (based on 201 tagged pups, 135 untagged pups and 201 cumulative dead pups). This is comparable to the Petersen estimates of 520 pups (95% CL 509-535) also in the fifth month of breeding (August 2008). The higher of these estimates is 537, although this is an underestimate as some pups were likely to have been born between the final survey in August, and the estimated end of the breeding season in November.

Trends in abundance at Dangerous Reef

Live and dead pup surveys

For the Dangerous Reef Australian sea lion population, estimates of pup numbers by direct counting are available for 13 pupping seasons from 1975 to 2008, and range from 248 to 585 with an average of 403 (sd = 116) (Table 4.5, Figure 4.2).

Because dead pups were not counted in the 1994-95 season, the number of live pups in that season has been adjusted to estimate the number of births (Table 4.4, see Shaughnessy (2005b). Using the maximum live-pup counts and numbers of cumulative dead pups over these 13 breeding seasons (1975 to 2008) as an index of pup production, the number of pups born at Dangerous Reef has increased at an exponential rate of r = 0.029 or 3.0% per breeding season (~ 1.5 years) or r= 0.019 or 2.0% per year. The trend is significant for both season and year (both linear regressions, $F_{1,12}$ =10.073, P=0.009, R^2=0.478).

Data from three pupping seasons are considerably smaller than the others: 262 pups in 1976-77, 260 in 1990 and 248 in 1997-98 (Figure 4.2). Each of these counts was made in the fourth month after pupping began, whereas maximum counts for all but one of the other seasons were made in the fifth month or later (Table 4.5). Counting that ended in the fourth month of a pupping season is likely to underestimate pup production considerably. Data for the1994-95 season were incomplete, did not include counts of dead pups and were adjusted for mortality based on the averages from the preceding three seasons (Table 4.5). The most accurate pup count data have been collected since 1996. Analyses of eight pupping seasons from 1996 (excluding 1997-98), indicate that pup counts have increased at r = 0.066 or 6.9% per breeding season, equivalent to *r* = 0.044 or 4.5% per year. This is the best interpretation of these data and the increasing trends are significant (both linear regressions, $F_{1,7}$ =33.475, P=0.001, R^2=0.848) (Figure 4.2).

Mark-recapture surveys

Mark-recapture estimates for live pups plus cumulative dead pups to the time of survey, have been undertaken over five breeding seasons (1995 to 2008, Table 4.3). Trend data for the five seasons show an increase between seasons of r = 0.057 or 5.9% per season, which is equivalent to r = 0.038 or 3.9% increase per year (Figure 4.2). With the drop in pup numbers during the 2008 season, and with the limited time series of mark-recapture data, these trends are not significant (both linear regressions, $F_{1,4}$ =2.943, P=0.185, R^2=0.495).

Pup mortality

For the 2008 pupping season at Dangerous Reef, 231 dead pups were recorded by 26 August when the estimated number of births reached a maximum of 537, giving an incidence of pup mortality of 43.0% for the 2008 breeding season (Table 4.5).

For the last nine pupping seasons at Dangerous Reef (since 1996), the incidence of pup mortality has ranged from 15.3% to 44.6% (Table 4.5, Figure 4.2). It was high for pupping seasons that occurred predominantly in winter (30.3% in 1996, 42.0% in 1999, 44.6% in 2002 and 31.1% in 2005, 43.0% in 2008, with unweighted average 38.2%) and lower for pupping seasons that occurred predominantly in summer (15.3% in 1997-98, 22.9% in 2000-01, 18.6% in 2003-04, and 13.9% in 2006-07 with unweighted average 17.7%). For this analysis, data for pupping seasons before 1996 have been omitted because insufficient attention had been directed at dead pups. A one-way ANOVA comparing the mortality rate between summer and winter breeding seasons, indicated that mortality rates (proportion of dead pups) were significantly higher in winter breeding seasons ($F_{1,7}$ =26.442, P=0.0013, arcsine transformed data).

Despite variable and often high rates of pup mortality between season, the minimum number of live pups (maximum pup count – maximum cumulative dead pups), still showed a significant increase between seasons (r = 0.063, 6.5%) and year (r = 0.044, 4.3%) using data from 1996 (both linear regressions, $F_{1,8}$ =6.592, P=0.037, R^2=0.485) (Figure 4.2).

Table 4.1. Summary of details of Australian sea lion pup counts, tagging, cumulative mortalities and various direct count and mark-recapture abundance estimates during 4 visits (sessions) to Dangerous Reef between February and August 2008.

