Marine Environment & Ecology

Pup production assessment of the Australian sea lion *Neophoca cinerea* at Dangerous Reef and English Island, South Australia, in the 2009/10 breeding season

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SARDI Publication Number F2010/000639-1
SARDI Research Report series No. 480

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

Report to the SA Department of Environment and Natural Resources Wildlife Conservation Fund

Simon D Goldsworthy, Brad Page and Peter D Shaughnessy

July 2010

Government of South Australia
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by

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FRDC PROJECT NUMBER: 2007/041

SARDI Publication No. F2010/000639-1
SARDI Research Report Series No. 480

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This publication may be cited as:
Goldsworthy, S.D., Page, B., Shaughnessy, P.D. (2010). Pup production assessment of the Australian sea lion *Neophoca cinerea* at Dangerous Reef and English Island, South Australia, in the 2009/10 breeding season. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000639-1. SARDI Research Report Series No. 480.

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Printed in Adelaide, July 2010

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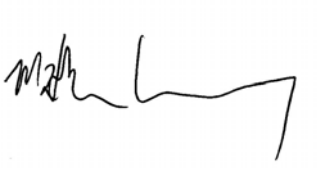
Approved by: M Deveney



Signed:

Date: July 2010

Circulation: Public Domain

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1 EXECUTIVE SUMMARY

Australian sea lion pup production was determined for the Dangerous Reef and English Island populations during the 2009/10 breeding season. A combination of mark-recapture methods, counts of live and dead pups (including cumulative mortality) and a method to estimate cumulative pup production between surveys were used to estimate pup production at Dangerous Reef. The breeding season at Dangerous Reef commenced in June or July 2009 and continued through to March 2010, a period of eight to nine months. Surveys were conducted in September, December 2009, and January and March 2010, roughly corresponding to the third, sixth, seventh and ninth month of the breeding season. Mark-recapture (Petersen) estimates in conjunction with cumulative counts of dead pups indicated that 488 pups (465-511 95% confidence limits) had been born by the sixth month of the breeding season (December 2009). This is comparable to the maximum pup count of 392 pups (based on 230 tagged pups, 112 untagged pups and 50 cumulative dead pups) in the seventh month of the breeding season (January 2010). Using the cumulative pup production method, the estimate was 715 pups (95% CL 672-755) for the 2009/10 breeding season. The estimate of pup mortality to the sixth month of the breeding season based on maximum pup counts was 9.9%, similar to that estimated based on cumulative pup production and dead pups (9.6%) in the last survey in March 2010.

Petersen estimates of pup production are available for six breeding seasons at Dangerous Reef. With successive increases in pup production estimates over the first four seasons (1999 to 2006/07), and declines in the 2008 and 2009/10 breeding seasons, there is no significant trend in abundance with this limited time-series. However, based on a longer time-series of pup abundance based on surveys of live and dead pups, including most breeding seasons since 1996, pup abundance is increasing by about 3.9% per breeding season. Estimates of pup production based on the cumulative pup production method are only available for three consecutive breeding seasons (2006/07, 2008, 2009/10): 831, 541 and 715.

Only one survey of English Island was possible this breeding season (5 December 2009) during which a minimum estimate of 39 pups was determined, representing the highest number of pups reported for this colony. The dispersal of pups to English Island from Dangerous Reef has confounded surveys at English Island, and makes statistical assessment of trends difficult. However, based on historical and recent surveys, the trends in pup production for the colony appear to be positive.

2 INTRODUCTION

The Australian sea lion (*Neophoca cinerea*) is Australia's only endemic seal species and is also its least numerous. It is unique among pinnipeds because it is the only species that has a non-annual breeding cycle, which is temporally asynchronous across its range. It has the longest gestation period of any pinniped, as well as protracted breeding and lactation periods. The evolutionary determinants of this unusual reproductive strategy remain enigmatic. These factors, including the species' small population size (~14,700 individuals), which is distributed over numerous, small colonies, make the Australian sea lion vulnerable to extinction (Goldsworthy & Page 2007). Recent population genetic studies have indicated little or no interchange of females among breeding colonies, even those separated by short distances (Campbell et al. 2008). The important conservation implication is that each breeding colony is a closed population. As such, the Australian sea lion poses significant conservation and management challenges. The species is listed as vulnerable under the threatened species category of the Commonwealth *Environment Protection and Biodiversity 1999 Act* (EPBC Act), vulnerable under the South Australian *National Parks and Wildlife Act* (1972) and recently it was upgraded to endangered by the IUCN Red List (www.iucnredlist.org).

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, abundance was monitored by direct pup counts. Since 1999, multiple counts throughout the breeding season, in conjunction with mark-recapture methods have been used to estimate pup production. Mark-recapture provides a more robust means to estimate pup abundance because the method enables the calculation of confidence intervals. Results from five breeding seasons between 1999 and 2008 at Dangerous Reef using this method have been detailed by Goldsworthy et al. (2009b).

