Developing population monitoring protocols for Australian sea lions: enhancing large and small colony survey methodology

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Final Report to the Australian Centre for Applied Marine Mammal Science (ACAMMS), Department of the Environment, Water, Heritage and Arts

SD Goldsworthy[1], PD Shaughnessy[2], B Page[1], A Lowther[1,3], CJA Bradshaw[1,3]

[1] South Australian Research & Development Institute (SARDI), 2 Hamra Avenue, West Beach SA 5024
[2] South Australian Museum, North Terrace, Adelaide, SA 5000
[3] School of Earth and Environmental Sciences, University of Adelaide, Adelaide, South Australia 5005

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South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024
Telephone: (08) 8207 5400
Facsimile: (08) 8207 5481
www.sardi.sa.gov.au

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Authors:	SD Goldsworthy, PD Shaughnessy, B Page, A Lowther, CJA Bradshaw
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1 EXECUTIVE SUMMARY

Australian sea lions (ASL) were 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.

Goldsworthy et al. (2007a), addressed these challenges by trialling new methodological approaches to estimating pup production at large (>40 pups) and small (<40 pups) ASL subpopulations. At Olive Island they collected individual re-sight histories of pups throughout the breeding season and used Cormack-Jolly-Seber (CJS) models in conjunction with standard mark-recapture (Petersen estimate) methods to improve estimates of pup production for large ASL subpopulations (>40 pups). They also developed a cumulative mark and count (CMC) method for improving estimates of pup production in small ASL subpopulations, and trialled this at the Seal Slide (Kangaroo Island).

This study extends that of Goldsworthy et al. (2007a), by continuing the trials of the Petersen/CJS estimate for large colonies at Olive Island and Lewis Island, and for the CMC method at two small colonies (the Seal Slide and Jones Island), all of which had breeding seasons during 2007. The estimates of pup production for Olive Island were 161 (151-172, ±95% CL), indicating a large decrease (21%) in pup production from the 2006 breeding season. For Lewis Island the 2007 estimate of pup production was 131 (116-146, ±95% CL), representing the first accurate survey of this subpopulation since its confirmation as a breeding colony in 2005. Estimates of pup production at Lewis Island were confounded by dispersal of pups from neighbouring Dangerous Reef. The estimate of pup production at the Seal Slide was 16 (range 15-18), and 15 for Jones Island.

This study has confirmed that mark-recapture methods using the Petersen estimate are likely to accurately estimate true pup abundance if surveys are undertaken at the appropriate times throughout the breeding season with the appropriate effort. The main source of error comes from unaccounted mortality, and CJS estimates of apparent survival provide a simple internal check against which cumulative recovered mortalities can be compared, and if necessary adjusted. The study has also confirmed that CMC and Petersen estimate methods provide suitable means to estimate pup production with confidence limits at small Australian sea lion colonies. Standardisation of methodologies will enhance the accuracy and precision of estimates, and facilitate assessment of trends in abundance at key monitoring sites.

2 INTRODUCTION

Background

The Australian sea lion (ASL), *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 California sea lions in California and Mexico is increasing (Caretta 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 and Salazar 2006), and the Japanese subspecies, *Z. c. japonicus,* is possibly extinct (Mate 1982). Numbers of South American sea lions, *Otaria flavescens*, have reduced considerably in recent years (Crespo and 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 and Bradshaw 2003), and ASL (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 and Costa 1997). It has the longest gestation period of any pinniped, and a protracted breeding and lactation period (Higgins and Gass 1993, Gales and Costa1997). The evolutionary determinates of 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 73 known breeding locations for ASLs, 47 of which occur in South Australia (SA) where the species is most numerous (80% of pups counted), with the remainder (26 colonies) in Western Australia (McKenzie et al. 2005). The species was subject to sealing in the late 18^{th}, the 19^{th} and early 20^{th} centuries, resulting in a reduction in overall population size and extinction of populations in Bass Strait and other localities within its current range. Total pup production for the entire species during each breeding cycle has been estimated at about 2,500 with an estimated overall population size based on a demographic model developed by Goldsworthy et al (2003), of around 9,800 (McKenzie et al. 2005). A re-analysis of this demographic model, in conjunction with improved estimates of pup production for some sites, increased pup production estimates for SA to 2,674 (10,905 individuals) (Goldsworthy and Page 2007). With more recent estimates for The Pages (Shaughnessy and Goldsworthy 2007), Olive Island (Goldsworthy et al. 2007a) and Dangerous Reef (Goldsworthy et al. 2007b), pup production in SA is now estimated at 3,087 per breeding cycle (with total population size being 12,959 individuals, using a pup production to total population multiplication factor of 4.08 developed by Goldsworthy and Page 2007). Adding the pup production estimate of 706 for WA sites (Goldsworthy et al. 2003), the total pup production for the species is currently estimated at about 3,793 per breeding cycle, with an estimated overall population estimate of around 15,475.

There are 39 ASL breeding sites in SA, when the criterion for classification as a breeding colony is set at ≥ 5 pups present per breeding cycle (McKenzie et al. 2005, see Fig. 2.1). Of these, only eight (21%) produce more than 100 pups, and these account for 66% of the State's pup production. The largest population is Dangerous Reef in Southern Spencer Gulf (709 pups from 2007 survey, Goldsworthy et al. 2007b), followed by The Pages (North and South Page Islands combined, 589 pups from 2005 survey; Shaughnessy and Goldsworthy 2007) in Backstairs Passage between Kangaroo Island and mainland Australia. The next largest populations are Seal Bay (260 pups from 2007 survey; Goldsworthy et al. Unpublished data) on Kangaroo Island, West Waldegrave (157 pups; Shaughnessy et al. 2005) and Olive Islands (206 pups; Goldsworthy et al. 2007a) off the west coast of the Eyre Peninsula, and Purdie Island in the Nuyts Archipelago (132 pups; Goldsworthy et al. in review). The median pup production for SA colonies is 27 per colony, with 60% of breeding sites producing fewer than 30 pups per season, 42 % fewer than 20 pups, and 13% fewer than 10 pups (Goldsworthy and Page 2007). These analyses do not take into account at least another 11 breeding sites (termed 'haul-out sites' with occasional pupping), where fewer than 5 pups have been recorded at some time (McKenzie et al. 2005).

Although the pre-harvested population size of the ASL is unknown, the overall population is believed to be in recovery. Unlike Australian fur seal, *Arctocephalus pusillus doriferus* and New Zealand fur seal, *A. forsteri* populations, which have been recovering rapidly throughout southern Australia, there is a general view that the overall population recovery of the

Australian sea lion 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 Australian sea lions was typically poor. Poor data are 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 accumulated 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, in conjunction with the absence of a realistic and representative population model, make it difficult to estimate the size of the Australian sea lion population accurately.

Further, reliable estimates of pup abundance are available for 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 interpreting trends in population abundance with any level of confidence difficult.

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 Australian sea lion 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. (2007a) developed and tested the appropriateness of two new methods for estimating pup production in ASL subpopulations. The first utilised individual re-sight histories of pups and Cormack-Jolly-Seber (CJS) models in conjunction with standard mark-recapture methods to improve estimates of pup production for large ASL subpopulations (>40 pups). The second developed a cumulative mark and count (CMC) method for improving estimates of pup production in small ASL subpopulations (<40 pups).

CJS methods were trialled at Olive Island and produced pup production estimates that were greater than those based on direct counting and on mark-recapture (Petersen estimate) methods (Goldsworthy et al. 2007a). There was no evidence for permanent emigration, suggesting that the most important source of error in mark-recapture procedures at Olive Island were due to unaccounted mortality. Pup mortality during the study period was estimated to have ranged from 15-52. As 34 dead pups were found, ground surveys may have underestimated pup mortality by up to 35%. The best estimate of pup production for the 2006 season at Olive Island based on CJS methods was 205 (range 193-256). This was 1.37 times the estimate based on direct counting methods (150 pups), but was similar to the result (1.03 times larger) obtained from the Petersen estimate (mean 197, range 191-203). However, an adjusted Petersen estimate (adding the mortality range 34-52) produced almost the same estimate as the CJS approach (206, range 191-223) (Goldsworthy et al. 2007a).