Session		**1**	**2**	**3**
Date	**2-Feb**	**20-May**	**25-Jun**	**26-Aug**
Cumulative tagged		170	201	201
Maximum untagged counted	3	109	99	135
Maximum count (live)	3	270	242	210
Cumulative dead (un-tagged)	0	65	146	201
Cumulative dead (tagged)	0	0	16	30
Total accumulative dead	0	65	162	231
Maximum count (live) + cumulative dead	3	335	404	441
Cumulative tagged + dead (unmarked) + max un-tagged	3	344	446	537
Petersen Estimate (live)		334	331	289
Petersen Estimate Lower–Upper CL		322-346	315-347	275-304
(No. recapture estimates)				
Petersen Estimate (live) + cumulative dead		399	493	520
Lower–Upper CL		387-411	447-509	506-535

Table 4.2. Details of Petersen mark-recapture procedures undertaken at Dangerous Reef between May and August 2008. 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 s = variance. % = the percentage of marked pups in each sample, CV = the coefficient of variation. The lower and upper 95% confidence limits (CL)of each estimate, respectively.

Date	Recapture No.	Marked M	Examined n	M-R m	N	sd	s	%	CV	Nlo	Nup
Session 1											
20-May	1	170	207	111	317	12	142	54%			
20-May	2	170	156	87	304	15	223	56%			
20-May	3	170	203	110	313	12	141	54%			
20-May	4	170	220	111	336	13	171	50%			
20-May	5	170	184	79	394	24	583	43%			
20-May	6	170	218	109	339	14	185	50%			
				Mean	**334**	**6**		**51%**	**1.9%**	**322**	**346**
Session 2											
26-Jun	1	151	175	79	333	19	357	45%			
26-Jun	2	151	184	89	311	15	225	48%			
26-Jun	3	151	131	56	351	28	759	43%			
26-Jun	4	151	160	72	334	21	431	45%			
26-Jun	5	151	180	87	312	15	238	48%			
26-Jun	6	151	175	76	346	21	430	43%			
				Mean	**331**	**8**		46%	**2.5%**	**315**	**347**
Session 3											
26-Aug	1	110	216	81	293	13	169	38%			
26-Aug	2	110	191	70	299	17	284	37%			
26-Aug	3	110	174	70	273	15	223	40%			
27-Aug	4	109	183	74	269	13	181	40%			
27-Aug	5	109	210	77	297	14	206	37%			
27-Aug	6	109	181	62	317	21	441	34%			
27-Aug	7	109	197	86	249	9	83	44%			
27-Aug	8	109	191	71	292	16	254	37%			
27-Aug	9	109	170	56	329	25	603	33%			
28-Aug	10	108	188	73	277	14	202	39%			
				Mean	**289**	**5**		**38%**	**2.5%**	**275**	**304**

Table 4.3. Summary of mark-recapture estimates of the abundance of Australian sea lion pups at Dangerous Reef over four breeding seasons, highlighting comparison between mark-recapture estimates and live pup counts. For the 2006/07 season comparisons between methods can be made for two of the three mark-recapture estimates.

Date	Max. direct count (inc. dead)	Direct count of pups	Mark-recapture estimate of pups	Comparison	95% confidence interval	No. month since pupping commence to		Source
						Max count	Mark-recapture estimate	
July 1999	383	240	285	1.19	1.12 to 1.25	4	4	(Shaughnessy & Dennis 1999)
Jan 2004	499	333	423	1.27	1.21 to 1.31	5.5	5	(Shaughnessy 2004)
July 2005	585	272	326	1.20	1.15 to 1.25	6	6	(Shaughnessy 2005a)
Nov 2006	397	330	436	1.32	1.26 to 1.38	4	4	(Goldsworthy et al. 2007b))
Jan 2007	575	495	629	1.27	1.12 to 1.42	6	6	(Goldsworthy et al. 2007b)
Aug 2008	537	210	289	1.38	1.31 to 1.45	6-7	6-7	This report

Table 4.4. Leslie's test for equal catchability across each recapture session at Dangerous Reef. *m* is the number of individually tagged pups resighted during each recapture, *i* is the number of times individual pups were resighted during recapture session and *f* is the number of individuals resighted *i* times. Chi-squared (X^2) and degrees of freedom (df) values are also given. Non-significant (NS), probability (*P)* values indicate equal catchability.