Australian sea lion pup abundance has been surveyed at English Island over seven breeding seasons using pup counts. From 1998 to 2002, between four and 15 pups were recorded per season (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. 2009c) and June 2008 it was estimated to be 23 (Goldsworthy et al. 2009b).

Aims and Objectives

The aims of this study were to: 1) monitor the pup numbers at Dangerous Reef and English Island by conducting four pup production surveys during the 2009-10 breeding season; 2) monitor dead pup numbers during each survey; 3) estimate pup numbers using mark-recapture methods; and 4) compare the 2009-10 pup production data with data from previous breeding seasons at Dangerous Reef and English Island.

3 METHODS

Field sites

Dangerous Reef (34.870 S, 136.2170 E) is 35 km south-east of Port Lincoln, South Australia, and forms part of the Sir Joseph Banks Group Conservation Park (Figure 1). It comprises Main Reef with nearby East Reef and West Reef, covering about 12 ha in total (Robinson et al. 1996). Sea lion pups are born on Main Reef, and some move to the West Reef several weeks after birth. Dangerous Reef was accessed by vessel from Port Lincoln four times between 18 September 2009 and 13 March 2010. During each visit to the island, sea lion pup numbers were surveyed by direct counting of live pups, surveying of dead pups and by mark-recapture. Each survey is defined as a session. 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 Conservation Park. Australian sea lion pups there were surveyed on 5 December 2009 (Figure 1).

Live and dead pup counts

The number of live pups was counted while slowly 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 its centre to count the pups.

Live pups were recorded in one of three categories: black pups (considered to be <4 weeks), brown pups (approximately 4-20 weeks) and moulted (>20 weeks age) (Shaughnessy et al. 2005). We recorded the number of pups that had died since the previous visit. To avoid double counting, dead pups were covered with rocks when they were counted. The number

of dead pups was summed to give the number of 'accumulated dead pups'. For each survey the number of live pups was added to the number of cumulative dead pups to estimate pup production for the season to that date.

Mark-recapture

Direct counting pups of pups to determine their abundance is known to underestimate total pup abundance, because pups that are hidden from view (sightability bias) or absent from the colony (availability bias) at the time of the survey are not included. The influence of these factors on estimates of pup numbers can be reduced to some degree by undertaking a mark-recapture procedure. Mark-recapture methods have been used to estimate pup production at fur seal colonies in Australia since 1988 (Shaughnessy et al. 1995, Shaughnessy & McKeown 2002, Kirkwood et al. 2005), but have only been recently applied to estimating pup production in the Australian sea lion population at Seal Bay, Dangerous Reef, Olive and North Page and South Page Islands (McIntosh et al. 2006, Shaughnessy et al. 2006, Goldsworthy et al. 2007c).

A mark-recapture procedure was used to estimate the number of live pups on the Main Reef of Dangerous Reef on four occasions; in September and December 2009, and January and March 2010. During the first three occasions, pups were tagged in the trailing edge of each fore-flipper with individually numbered plastic tags (Dalton® Size 1 Supertags). During each field trip to Dangerous Reef, individual re-sight records were collected for marked individuals with the aid of binocular observations. As noted above, rocks were placed on top of dead pups to avoid repeat counting. Records of the total number of tagged, untagged and newly recorded dead pups were noted on each re-sight (recapture) survey.

Recaptures were undertaken on each occasion that the island was visited: 9 times in September 2009, 6 times in December 2009, 8 times in January 2010 and 6 times in March 2010. Individual re-sights of tagged pups were usually undertaken over a minimum of three days prior to recapture surveys; they were used as the sample of 'marked' individuals in the population available for the recapture surveys on the last day. During recapture surveys, the individual identity of tagged pups was determined by reading tag numbers with binoculars. The number of untagged pups seen was also recorded, as was the number of recently dead pups that had not been marked. Pups sighted in future surveys (i.e., known to be alive) were included as being available for re-sighting in previous recapture sessions.

Mark-recapture estimates of pup numbers (N) were calculated using a variation of the Petersen method (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

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

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

Cumulative pup production

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

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

Where $\hat{N}_1$ is the estimated total number of pups born from Petersen estimates plus cumulative dead pups up until session 1, and $\hat{N}_2$ is the number of pups estimated in session 2. $\hat{N}_2 - \hat{N}_1$ is therefore the net pup production between sessions 1 and 2 (i.e. the number of births minus the number of deaths that have occurred between each session). $\hat{\varphi}_{1-2}$, is the apparent survival of pups between session 1 and 2 and is estimated as the proportion of the marked pups known to be alive in session 1 (M_1), that were known to be alive in session 2 (or M_2 / M_1). This approach was repeated to estimate the number of births that occurred between session 2 and 3, and sessions 3 and 4. Total cumulative pup production (N) was hence estimated as:

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

Confidence limits (± 95% CL) for each between-session estimate were calculated using either the +95% CL or -95%CL estimates, rather than the mean estimate of $\hat{N}$.