The cumulative mark and count (CMC) method trialled at a small colony (Seal Slide, Kangaroo Island), supported the observation that not all pups are available for counting during ground surveys, and produced a consistent (repeatable) estimate on two occasions (10 pups). The surveys would have benefited from greater numbers of pups being marked over more sessions. The development of both CJS and CMC methods has advanced the methods of monitoring for both large and small ASL colonies (Goldsworthy et al. 2007a).

Aims & Objectives of document

This study builds upon that of Goldsworthy et al. (2007a) and aims to: 1) repeat surveys using the same methodology at Olive Island and the Seal Slide; 2) expand the survey to include two other colonies where breeding occurred during 2007, Lewis Island (a recently discovered large colony in southern Spencer Gulf) and Jones Island (a small colony) on the west coast Eyre Peninsula; and 3) use results from all surveys to continue to refine survey methodology.

Format of the report

Survey methodologies and results for the two large colonies (Olive and Lewis Islands) are reported in one chapter. Similarly, methods and results for surveying the two smaller colonies (Seal Slide and Jones Island) are reported together in another chapter. A concluding chapter is also provided.

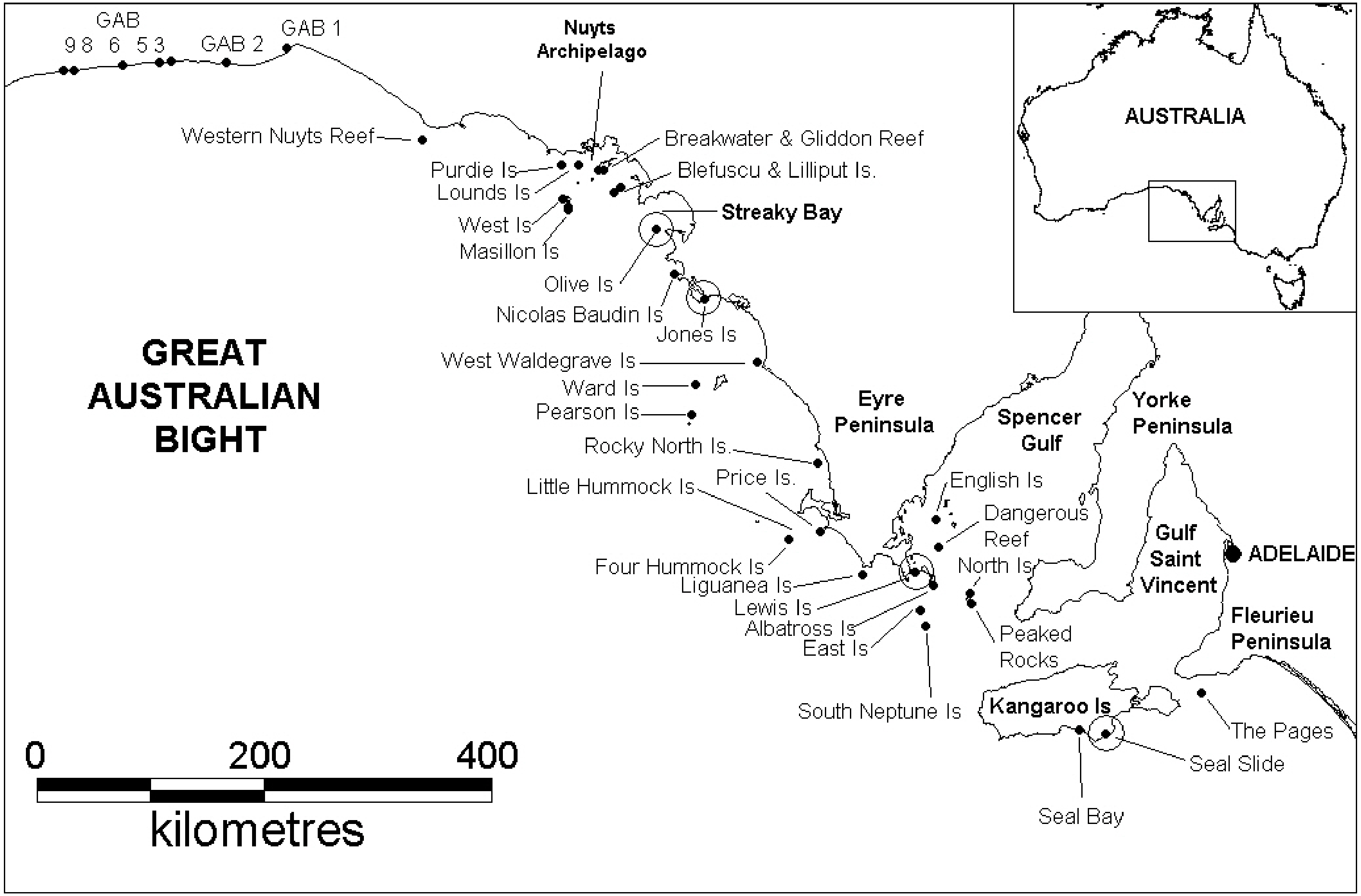

Figure 2.1 Distribution of Australian sea lion breeding sites, in South Australia. Surveyed colonies are highlighted with a circle.

3 PUP PRODUCTION AT LEWIS AND OLIVE ISLANDS - 2007 BREEDING SEASON

Introduction

The chapter details results from mark-recapture and CJS surveys undertaken at two large Australian sea lion colonies, Olive Island (west coast of Eyre Peninsula) and Lewis Island (southern Spencer Gulf) during 2007.

Methods

Field site

Field-work was undertaken at Lewis Island (34.957 S, 136.034 E) and Olive Island (32.719 S, 133.695 E) during 2007. Lewis Island was accessed by charter vessel from Port Lincoln with four visits to the colony between 30 January and 1 July 2007, and. Olive Island was accessed by charter vessel from the township of Streaky Bay (see Figure 2.1), with three visits being made between 30 August and 9 November 2007. 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. A record of dead pups was obtained 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, and mark-recapture procedures undertaken to provide information on the numbers of pups present during each survey. 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).

Pup production

As per the 2007 assessment of pup production at Olive Island (Goldsworthy et al. 2007a), the principal method to estimate pup production in this study was the Petersen estimate. Goldsworthy et al. (2007a) used various capture-mark-recapture (CMR) models to account for the many factors that can bias pup production estimates in this species. However, their study determined there was no permanent emigration, and identified that the main source of error was unaccounted mortality. These findings and practical limitations on the re-sight effort possible in the current study precluded the use of Pradel recruitment models. As such, we simplified the Cormack-Jolly Seber (CJS) analyses to estimate re-sight probability and survival.

The approach therefore 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; 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.

1) Live and dead pup counts

For each visit to Lewis and Olive 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 give the number of 'accumulated dead pups'. When that number was added to the number of live pups, it gave an estimate of pup numbers to that date.

2) Petersen estimates

A mark-recapture procedure was used to estimate the number of live pups present during each visit to Lewis and Olive Islands. During each visit to each island (sessions), individual re-sight records were collected for tagged individuals with the aid of binoculars. As noted above, a record of dead pups was obtained by placing rocks on top of carcases to avoid repeat counting. Records of the total number of tagged, untagged and newly recorded dead pups were noted on each field trip. 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 session 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

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

3) 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 sessions, 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).

4) 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 Burnham (1993) joint live-dead modification to the CJS model. 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 are 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 assessment at Olive Island determined that *F* was approximately equal to 1 (i.e., no permanent emigration, see Goldsworthy et al. 2007a), we used the simpler CJS model with live captures only to estimate true survival (ϕ is equivalent to *S* when *F* = 1).

Results

a) Lewis Island

Timing of breeding season

The pupping season at Lewis Island was well underway during the first visit (session 1) to the Island on 30 January 2007, when 38 live and 3 dead pups were counted. Four visits to the island were made during the breeding season. New born pups with mate-guarded females were observed on the second (27 -30 March 2007, session 2) and third (5-6 May 2007, session 3) trips, but were absent on the fourth trip (28 June – 1 July, session 4), suggesting that the breeding season had ended by late June.

Marking and absolute counts

A total of 77 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 3.1). 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 3.1). Minimum estimates of pups based on these approaches increased over the four sessions: 38, 85, 104 and 132, respectively (Table 3.1).