Session No.	Recapture No.	*m*	m^2	*i*	*f*	*f. i*	$f.i^2$	X^2	df	*P*
2	1	48	2304	0	66	0	0			
	2	22	484	1	39	39	39			
	3	30	900	2	21	42	84			
	4	32	1024	3	18	54	162			
	5	27	729	4	8	32	128			
	6	18	324	5	2	10	50			
				6	0	0	0			
	Σ	177	5765		154	177	463	0.045	153	>0.05
3	1	58	3364	0	17	0	0			
	2	74	5476	1	12	12	12			
	3	53	2809	2	25	50	100			
	4	60	3600	3	18	54	162			
	5	60	3600	4	21	84	336			
	6	44	1936	5	18	90	450			
	7	65	4225	6	11	66	396			
				7	0	0	0			
	Σ	414	25010		122	356	1456	0.017	121	>0.05

Table 4.5. Estimated number of births of Australian sea lions at Dangerous Reef, South Australia for 13 pupping seasons between 1975 and 2008. Data are collated from Dennis (2005), Shaughnessy and Dennis (2001) and (2003), Shaughnessy (2004) and (2005a), Goldsworthy et al. (2007a) 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 (2005).

Pupping season	Cumulative dead pups at max. live 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	231	537	43.0	6-7	231

[a] 'Cumulative dead pups' refers to the number of dead pups counted through to the maximum live 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.

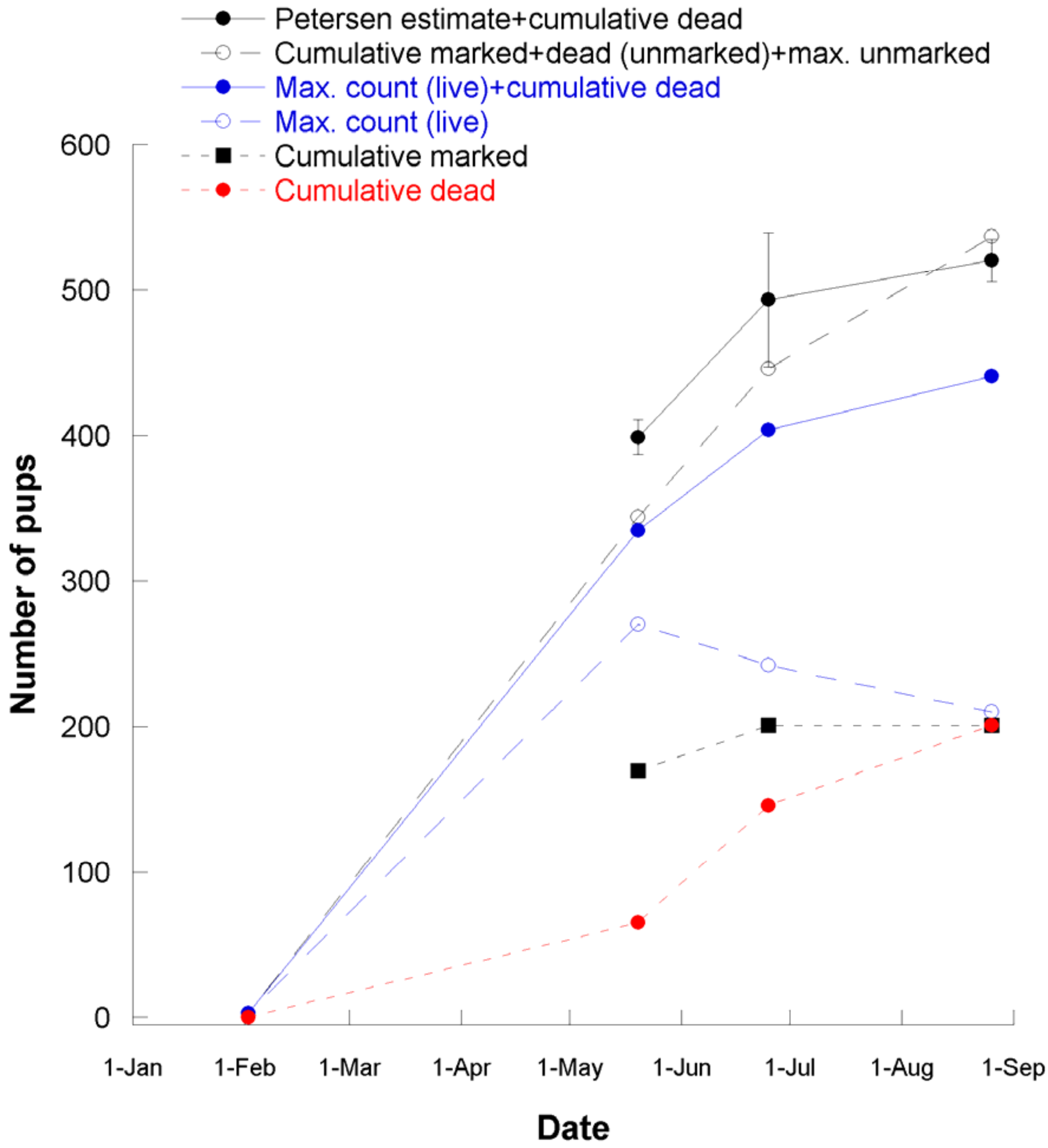


Figure 4.1. Trends in pup numbers at Dangerous Reef between February and August 2008, including cumulative dead, cumulative marked (tagged), maximum counted, and estimated pup production (± 95% CL) from Petersen estimates.

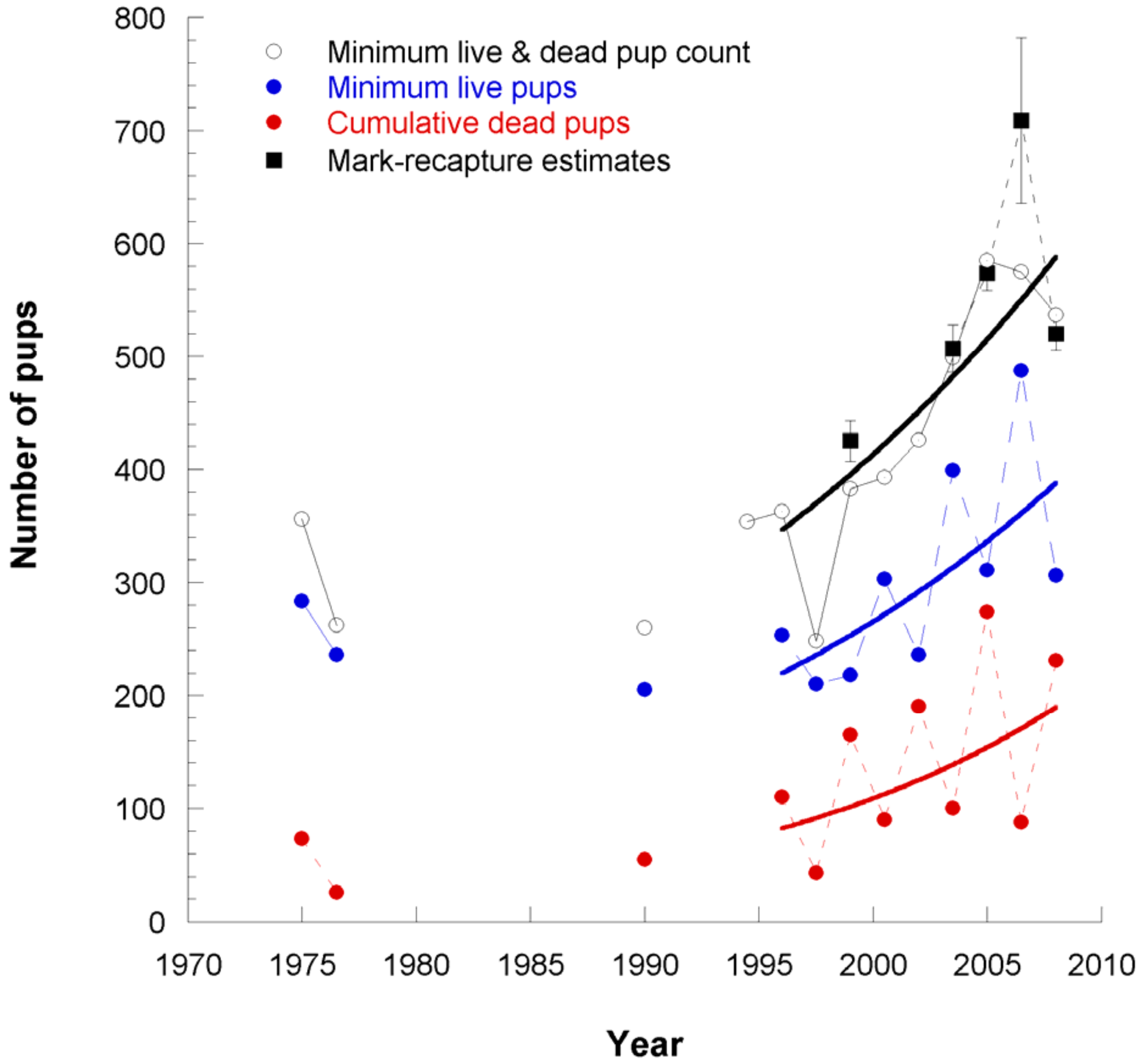


Figure 4.2. Trends in the abundance of Australian sea lion pups at Dangerous Reef, based upon minimum live and cumulative dead pup counts, minimum live pups count, cumulative dead pups and mark-recapture estimates (inclusive of cumulative dead pups) for 14 breeding season between 1975 and 2008. Error bars around mark-recapture estimates are ± 95% CL. Exponential curves are fitted to subsets of minimum live and cumulative dead pup counts, minimum live pups count and cumulative dead pups.