Accounting for Dangerous Reef pups

Orange-tagged pups from Dangerous Reef were sighted on the second, third and fourth session at Lewis Island. One tagged pup was seen on 30 March, and nine different individual tagged pups were sighted over sessions 3 and 4 (Table 3.1). Given the different coloured tags used at Lewis Island and Dangerous Reef, it was easy to distinguish between tagged pups from the two colonies. The breeding season was estimated to have ended at Dangerous Reef in December 2006, just prior to the commencement of the breeding season at Lewis Island. Based on the presence of tagged pups from Dangerous Reef at Lewis Island, it is likely that untagged pups were also hauling-out at Lewis Island during the breeding season. Even though the breeding seasons of the two islands did not overlap, it was not possible to distinguish between untagged pups born at Lewis Island from those that may have hauled-out from Dangerous Reef. This was because late-season pups at Dangerous Reef may have been only 1-2 month older than early season pups at Lewis Island. Once Lewis Island pups had moulted, it was not possible to distinguish them from moulted pups from

Dangerous Reef, although there may have been some size differences in pups given differences in their age, such distinctions were subjective.

At the end of the 2006-07 breeding season at Dangerous Reef, there were an estimated 629 (range 560-707) live pups in the population, of which 200 were tagged (Goldsworthy et al. 2007b). Based on these figures, 0.5% of Dangerous Reef tagged pups were sighted at Lewis Island on the second session, and 4.5% on the third and fourth session at Lewis Island. Given an estimated 421 (range: 352-499) live untagged pups in the Dangerous Reef population at the end of the breeding season, these figures can be used to estimate that about 2.1 (range: 1.8-2.5) unmarked pups during the second session at Lewis Island were from Dangerous Reef, and that about 19 (16-22) unmarked pups during the third and fourth sessions at Lewis Island were from Dangerous Reef (Table 3.1). Accounting for these estimates of the numbers of Dangerous Reef pups present at Lewis Island during pup surveys suggests that the minimum estimate of pups counted (maximum unmarked counted + dead unmarked + cumulative marked – estimated number of untagged Dangerous Reef pups present) was 129 (range 126-132) (Table 3.1). Tagged Dangerous Reef pups were omitted from all surveys.

Petersen estimates

Results from Petersen estimates of pup abundance undertaken over sessions two, three and four at Lewis Island are presented in Table 3.1 and 3.2. Estimates suggest that the numbers of pups (including cumulative mortalities) present at Lewis Island increased from about 99 (95% CL, 95-102) to 150 (95% CL, 139-162) between sessions 2 and 4 (Table 3.1, 3.2, Figure 3.1). Accounting for the estimated numbers of pups from Dangerous Reef present at Lewis Island during these surveys provides an estimate of total pup production during session four, when the breeding season had ended, of 131 pups (95% CL, 116-146) (Table 3.1, 3.2, Figure 3.2).

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 four 'capture' sessions with 77 marked individuals (200 total re-sightings and one 'marked' dead return) were available for analyses. 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. 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 (0.98, i.e. apparent survival close to 1 for all sessions) and *p* (session 1-2), and time-variant *p* for session 2-3 (0.745, 30-day live-capture probability) and session 3-4 (0.857). 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 immigration of Dangerous Reef 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, cumulative pup mortality and accounting for dispersal from Dangerous Reef are likely to provide the best estimates of pup production for the season.

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 Lewis Island between January and July 2007.

Session	1	2	3	4
Date	**30-Jan**	**30-Mar[1]**	**6-May[2]**	**1-Jul[3]**
Cumulative marked	9	75	77	77
Maximum unmarked counted	29	10	27	55
Maximum count (live)	38	85	104	132
Cumulative dead (unmarked)	3	12	14	16
Cumulative dead (marked)	0	0	0	1
Total cumulative dead	3	12	14	17
Number of Tagged Dangerous Reef pups seen	0	1	9	9
Estimated proportion Dangerous Reef tagged pups seen	0	0.005	0.045	0.045
Estimated number Dangerous Reef untagged pups	0	2.1	18.9	18.9
Lower-Upper	0	2-2	16-22	16-22
Maximum count (live) + cumulative dead	41	97	118	148
Cumulative marked + dead (unmarked) + max unmarked	41	97	118	148
Maximum count (live), cumulative marked+ dead - estimated Dangerous Reef pups	41	95	99	129
Lower-Upper		93-97	96-102	126-132
Petersen Estimate (live)		86.6	112.3	134.3
Petersen Estimate Lower – Upper CL		83-90	107-118	123-146
(No. recapture estimates)		6	7	9
Petersen Estimate (live) + cumulative dead		98.6	126.3	150.3
Lower – Upper CL		95-102	121-132	139-162
Petersen Estimate + cumulative dead - D'Reef pups		96.48	107.33	131.34
Lower – Upper CL		93-100	98-116	116-146

1. 27-30 March 2007
2. 5-6 May 2007
3. 28June-1 July 2007

Table 3.2 Details of Petersen mark-recapture procedures undertaken at Lewis Island between March and July 2007 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	SE	V	%	CV	Nlo	Nup
Session 2											
29-Mar	1	72	44	37	85	3.8	14	84%			
29-Mar	2	72	47	39	87	3.8	14	83%			
29-Mar	3	72	45	39	83	3.2	10	87%			
29-Mar	4	72	43	36	86	3.9	16	84%			
30-Mar	5	72	48	38	91	4.5	20	79%			
30-Mar	6	72	38	31	88	4.9	24	82%			
				Mean	**87**	**1.7**		**83%**	**1.9%**	**83**	**90**
Session 4											
5-May	1	72	75	48	112	5.5	30	64%			
5-May	2	72	62	44	101	5.0	25	71%			
5-May	3	72	65	42	111	6.4	41	65%			
6-May	4	72	58	39	107	6.4	41	67%			
6-May	5	72	57	34	120	9.2	84	60%			
6-May	6	72	60	37	116	8.0	64	62%			
6-May	7	72	58	35	119	8.7	76	60%			
				Mean	**112**	**2.7**		**64%**	**2.4%**	**107**	**118**
Session 5											
29-Jun	1	62	93	38	151	11.3	128	41%			
29-Jun	2	62	60	32	115	9.3	87	53%			
30-Jun	3	62	66	30	135	12.6	158	45%			
30-Jun	4	62	61	26	144	15.5	241	43%			
30-Jun	5	62	36	20	110	12.7	161	56%			
30-Jun	6	62	42	17	150	22.3	495	40%			
30-Jun	7	62	48	24	122	13.2	173	50%			
1-Jul	8	62	54	23	143	17.1	291	43%			
1-Jul	9	62	52	23	138	16.2	262	44%			
				Mean	**134**	**5.0**		**46%**	**3.7%**	**125**	**144**

Table 3.3 Leslie's test for equal catchability across each recapture session at Lewis Island. *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 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.	*n*	n^2	*i*	*f*	*fi*	fi^2	χ^2	df	*P*
2	1	36	1296	0	13	0	0			
	2	38	1444	1	13	13	13			
	3	28	784	2	8	16	32			
	4	32	1024	3	9	27	81			
	5	37	1369	4	14	56	224			
	6	25	625	5	12	60	300			
				6	4	24	144			
	∑	196	6542		73	196	794	0.041	72	>0.05
3	1	47	2209	0	15	0	0			
	2	37	1369	1	11	11	11			
	3	29	841	2	8	16	32			
	4	26	676	3	18	54	162			
	5	21	441	4	11	44	176			
	6	25	625	5	6	30	150			
	7	18	324	6	6	36	216			
				7	1	7	49			
	∑	203	6485		76	198	796	0.043	75	>0.05
4	1	38	1444	0	15	0	0			
	2	32	1024	1	8	8	8			
	3	30	900	2	19	38	76			
	4	13	169	3	10	30	90			
	5	17	289	4	10	40	160			
	6	12	144	5	5	25	125			
	7	18	324	6	4	24	144			
	8	12	144	7	1	7	49			
	9	19	361	8	0	0	0			
				9	0	0	0			
	∑	191	4799		72	172	652	0.050	71	>0.05