b) English Island

Pup counts

English Island was surveyed on two occasions, 21 May and 23 June 2008. Details on the number of unmarked, marked and dead pups sighted on each survey are presented in Table 6. The minimum number of marked, dead and unmarked pups present in the population, based on the re-sight and marking history is also presented. On the first visit, 16 live (6 black, 10 brown) and 3 dead pups were observed, and 11 of the live pups (5 black, 6 brown) were marked. On the next survey, 12 live pups were sighted (4 black, 8 brown), and only 2 of these (brown pups) were marked. Based on this survey, the minimum number of pups estimated at English Island subpopulation was 24 (11 marked + 10 clear + 3 dead) (Table 4.6). However, given that four tagged pups from Dangerous reef were sighted at English Island on the second survey (not included in pup tally), it cannot be certain that all of the unmarked pups sighted were born at English Island. Because of the dispersal of Dangerous Reef pups, and the implications of the presences of these animals on the confidence of pup production estimates, no further surveys were undertaken during the 2008 season (Table 4.6). At Dangerous Reef during the June surveys, a maximum of 185 live tagged pups (201-16 dead) and a minimum of 242 live untagged, represents approximately 43% tagged. Given this, the presence of four tagged pups from Dangerous Reef at English may suggest that up to 9 additional pups (including the 4 tagged) from Dangerous Reef (4 x (1/0.43)), were present at English Island during the June survey (ie. another 5 untagged pups). Based on these results, the best estimate of pup production is likely to be derived from adding the 4 black pups (new births since the first survey) to the total estimate of the first survey, as it can be certain that these pups were born at English Island. This gives a total estimate of 23 pups for the 2008 season.

Trends in abundance at English Island

Australian sea lion pup abundances have now been surveyed at English Island over seven breeding seasons. Between 1998 and 2002, between 4 and 15 pups were recorded (Shaughnessy 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. in press-b), and with this most recent breeding season, a minimum of 23 pups have been reported. Clearly previous surveys have also been confounded by the issue of pups dispersing to the island from Dangerous Reef during the breeding season, as well as high variability in survey number and effort across breeding seasons. As such it is not possible at present to discern trends in pup production at English Island.

Table 4.6 Details of pup surveys undertaken at the Australian sea lion colony at the English Island in May and June 2008. The number of unmarked, marked, dead and total pups seen on each survey is indicated, in additional to the number of new marks applied. The number of marked pups available to be re-sighted at each survey is presented, along with the cumulative number of dead pups recorded. The minimum number of pups at each visit is estimated by summing the number of pups marked, maximum number of unmarked pups and cumulative dead pups.

Date	**Unmarked count**	**Marked count**	**Dead unmarked**	**Dead marked**	**Total live count**	**Total live & dead count**	**New marked**	**Cum. marked**	**Min Alive**	**Cum. dead clear**	**Min Total**
21-May	16	0	3	0	16	19	11	11	16	3	**19**
23-June	10	2	0	0	12	12	1	12	21	3	**24***

* Not including 4 tagged pups from Dangerous Reef sighted (tag numbers 612, 642, 655, 732).

Discussion

Based on surveys undertaken at Dangerous Reef during the 2008 breeding season, there has been an apparent decrease in pup production of about 24% (based on mark-recapture estimates) between the 2006-07 and 2008 breeding seasons. However, there are a number of factors about the 2008 Dangerous Reef breeding season and the surveys undertaken that cast some doubt over the accuracy of this survey. The most important of these were the extended breeding season (up to nine months in duration), and the limited number of surveys (funding only permitted four). The highly protracted breeding season meant that an unknown number of pups were born over the three months following the final survey. The proportion of pups born by the final survey is unknown, and hence estimates of pup production for the 2008 season based on these surveys represent an underestimate.

For most Australian sea lion breeding seasons, four surveys are usually enough to derive an accurate estimate of pup production, as long as they are adequately spaced. The first survey is used to determine the commencement or stage of the breeding season, and to estimate when the third month of breeding will occur. For large colonies where mark-recapture methods are appropriate, undertaking these surveys on the third, four and fifth month of breeding covers most of the breeding season. At Seal Bay, the four most recent breeding seasons (2002-03 to 2007) have lasted between 6-9 months, with 90% of births occurring over a 4.0 month period (range 3.4 – 4.6, n = 4) (Goldsworthy et al. 2008a). The 2002-03 breeding season at Seal Bay was of similar duration to the 2008 Dangerous Reef breeding season, lasting about 9 months. The first births were recorded in December 2002, with 90% of births occurring between 2 January and 21 May (4.6 months) (Goldsworthy et al. 2008a). Given the timing of surveys at Dangerous Reef during 2008, and based on a similar duration breeding season at Seal Bay, more than 90% of births were likely to have occurred by the time of the final survey in late August, almost 7 months after the commencement of the breeding season. As the duration of breeding seasons cannot be reliably anticipated in advance, the number of surveys required to minimise errors in estimates of pup production for any given breeding season can be difficult to determine. Clearly, for the 2008 breeding season at Dangerous Reef, additional surveys at month 5 and 8 would have enabled better estimates to be determined. Future surveys should build in some contingency (if possible) to conduct additional surveys if required.

Despite some uncertainties in the accuracy of the 2008 pup production estimate, there has clearly been a decline in pup production from the 2006-07 breeding season, although the decline of around 24% between seasons is likely to be an over estimate, based on the likelihood that the 2008 pup production has been somewhat underestimated. The decline in pup production between years represents a notable departure following at least four breeding seasons of successive sustained increases in pup production of around 10% per breeding season (Goldsworthy et al. 2007b). Given this, the decline most likely reflects a drop in fecundity rates between seasons, rather than a reduction in female population size, although surveying of subsequent breeding season will be needed to assess this. Marked variance in pup production between successive seasons has also been noted at Seal Bay and The Pages (Shaughnessy & Goldsworthy 2007, Goldsworthy et al. 2008a). At Seal Bay over four consecutive breeding seasons between 2002-03 and 2007, between season pup production increased by 27% (2002-03 to 2004), fell by 24% (2004 to 2005-06) and then increased by 19% (2005-06 to 2007), a mean deviation of 23% between seasons (Goldsworthy et al. 2008a). These results demonstrate the challenges faced in using pup production estimates to determine trends in Australian sea lion populations, and the imperative for long time-series of data to better understand population status and trends.

Although this study has identified a reduction in pup production for the 2008 breeding season, the overall trends from mark-recapture and pup counts support the general trend that the population has increased markedly in size since the 1990s (Figure 4.2). Goldsworthy et al. (2007a), identified that this recent pronounced increase in pup abundance at Dangerous Reef has coincided with the cessation of the demersal gillnet shark fishery in Spencer Gulf in 2001. Bycatch of sea lions in this fishery has been identified as a key threat to the species (Goldsworthy & Page 2007, Goldsworthy et al. in press-a), and the recent recovery of the Dangerous Reef population provides circumstantial evidence that positive growth has followed a reduction in anthropogenic mortality for this population (Goldsworthy et al. 2007a).

Difficulties were also met in undertaking a survey of pup production at English Island. Due to dispersal of Dangerous Reef pups to English Island during the breeding season, surveys can be significantly compromised because it is not possible to know the origin of all pups sighted. We estimated that up to 9 pups from Dangerous Reef were present on the final survey undertaken at English Island on 23 June 2008. Our best estimate of pup production up to 23 June was 23 pups. The most effective way to eliminate inclusion of dispersed pups in surveys is to make more regular surveys, and only count and mark new black coat pups (<1 month old). This approach has been used to overcome the issue of dispersed pups (from Seal Bay) being included in surveys at The Seal Slide on Kangaroo Island (Goldsworthy et al. 2008a). This alternate method for small colonies where dispersal from nearby colonies cannot be ruled out, is essentially a modification of the cumulative mark and count method (Goldsworthy et al. 2007c), where marking and counting of unmarked pups is directed only at pups <1 month of age.

Pup mortality

The mortality rate of pups at Dangerous Reef determined for the 2008 season (43.0%) is second only to that reported for the 2002 breeding season (44.6%, Goldsworthy et al. (2007b). There is now a very clear pattern of alternating high and low pup mortality between breeding seasons at Dangerous Reef, with high mortality seasons (mean ~38%) corresponding with breeding seasons that occur mostly over the winter months, and low mortality seasons (mean ~18%) occurring mostly over summer months. A difference in pup mortality between a winter and a summer pupping season has also been observed by Gales et al. (1992) at islands in the Jurien Bay region on the west coast of Western Australia. They reported high pup mortality in the first five months of a breeding season that included the 1989 winter, averaging 24% over the three islands. Pup mortality rates were considerably lower (7%) in the preceding pupping season, which occurred during the summer. At Seal Bay, there is also evidence over four consecutive breeding seasons of alternate high (33%) and low (22%) mortality seasons, although contrary to the pattern for Dangerous Reef and the Jurien Bay colonies in Western Australia, the correlation with season of breeding appears to be reversed, with high mortality corresponding with summer/autumn breeding, and low mortality corresponding with winter/spring breeding seasons (Goldsworthy et al. 2007b).