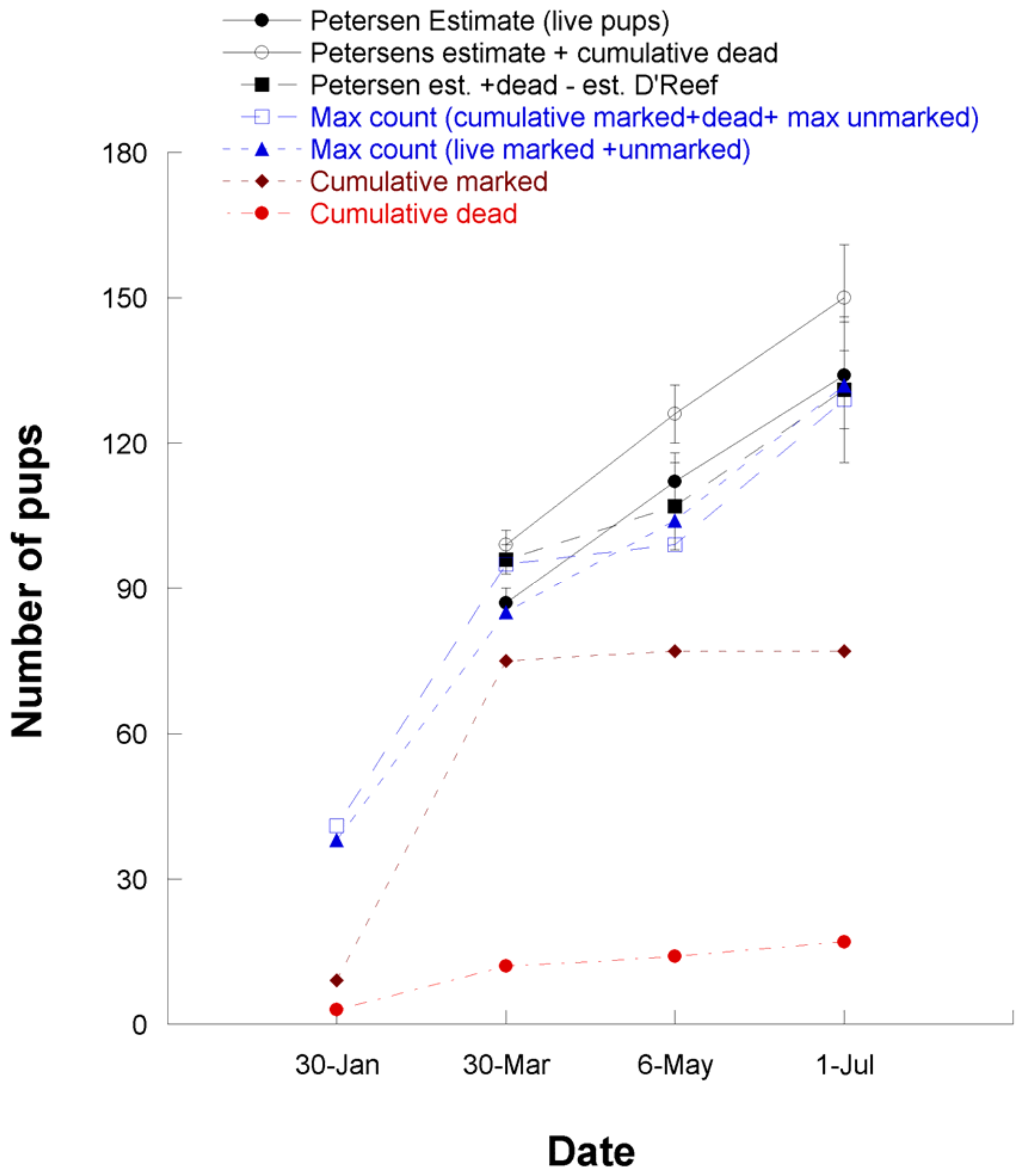

Figure 3.1 Trends in pup numbers at Lewis Island between January and July 2007, including cumulative dead, cumulative marked (tagged), maximum counted, and estimated pup production (± 95% CL) from Petersen estimates.

b) Olive Island

Timing of breeding season

The pupping season at Olive Island was well underway during the first visit in August 2007, with 94 pups (including 10 dead) observed. 65% of pups observed still had black coats, indicating they were less than 4 weeks old, 10% of pups were with mate-guarded mothers (<10 days old). 36% of pups had a brown pelage (<12 weeks old) and none had fully moulted. These data suggest that the pupping season had most likely commenced in June 2007. By 20 September, 80% had a brown pelage (~4-12 weeks), and only 5% of pups had mate-guarded mothers. By 9 November, no pups were observed with mate-guarded females suggesting that the breeding season had ended.

Marking and absolute counts

A total of 78 pups were marked (tagged) over the five 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). This enabled minimum estimates to be calculated for each 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 were: 94, 89, 129,130, and 144 respectively (Table 3.4). Counts based on total live pups, and live pups plus cumulative dead pups were greatest in session 5 (9 November) at 144 (Table 3.4, Figure 3.2).

Petersen estimates

Results from Petersen estimates of pup abundance undertaken over sessions two, four and five at Olive Island are presented in Table 3.4 and 3.5. Estimates suggest that the number of pups (including cumulative mortalities) at Olive Island increased from about 122 (95% CL, 111-131) to 161 (95% CL, 151-172) between sessions 2 and 4 and had declined to about 129 (95% CL, 125-134) by session 5 (9 November) (Figure 3.4). These data suggest that the breeding season was close to complete by session 4 (28 September) and that the minimum number of pups born at Olive Island in the 2007 breeding season was 159 (95% CL, 148-168) (Table 3.4, Figure 3.2).

Test for equal catchability

Results from Leslie's test of equal catchability are presented in Table 3.6. Results from all recapture sessions also support the assumption of equal catchability.

Survival

Data from a total of four 'capture' sessions with 78 marked individuals (479 total re-sightings and zero 'marked' dead returns) were available for analyses. Given the lack of tagged dead pups recovered, and limited recapture sessions, most parameters including survival (*S*), dead return probability (*r*) and fidelity (*F*) were inestimable. We therefore chose to model 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* and *p* that were equal to 1 between sessions 1 and 4 (30 August – 28 September), with time-variant $Ø = 0.8462$ (range 0.7989 – 0.8839, 30-day survival probability) and $p = 0.7784$ (range 0.7144 – 0.8313, 30-day live-capture probability) between sessions 4 and 5 (28 September to 9 November). The lower estimated survival and capture probability between sessions 4 and 5 are likely to reflect, in part, the reduced re-sight effort during session 5 that was restricted to a single day (9 November). However, despite this it is clear that a large proportion of pups were unavailable for re-sighting on the final visit (session 5) to Olive Island, when 30% fewer pups were estimated to be ashore compared to 28 September (session 3) (Table 3.5).

Based upon estimates of Ø, we estimated the number of pups unavailable for re-sighting at session 5 (Table 3.7). This included unaccounted mortality and pups that had dispersed. Discounting two new recovered dead pups between sessions 4 - 5 provided an adjusted estimated for session 5 of 161 (range 150 -172), the same results as the Petersen estimate for session 4 (Table 3.7).

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 Olive Island between August and November 2007.

Session	1	2	3	4	5
Date	**30-Aug**	**1-Sep**	**20-Sep**	**28-Sep**	**9-Nov**
Cumulative marked		43	43	63	78
Maximum unmarked counted	84	36	71	51	48
Maximum count (live)	84	79	114	114	126
Cumulative dead (unmarked)	10	10	15	16	18
Cumulative dead (marked)	0	0	0	0	0
Total accumulative dead	10	10	15	16	18
Maximum count (live) + cumulative dead	94	89	129	130	144
Cumulative marked + dead (unmarked) + max unmarked	94	89	129	130	144
Petersen Estimate (live)		112		145	111
Petersen Estimate Lower – Upper CL		101-123		135-156	107-116
(No. recapture estimates)		6		6	9
Petersen Estimate (live) + cumulative dead		122		161	129
Lower – Upper CL		111-133		151-172	125-134

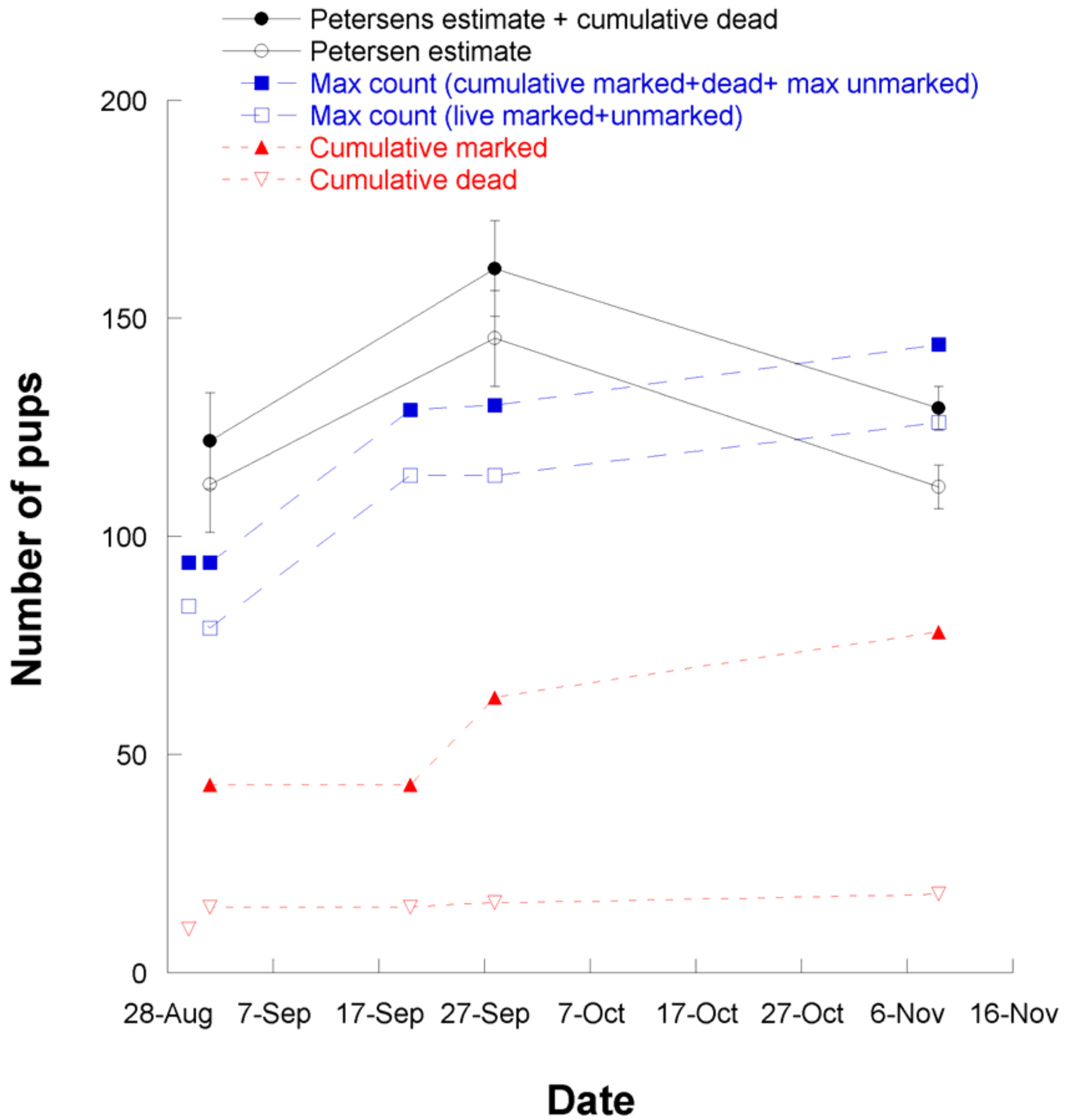

Figure 3.2 Trends in pup numbers at Olive Island between August and November 2007, including cumulative dead, cumulative marked (tagged), maximum counted, and estimated pup production (± 95% CL) from Petersen estimates.

Table 3.5 Details of Petersen mark-recapture procedures undertaken at Olive Island between August and November 2007. 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	SE	V	%	CV	Nlo	Nup
Session 2											
1-Sep	1	43	50	19	111	14.1	199	38%			
1-Sep	2	43	53	21	107	12.3	150	40%			
1-Sep	3	43	50	19	111	14.1	199	38%			
1-Sep	4	43	58	22	112	12.4	155	38%			
1-Sep	5	43	51	20	108	13.0	168	39%			
1-Sep	6	43	55	19	122	15.9	253	35%			
				Mean	**112**	**5.6**		**38%**	**5.0%**	**101**	**123**
Session 4											
28-Sep	1	62	78	32	150	13.6	185	41%			
28-Sep	2	62	69	25	169	19.8	393	36%			
29-Sep	3	62	86	38	140	10.2	104	44%			
29-Sep	4	62	94	43	135	8.2	67	46%			
30-Sep	5	62	77	33	144	12.4	155	43%			
30-Sep	6	62	88	40	136	9.2	84	45%			
				Mean	**145**	**5.2**		**43%**	**3.6%**	**135**	**156**
Session 5											
9-Nov	1	62	91	51	110	4.2	18	56%			
9-Nov	2	62	100	52	119	4.5	20	52%			
9-Nov	3	62	95	53	111	3.8	14	56%			
9-Nov	4	62	84	50	104	4.0	16	60%			
9-Nov	5	62	89	53	104	3.4	11	60%			
9-Nov	6	62	66	34	120	9.3	86	52%			
				Mean	**111**	**2.1**		**56%**	**1.9%**	**107**	**116**

Table 3.6 Leslie's test for equal catchability across each recapture session at Olive Island. *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 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.		n	n^2	i	f	fi	fi^2	χ^2	df	P
2	1		23	529	0	14	0	0			
	2		8	64	1	17	17	17			
	3		3	9	2	10	20	40			
	4		9	81	3	2	6	18			
					4	0	0	0			
		∑	43	683		43	43	75	0.047	42	>0.05
3	1		32	1024	0	2	0	0			
	2		25	625	1	6	6	6			
	3		38	1444	2	11	22	44			
	4		43	1849	3	18	54	162			
	5		33	1089	4	7	28	112			
	6		40	1600	5	14	70	350			
					6	4	24	144			
		∑	211	7631		62	204	818	0.019	61	>0.05
4	1		17	289	0	16	0	0			
	2		7	49	1	11	11	11			
	3		44	1936	2	9	18	36			
	4		38	1444	3	8	24	72			
	5		38	1444	4	14	56	224			
	6		31	961	5	8	40	200			
	7		25	625	6	6	36	216			
	8		14	196	7	3	21	147			
	9		11	121	8	2	16	128			
					9	0	0	0			
		∑	225	7065		77	222	1034	0.056	76	>0.05

Table 3.7 Petersen estimates and cumulative dead for sessions 2, 4 and 5, and estimates of the number of unaccounted for pups (dead or dispersed) between session 4-5 based upon survival estimates derived from CJS analyses. Subtracting the known (recovered) mortalities between session 4-5 from the total estimated unaccounted pups, then adding these to the Petersen estimate for session 5 is given and the adjusted session 5 estimate. Note the high level of agreement between the session 4 Petersen estimate and adjusted session 5 estimate.

Session	Parameter	lo CL	Mean	up CL
2	Petersen Estimate N	111	122	133
4	Petersen Estimate N	151	161	172
5	Petersen Estimate N	125	129	134
1-4	Survival rate Ø	1.0000	1.0000	1.0000
4-5	Survival rate Ø	0.8839	0.8462	0.7989
Est. Pups unavailable (dead/dispersed) session 4-5		27[1]	34[2]	41[3]
Recovered new pup deaths session S4-5		2	2	2
Adjusted S5 estimate N		150	161	172

[1] $N_{4\ (upper\ CL)} - N_{4\ (upper\ CL)}\ (Ø^t)$, where N_4 equals Petersen estimate for session 4, and t equals time between session 4-5 (1.4 m), [2] $N_{4\ (mean)} - N_{4\ (mean)}\ (Ø^t)$, and [3] $N_{4\ (lower\ CL)} - N_{4\ (lower\ CL)}\ (Ø^t)$.