The cause of the large variance and apparent seasonality in mortality rates at Dangerous Reef is presently unknown. McIntosh (2007) provides some of the best information on causes of mortality in Australian sea lion pups. During three breeding seasons at Seal Bay (2002-03, 2004, 2005-06), 128 pups were examined to determine the cause of death. In 51% of cases cause of death could be determined and included trauma from con-specific aggression (31.6%), emaciation (10.4%), still-birth (7.6%) and possible shark attack (1.4%). However, in 49% of cases the cause of death could not be assessed, and it is possible that disease and parasites (not assessed in necropsies) were the primary cause of mortality in these cases. It would seem improbable for there to be a strong seasonal pattern in the prevalence of the main causes of mortality identified by McIntosh (2007) (eg. conspecific aggression). It is more likely that the seasonal pattern of mortality observed at Dangerous Reef is related to disease or parasites where seasonality in the environment may influence the prevalence and severity of infection.

Hookworm, *Uncinaria hamiltoni* (Beveridge 1980) and tuberculosis, *Mycobacterium pinnipedii* (Mawson & Coughran 1999, Cousins et al. 2003) have been recorded in Australian sea lions and New Zealand fur seals. Their prevalence in wild populations and their effect on survival and reproduction are unknown. Hookworms are common parasites of fur seals and sea lions, and have recently been recorded in pups at Dangerous Reef (R. Gray, pers. comm.). Hookworm can cause anaemia and enteritis and has been associated with morbidity and mortality of sea lion and fur seal pups (Lyons & Keyes 1978, Sepulveda 1998, Lyons et al. 2001, Castinel et al. 2004, Spraker et al. 2004, Lyons et al. 2005, Castinel et al. 2007a, Castinel et al. 2007b, Spraker et al. 2007). Although the relationship between infection rate and mortality is unclear (Lyons et al. 2001), hookworms (*Uncinaria* spp.) have been identified as the primary cause of death in northern fur seal and Californian sea lion pups (*Zalophus californianus*) in some years (Lyons 1963, Lyons et al. 1997, Lyons et al. 2001, Lyons et al. 2005). A hookworm enteritis-bacteraemia complex was the main cause of California sea lion pup mortality at San Miguel Island in 2002-03, and was thought to be a density-dependent disease (Spraker et al. 2007). Hookworm also appears to play a role in the mortality of pups of the New Zealand sea lion, *Phocartos hookeri* (Castinel et al. 2004, Castinel et al. 2007a, Castinel et al. 2007b), South American sea lion, *Otaria flavescens* (Beron-Vera et al. 2004) and Steller sea lion, *Eumetopias jubatus* (Burek et al. 2004) indicating the importance of this pathogen in sea lion populations.

The main point of infection of hookworm to seal pups is via trans-mammary transmission of third-stage larvae (L_3) through the colostrum (first-milk) within the first few days following birth (Castinel et al. 2007a). Larvae mature into adults in this *intestinal phase*, with hookworm eggs appearing in pup faeces by the time they are 2-3 weeks old (Castinel et al. 2007a). Larvae develop through stages L_1 to L_3 within the eggshell, before hatching around the 23rd day (Castinel et al. 2007a). In this *free-living phase*, L_3 larvae can remain in the soil for some period, before they burrow through the skin or are ingested directly by seals where they migrate to fatty tissue (usually in the ventral abdominal blubber and/or mammary glands) in what is know as the *tissue phase* (Castinel et al. 2007a). The L_3 larvae can then remain in arrested development until migrating to the mammary glands in lactating females, potentially under a hormonal signal (Lyons 1963, Lyons & Keyes 1978).

There is still much uncertainty about the ecology of hookworm, particularly how long larvae can survive in the soil, in other substrates types, and the role of temperature and moisture on larvae survival during the free-living phase. Over-wintering larvae have been detected in the soil on the Pribilof Islands which are cold and wet, but not at San Miguel Island in California which is warmer and dryer (Olsen & Lyons 1965, Lyons et al. 2001). In addition, there is uncertainty about the relative contribution of the L_3 larvae surviving in the free-living and tissue phases, as the source of infection of pups born in the next breeding season. This point is particularly pertinent in the case of Australian sea lions, which are the only non-annually breeding pinniped, and where hookworm larvae would need to survive up to 18 months in their *free-living* or *tissue phases* in order to infect the next cohort of pups. Given the marked seasonal temperature and moisture fluctuations experienced at Dangerous Reef, marked differences in the survival of free-living larvae produced during summer and winter breeding season is likely, and the hypothesis that climate and season induce fluctuations in hookworm infection and their consequential enteritis-bacteraemia complexes, appears a plausible explanation for the observed marked inter-seasonal fluctuation in pup mortality, and should be investigated further.