Discussion

Lewis Island

The results presented here provide the first complete estimate for pup production for this colony. Although seven moulted pups were reported from aerial surveys in 1975 (Ling & Walker 1976, Dennis 2005), and from boat surveys in 1976 (9 moulted pups, Dennis 2005), the island was recorded as only a 'possible breeding location' by Gales et al. (1994). Presumably this is because of the potential for moulted pups to have originated from neighbouring populations such as Dangerous Reef and the difficulty of distinguishing moulted pups from juveniles from aerial and boat surveys. The first confirmed breeding on the island based on a ground surveys was in June 2005 (6 brown pups), and two follow-up surveys in July and November of the same breeding season (24 and 78 pups respectively) (Goldsworthy et al. in review). The pup production estimates detailed in this report are from the subsequent breeding season, and place this newly discovered (or rediscovered) colony within the top ten for the species in terms of pup production.

The major problem encountered surveying pup production at Lewis Island, was the dispersal of pups from Dangerous Reef in the mid to latter stages of the breeding season, which may have led to an over-estimation of the numbers of pups. Because we had tagged a subsample of pups at Dangerous Reef, we could estimate the range in numbers that were likely to be present during surveys at Lewis Island. However, because the actual number of untagged pups from Dangerous Reef present during each survey was not known, there is some uncertainty about the accuracy of the pup production estimate for Lewis Island.

Olive Island

Olive Island was recorded as a breeding colony in November 1977 when 52 pups were seen (Dennis 2005). Pups were also seen there in April 1979 (49 unclassed, Ling and Walker 1979) and in November 1990 (27 moulted and one dead, Gales et al. 1994, Dennis 2005). Based on three ground counts undertaken between February and July 2003, 121 pups were estimated to have been born (117 pups were seen in July plus 4 dead in May 2003, Shaughnessy et al. 2005). Ground counts undertaken in September 2004 and January 2005 estimated pup production as 131 pups (Shaughnessy 2005). During the 2006 season, the highest ground count was 126 on 13 April with 24 dead recorded to that date (i.e. 150 in total). Combined Petersen and CJS estimates for the 2006 season determined that pup production was 206 (191-267), 1.37 times the estimate based on direct counting (Goldsworthy et al. 2007a). The estimate for the most recent breeding season in 2007 using the same approach determined pup production to be 161 (151-172), implying a 21% reduction in pup production between the two breeding seasons. The next breeding season is scheduled to commence in December 2008.

The reason for the decrease in pup production between the last two seasons is unclear, although alternate high and low estimates of pup production between breeding seasons have been noted at Seal Bay (Shaughnessy et al. 2006). Whether this pattern occurs at Olive Island, or whether declines in pup production reflect real changes in population size can only be determined by continuing pup production surveys. Estimated mortality rates (cumulative dead pups/ estimated pup production) were actually higher in the 2006 (17%) season compared to the 2007 (11%) season.

Large population survey approach

The recent pup production surveys of two large colonies presented here (Lewis and Olive Islands) indicate that the Petersen estimate procedure provides an improved methodology to estimate changes in pup abundance throughout the breeding season. Provided surveys are timed appropriately to the peak numbers of pups, and the effort used is adequate and consistent between surveys, the method provides the most expedient means of obtaining an accurate estimate of pup abundance with estimable confidence limits. These estimates can be improved by obtaining re-sight data on a sub-sample of marked (tagged) pups to obtain independent measures of capture probability and apparent survival to be calculated using CJS methods. These measures provide a means of validating some of the assumptions of the Petersen estimate, and would account for pups that may be unavailable for re-sighting, either because they are dead (unaccounted mortality) or temporarily dispersed.

4 PUP PRODUCTION AT THE SEAL SLIDE AND JONES ISLAND – 2007 BREEDING SEASON

Introduction

This chapter details results from the survey of two small Australian sea lion colonies, the Seal Slide (Kangaroo Island) and Jones Island (Baird Bay), using an approach developed by Goldsworthy et al. (2007a), termed the cumulative mark and count (CMC) method. This represents the second survey for the Seal Slide using this methodology (see Goldsworthy et al. 2007a), and the first time it has been used at Jones Island, where only direct ground counts have been undertaken.

Methods

The Australian sea lion colony known as the Seal Slide (36.028 S, 137.539 E, Figure 2.1) is located in the Cape Gantheaume Conservation Park, south-east Kangaroo Island. The colony can be accessed by 4WD vehicle and was visited on five occasions during the 2007 breeding season (3 September, 18 September, 5 October, 22 October and 23 October). Jones Island (33.185 S, 134.367 E) is situated at the entrance of Baird Bay on the west coast of the Eyre Peninsula, and was accessed by boat (owner Alan Payne) from the settlement at Baird Bay. The island was visited by researchers on two occasions during the 2007 breeding season (7 September and 27 November), but the colony was observed almost daily by boat throughout the breeding season by A. Payne.

The methodology to survey these sites followed that describe by Goldsworthy et al. (2007a) 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. RFID microchips (23mm glass TIRIS) were also inserted under the skin in the rump in marked pups at the Seal Slide to ensure they were not confused with those micro-chipped at Seal Bay (~24km away).

The number of marked, unmarked and dead pups sighted was recorded on each visit to the colonies, and where possible, additional pups were marked. Marked pups at the Seal Slide were also scanned for a microchip with an RFID antenna to determine where they were born. 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 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.

In addition, the Petersen estimate was used to provide a mean estimate, with confidence limits, following methods detailed in Chapter 3. The lower bounds in confidence limits were determined by the minimum estimate of pup abundance based on the CMC method.

Results

The Seal Slide

A total of 8 pups were marked over the five visits to the colony. Details on the number of unmarked, marked and dead pups sighted on each survey are presented in Table 4.1. The minimum number of marked, dead and unmarked pups present in the population, based on the re-sight and marking history is also presented. The minimum number of pups estimated to have been born in the subpopulation was 15, based on two consecutive surveys undertaken on the 22 and 23 October (Table 4.1). This estimate is greater than the 11 maximum live plus cumulative dead pups sighted on two of the surveys (Table 4.1).

Petersen estimate results for the second to fifth surveys are given in Table 4.2. The surveys conducted on 22 and 23 October were used to calculate a means estimate of 16 pups (± 95% CL 14-18), as these two estimates were undertaken when all pups had been born. Using the minimum estimate of pups based on the CMC method to bound the lower limit of the estimate, provides an overall estimate of pup production for the Seal Slide of 16 pups (range 15-18).

Jones Island

A total of 12 pups were sighted on the first visit to Jones Island on27 September, 10 of which were marked. On a subsequent visit to the island on 7 November, 5 clear and 10 marked pups were observed indicating a minimum estimate of 15 pups (Table 4.3). Only one mate-guarding adult male was seen on this visit, and all pups had a brown or moulted pelage, indicating that the breeding season was close to being finished. This was confirmed by almost daily observations made by Mr Alan Payne from his boat, who observed no additional breeding activity (births) following the 7 November survey. Because all marked pups were sighted on the second survey, the Petersen estimate yielded the same result (15 pups, sd = 0). Based on these data, the minimum number of pups estimated to have been born in the subpopulation during the 2007 breeding season was 15 (Table 4.3).

Discussion

This is the second season for which the cumulative mark and count (CMC) method has been used to estimate pup production at the Seal Slide. In both seasons the method has demonstrated that not all pups were present or visible during any of the surveys. In the 2006 survey, based on the CMC estimate, between 10-40% of pups were not sighted on each survey (Goldsworthy et al. 2007a). Similarly, during the 2007 breeding season about one- third (33%, sd = 4.8) of pups estimated to have been born based on the CMC method, were not sighted on each survey (2^{nd} 33%, 3^{rd} 38%, 4^{th} 33% and 5^{th} 27%, Table 4.1). In contrast, results from Jones Island indicate less sightability bias of pups at this subpopulation, as all of the pups marked during the first survey were sighted on the second survey (Table 4.2). This suggests that ground counts may be less prone to sightability bias at Jones Island compared to other sites such as the Seal Slide.

We applied the Petersen estimate to the re-sight data at the Seal Slide and this provided a good means to determine the confidence limits around the estimate of pup production. In fact the CMC method provides a benefit by fixing the minimum value of the pup production estimate, reducing the range in estimates for these small colonies. For Jones Island, the Petersen estimate produced the same result as the CMC method because all the marked pups were sighted in the second survey, producing a standard deviation and variance of zero. Future surveys could be improved by undertaking multiple recaptures during each survey as is done for larger colonies.