Such marked fluctuations in pup mortality between seasons, is likely to induce marked variance in recruitment and age-structure within ASL populations, and this may explain why we often observe marked inter-seasonal variance in pup production in this species. As such, there is a critical need to understand the role of disease and parasites on pup survival and on the broader population structure and demography of Australian sea lion populations, as it may exert strong density-dependence, as has been shown for other sea lion species (Lyons et al. 2005).

5 CONCLUSIONS

Australian sea lions present unique challenges in obtaining accurate information about the size and trends in their populations. This stems from a combination of factors including the extended breeding season, the large number of colonies or subpopulations, and asynchronous breeding schedules. In addition, inter-colony differences in ease of access and the sightability of pups have led to marked differences in both the extent and quality of data. All of these factors contribute to difficulties in obtaining accurate (close to true value) and precise (low variance) estimates of pup production.

The principal purpose of this and previous studies (Goldsworthy et al. 2007c, Goldsworthy et al. 2008b) was to address the challenges and shortcomings in extant survey methods by developing new methodologies that provide consistent and accurate estimates of pup production for both large and small colonies. Such methodological development is essential for conservation and management purposes, where there is a critical need to determine the status and trends in the abundance of subpopulations over the shortest possible time-series.

This study has provided the most precise estimates of Australian sea lion pup production at Lilliput and Blefuscu Islands, the second surveys of Breakwater and Gliddon Reefs, and the most comprehensive survey of all breeding, potential breeding, and haul-out sites in the Nuyts Archipelago. It has also extended the time series of pup production estimates for the Dangerous Reef and English Island colonies.

For the large colonies, this study and previous ones has shown that the Petersen estimate procedure in conjunction with counts of unmarked, marked and cumulative pup deaths provides a robust means of obtaining accurate estimates of pup production, as long as 3-4 surveys are undertaken between the period just prior to peak in pup production and the end of the breeding season. Tests for equal catchability of marked pups, and Cormack-Jolly Seber methods also provide within estimate checks on the assumptions of mark recapture procedures, particularly equal catchability, re-sight probability and fidelity (no permanent emigration). CJS estimates of apparent survival also provide a simple internal check against which cumulative recovered mortalities can be compared, and if necessary adjusted. One down-side to limiting surveys to only 3-4 capture and re-sight sessions is that independent assessments of pup production using more complex CJS analyses such as robust models, cannot be undertaken. This method of survey was achieved for the Olive Island Australian sea lion colony in 2006, where it provided the same estimate as the Petersen estimate (Goldsworthy et al. 2007c).

For surveys undertaken during this study, we are confident that the Petersen method provides accurate estimates of pup production at Lilliput and Blefuscu Islands, however, those undertaken at Dangerous Reef underestimated total pup production, with the largest estimate being provided by counts of marked, unmarked and cumulative dead pups. The long nine-month breeding season meant that at least one additional survey should have been undertaken, but limited funds prohibited this. Future surveys should build in some contingency to conduct additional surveys if required due to unforeseen extended breeding seasons.

For the small colony surveys undertaken in this study at Breakwater and Gliddon Reef, and English Island, two major problems were unforeseen. Firstly, access at Breakwater and Gliddon Reefs was challenging, with landings being only possible once over three attempts. Given that accessibility was one of the key criteria against which these two colonies were selected as the most suitable long-term survey sites for small colonies in the Nuyts Archipelago (Goldsworthy et al. 2007c), results from this study suggest that future surveys will also be undermined by access difficulties. Unfortunately these two sites represent the only small colonies in the Nuyts Archipelago metapopulation. The second major problem encountered was at English Island, where dispersal of Dangerous Reef pups to English Island during the breeding season undermined the cumulative count and mark (CMC) method, because an unknown proportion of unmarked pups were from Dangerous Reef. The only way to eliminate the inclusion of dispersed pups from these surveys is to modify the CMC method to only include new black-coat and brown pups and increase the number of surveys (eg. monthly from the second month of breeding).

A stakeholder workshop is currently proposed to be held in May 2009 by DEWHA, to develop a national survey strategy for monitoring of Australian sea lion populations. This workshop will aim in part to identify key representative monitoring sites and the appropriate methodologies and frequency of surveys required. Result from this and previous studies will provide critical input into this process.

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