Trends in abundance

Although records of pups born at the Seal Slide go back to 1975 (Dennis 2005), the quality of some surveys relative to the timing of breeding is uncertain, and as such there is the potential that many of the pups recorded in the past at the Seal Slide may represent dispersed pups from Seal Bay. To this end, Shaughnessy et al. (in press) restricted counts of pups to those observed within four months of the beginning of the breeding season at Seal Bay. Although controlling for dispersed pups from Seal Bay, this adjustment is likely to have resulted in conservative conclusions, as noted by the authors. Surveys undertaken in the 2002/03 and 2004 breeding season differ from earlier ones in that they included monthly surveys where only pups <1 month old (and therefore assumed to have been born at the Seal Slide) were counted on each survey by experienced observers. The cumulative number of pups <1 month old observed on each survey was used to estimate the number of pups born in that season. Estimates based on this method from these two seasons (2002/03 9 pups, 2004 11 pups), including the two using the CMC methods (2005/06 10 pups, range 10-11 based upon Peterson estimate; 2007 16 pups, range 15-18) provide four consecutive breeding seasons with estimates of pup production with a high level of confidence (Shaughnessy et al. in press, Goldsworthy et al. 2007a, this report). Although there is a general trend for an increase in pup production over these four seasons, there was little evidence to reject the null hypothesis of no change ($F=7.894$, $df=3$, $P = 0.1068$, Figure 4.1). On the basis of data from four breeding seasons, the Seal Slide population appears stable.

Results from the 2007 CMC survey of pup production at Jones Island suggest that thorough ground surveys may not under-estimate pup abundance estimates. Given this, historic ground survey data may provide insights into trends in pup production at Jones Island. The first record of breeding at Jones Island was in August 1977 (2 pups) based on a ground survey, and the next survey when pups were seen was not until December 1990 (5 pups, Gales et al. 1994). More complete ground count data are available for the 1998/99 (9 pups), 2000 (6 pups), 2001/02 (12 pups), 2003 (7 pups) and 2004/05 (15 pups) breeding seasons (Shaughnessy et al. 2005). No data were obtained for the 2006 breeding season. Combining these data with the estimate of 15 pups for the 2007 season (this report), provides trend data for six breeding seasons over seven breeding cycles (Figure 4.2). Over this period there is an increasing trend of ~8.8%/year, but this is not significant ($F=4.527$, $df=5$, $P = 0.10$).

Table 4.1 Details of pup surveys undertaken at the Australian sea lion colony at the Seal Slide (Kangaroo Island) between September and October 2007. The number of clear (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	Clear count	Marked count	Dead clear	Dead marked	Total live count	Total live & dead count	New marked	Cum. marked	Min Alive	Cum. dead clear	Min Total
3-Sep	8	0	3	0	8	11	3	3	8	3	**11**
18-Sep	6	2	0	0	8	8	4	7	9	3	**12**
5-Oct	3	5	0	0	8	8	0	7	10	3	**13**
22-Oct	5	5	0	0	10	10	1	8	12	3	**15**
23-Oct	4	7	0	0	11	11	0	8	12	3	**15**

Table 4.2 Details of Petersen mark-recapture procedures undertaken at the Seal Slide between September and October 2007. 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, Dead is the cumulative number of unmarked dead pups, sd = standard deviation and V = variance. %m = the percentage of marked pups in each sample. The SE (standard error), CV (coefficient of variance), and Nlo (lower 95%confidence limits) and Nup (upper 95% confidence limits) are estimated from the last two surveys (22-23 October 2007).

Date	M	n	m	N	Dead	N+dead	SE	V	%m	CV	Nlo	Nup
18-Sep	3	8	2	11.0	3	14.0	2.4	6.0	25%			
05-Oct	7	8	5	11.0	3	14.0	1.3	1.7	63%			
22-Oct	7	10	5	13.7	3	16.7	1.9	3.5	50%			
23-Oct	8	11	7	12.5	3	15.5	0.9	0.8	64%			
		Mean	**22-23 Oct**	**13.1**		**16.1**	**1.0**		**50%**	6.4%	14.1	18.1
			(±95% CL)	**(11-15)**		**(14-18)**						

Table 4.3 Details of pup surveys undertaken at the Australian sea lion colony at Jones Island between September and November 2007. 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	Clear count	Marked count	Dead clear	Dead marked	Total live count	Total live & dead count	New marked	Cum. marked	Min Alive	Cum. dead clear	Min Total
27-Sept	12	0	0	0	12	12	10	10	12	0	**12**
7-Nov	5	10	0	0	15	15	0	10	15	0	**15**

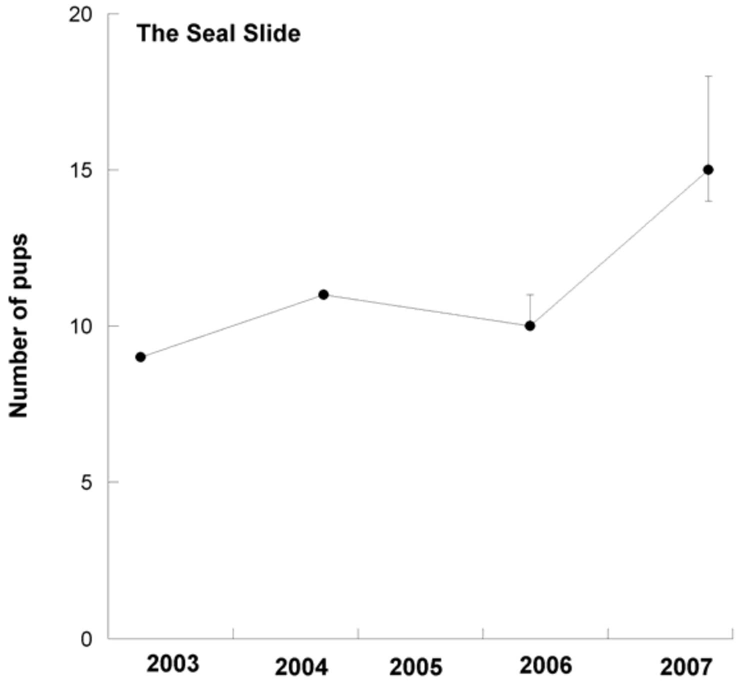

Figure 4.1 Trends in the abundance of Australian sea lion pups born at the Seal Slide (Kangaroo Island) over four consecutive breeding seasons between 2002-03 and 2007. Upper (95%) and lower (absolute minimum) confidence limits are given for the 2006 and 2007 breeding seasons.

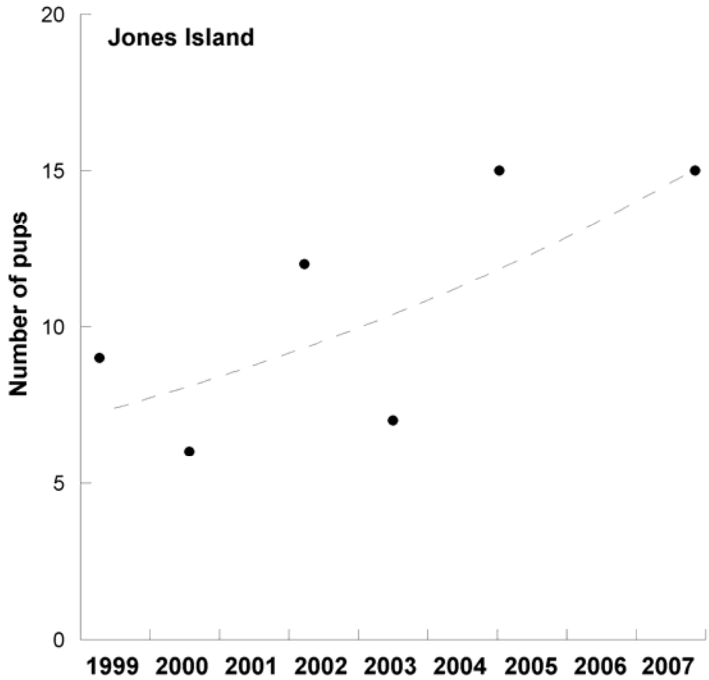

Figure 4.2 Trends in the abundance of Australian sea lion pups born at Jones Island over six breeding seasons between1998-99 and 2007. No survey was undertaken for the 2006 breeding season. An exponential trend line (non-significant) is also presented.

5 CONCLUSIONS AND RECOMMENDATIONS

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, asynchronous breeding schedules and logistical challenges in accessing colonies. 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 standard deviation) estimates of pup production.

The principal purpose of the Goldsworthy et al. (2007a) study and this one were 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 methodology 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.

For large colonies, we now have two consecutive surveys for Olive Island and one for Lewis Island where a combination of Petersen estimates and Cormack-Jolly-Seber (CJS) methods using re-sight histories of individual pups, have been used. The CJS analyses used for Olive Island in 2006 (Goldsworthy et al. 2007a) differed from those used for Olive and Lewis Islands in 2007, in that the greater number of re-sight sessions in the former survey enabled more complex analyses to be used (e.g. Pradel recruitment models, Pollock robust models). Regardless, there is strong conformity in all the results to date demonstrating constant re-catchability of tagged pups (Leslie's test of equal catchability supported in all cases), and support for the assumption of a closed population with no permanent emigration (from Pollock models) (Goldsworthy et al. 2007a).

Based upon these results, Petersen estimates are likely to accurately estimate true pup abundance if undertaken at the appropriate times with the appropriate effort. The main source of error comes from unaccounted mortality, and CJS estimates of apparent survival provide a simple internal check against which cumulative recovered mortalities can be compared, and if necessary adjusted. For the Olive Island pup production estimate of the 2006 season, adjustment of the Petersen estimate using CJS estimates of unaccounted mortality produced the same result as the combined Petersen estimate with Pradel recruitment and Pollock robust model analyses (Goldsworthy et al. 2007a). Similarly, analyses for the 2007 breeding season at Olive Island determined that the Petersen estimate for the fourth session provided the best estimate of pup production, as adjustment of the final recapture session accounting for differences in apparent survival produced the same result (see Table 4.7).

Immigration (or dispersal) of pups from neighbouring colonies needs to be taken into account, especially where such colonies occur in close proximity and where breeding schedules are similar. For Olive Island, this is unlikely to be an issue because it is situated more than 30km from the next nearest colonies (36km from Nicholas Baudin Island, >40km from Lilliput and Belfuscu Island), and at least for the Nuyts Archipelago colonies, its breeding season occurs several months earlier. Both these factors are likely to limit the potential dispersal of new season pups to Olive Island during its breeding season. In contrast, immigration of new season pups from neighbouring colonies at Lewis Island was identified as a major issue that may confound estimates of pup production at this site. The Dangerous Reef breeding season occurs some 5-6 months earlier than at Lewis Island which is only 25km away. At least nine tagged pups from Dangerous Reef were observed at Lewis Island on the third and fourth re-sight session. If pups had not been tagged at Dangerous Reef, their presence at Lewis Island would have been undetectable and estimates of pup production would have been inflated. Based upon Petersen estimates of the number of live pups present at the end of the breeding season at Dangerous Reef (Goldsworthy et al. 2007b), and the number of those tagged, we were able to estimate the numbers of untagged pups from Dangerous Reef that may have been present at Lewis Island during surveys, and subtract these from the overall estimate of pup abundance. However, because the level of immigration/dispersal from Dangerous Reef may not always be calculated, as it will be dependent upon surveys and tagging undertaken at Dangerous Reef in the preceding breeding season, Lewis Island should not be used as one of the regionally representative colonies as determined by Goldsworthy et al. (2007a).

The small colony surveys undertaken at the Seal Slide and Jones Island using the cumulative mark and count (CMC) method also proved to be highly successful in determining minimum estimates of pup production for these sites, and indicated inter-colony difference in sightability biases. For Jones Island, this suggested that some of the historic ground surveys may well provide an accurate measure of pup production, providing a time series back to 1999. Importantly, we were able to demonstrate that Petersen estimates can also be applied to small colony surveys and provide estimates of confidence limits. In the past, Petersen estimates have been considered inappropriate for estimating abundance in small colonies, because pups are often widely dispersed with limited mixing of marked and unmarked pups (McKenzie et al. 2005, Goldsworthy et al. 2007a). However, as the CMC method can only provide a minimum estimate of pup production, with confidence in this estimate increasing as the number of unmarked pups is reduced through marking on subsequent surveys, a mark-recapture procedure using the Petersen estimate provides an approach to calculate a mean estimate and a method to determine the upper confidence limit. Although the Seal Slide and Jones Island colonies are small in number, pups tend not to be widely dispersed and mixing of pups for mark-recapture purposes is adequate. As long as the main conditions for the Petersen estimate are met, then size of colony should not affect the suitability of the method. These main conditions include that 1) the probability of capturing an individual is the same for all individuals in the population, 2) no animal is born or immigrates into the study area between marking and recapturing, 3) marked and un-marked individuals die or leave the area at the same rate, and 4) no marks are lost (Caughley 1977). As per the larger colonies, the use of multiple recaptures within each survey will improve the accuracy and precision of Petersen estimates. Six recapture estimates within each survey is considered the optimal approach, as beyond this number improvements in the accuracy and precision of estimates are negligible (Shaughnessy et al. 1995). We therefore recommend six recapture estimates are made during each survey for subsequent small colony surveys.

Trend analyses of historic and current estimates of pup production at the Seal Slide and Jones Island suggest that there has been no evidence for a change in abundance over the previous four and eight years at these sites. In contrast, the last two surveys at the Olive Island subpopulation indicate a 21% reduction in pup production between successive breeding seasons. It is unclear whether this drop in pup production is a consequence of natural factors operating within the population that cause fluctuations in pup production between seasons. There is evidence of alternating high and low pup production years in the Seal Bay population (Shaughnessy et al. 2006), however, given the magnitude of the reduction in pup production observed between two successive breeding seasons, ongoing assessment of pup production is recommended. The next breeding season at Olive Island is scheduled to commence in November 2008.

At the time of writing this report, surveys of Australian sea lion populations at Lilliput and Blefuscu Islands and Breakwater and Gliddon Reefs in the Nuyts Archipelago; and Dangerous Reef and English Island in southern Spencer Gulf are underway (ACAMMS supported project No. 27). As part of that project, and following discussions with DEWHA staff in the Migratory and Marine section, a stakeholder workshop was recommended to be held in 2008 following submission of this report (and before the closure of the ACAMMS funding round for 2009). Discussions should be held in order to reach agreement on the appropriate survey methodologies for the species, and the subset of subpopulations that should form the basis for an ongoing monitoring program. This should enable a critical performance measure of the draft Australian sea lion Recovery Plan to be agreed upon.

Recommendations:

- Mark-recapture methods using the Peterson estimate in conjunction with estimates of cumulative mortality provide an appropriate means of obtaining accurate estimates of pup abundance with estimable confidence limits for large Australian sea lion colonies.
- Petersen estimates can be improved by obtaining re-sight data on a sub-sample of tagged pups that enable independent measures of capture probability and apparent survival to be calculated using CJS methods. These improvements provide a means to account for pups that may be unavailable for re-sighting, either because they are dead (unaccounted mortality) or temporarily dispersed.
- Standardisation of large colony survey design should include:
    - a minimum of three surveys targeting the fourth, fifth and sixth months of the breeding season;
    - appropriate tagging effort of pups (~40% of live pups);
    - six recapture sessions for each survey;
    - adequate and consistent re-sight effort of tagged pups; and
    - consistent efforts to locate and record cumulative mortalities.
- CMC and Petersen estimate methods provide suitable means to estimate pup production with confidence limits at small Australian sea lion colonies.
- Standardisation of small colony survey design should include:
    - a minimum of three surveys targeting the fourth, fifth and sixth months of the breeding season;
    - efforts to mark as many clear pups as practical during each survey;

    - six recapture sessions for each survey; and
    - consistent efforts to locate and record cumulative mortalities.
- There is a need for a workshop among stakeholders to discuss and develop a National survey strategy for Australian sea lions that will underpin the Recovery Plan process. Key aspects that will need to be agreed upon include:
    - identification of regionally representative colonies (“key monitoring sites” as developed by Goldsworthy et al. 2007a) that will form the basis for ongoing surveys across the range of the species;
    - agreement of survey methodology;
    - strategies to ensure appropriate funding resources are available to support ongoing surveys at these key monitoring sites.

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