English Island

One survey of English Island was made during the 2009/10 breeding season. This was undertaken on 5 December 2009. Live and dead pups were counted while slowly walking around the island and checking under rock ledges and in caves. Live pups were recorded in one of three categories: black pups (considered to be <4 weeks), brown pups (approximately 4-20 weeks) and moulted (>20 weeks age) (Shaughnessy et al. 2005).

Trends in abundance

The rate of change in pup production 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 formula

$$r = (e^r - 1) * 100.$$

4 RESULTS AND DISCUSSION

Dangerous Reef

Pup counts

On the first visit to Dangerous Reef on 18 September 2009, 136 live pups were recorded, suggesting the breeding season had commenced 2-3 months earlier (in June or July). Newborn pups were sighted in the final surveys in March 2010, suggesting that the duration of the breeding season for 2009-10 was about 8-9 months. Counts of live and dead pups surveyed at Dangerous Reef during the 2009-10 pupping season are presented in Table 1 and Figures 2 and 3. The largest estimate of pups, based on the maximum live pups counted (392) and cumulative dead pups (43), was 435 on 5 December 2009 (Table 1, Figure 3).

Mark-recapture estimates of pup numbers

Two hundred and thirty pups were marked for the mark-recapture estimate procedure. The number of tagged pups available to be re-sighted varied considerably between surveys (from 52 to 168, Table 2). Petersen estimates of the number of live pups were greatest during the second session, in December 2009 (mean 445, 95% CL 422-468), and then progressively declined in the third (mean 417, 95% CL 383-444) and fourth recapture sessions (mean 293, 95%CL 272-315, Table 2). The addition of cumulative dead pups to these values provided higher estimates of pup numbers than counts, the maximum being 488 in December 2009 (95% CL 465-511, Table 1).

Comparisons of Petersen estimates with direct counts at Dangerous Reef have now been made over six breeding seasons (Table 3). Petersen estimates are between 1.19 and 1.38 times the direct count figures (95% confidence limits of comparisons ranged from 1.12 to 1.45). The discrepancy between the direct counts and the Petersen estimates on each occasion results from the difficulty of sighting all pups in the colony. Some pups may not be viewed during counting because they are away from the island, swimming in the shallows or obscured by rocks.

Cumulative pup production estimates

The cumulative pup production method assumes that the sum of the Petersen estimate and cumulative mortalities in the first session (158, 95% CL 149-167; 18 September 2009) are representative of all pups born to that date. Based on the pelage pattern of pups, this

assumption is supported as most pups are likely to have been <3 months old, and as such would be unlikely to be spending significant time at sea. Based on tag re-sights between sessions 1 and 2, 2 and 3 and 3 and 4, apparent survival rates (φ) were 0.75, 0.67 and 0.67, respectively (Table 1). Based on Petersen estimates of live pups plus cumulative dead pups, the numbers of births between these sessions was 370, 141 and 46, providing a cumulative pup production estimate for the 2009/10 breeding season of 715 (672-755, ±95%CL) (Table 1). This estimate is 38.4% greater than the largest Petersen estimate of live pups plus cumulative dead pups. The cumulative pup production method was also applied to the previous two breeding seasons at Dangerous Reef (2006/07; 2008) (Table 5). Cumulative pup production estimates range from 1.04 to 1.87 times Petersen estimate methods. Cumulative estimates are larger because by the end of the breeding season some pups may be spending time at or other haul-out, precluding their re-sight and recording by other census methods.

Assuming the 2009/10 breeding season at Dangerous Reef commenced 3 months before the first survey (i.e., on 18 June 2009), the estimated cumulative pup production curve is presented in Figure 4. A probit analysis of the sigmoidal function fitted to these data to determine the season of births (Caughley 1977) identified the median pupping date of 11 November 2009, with 90% of births occurring between 11 August 2009 and 11 January 2010 (184 days or 6.1 months).

Pup mortality

For the 2009-10 pupping season at Dangerous Reef, 43 dead pups were recorded by 5 December 2009 when the estimated number of births reached a maximum of 435, giving an incidence of pup mortality of 9.9% (Table 4).

For the last ten pupping seasons at Dangerous Reef (since 1996), the incidence of pup mortality has ranged from 9.9% to 44.6% (Table 4). It was higher for pupping seasons that occurred predominantly in winter (30.3% in 1996, 42.0% in 1999, 44.6% in 2002, 31.1% in 2005, and 43.0% in 2008, with un-weighted 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, 13.9% in 2006-07 and 9.9% in 2009-10, with un-weighted average 16.1%). 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 rate (proportion of

dead pups) was significantly higher in winter breeding seasons than summer ($F_{1,8}$ =33.074, P<0.001, arcsine transformed data).

Based on cumulative pup production estimates calculated for the last three breeding seasons at Dangerous Reef, mortality rates to the last survey (2006/07, 2008, 2009/10) have been 10.6%, 42.7% and 9.6%, respectively (Table 5).

Trends in abundance at Dangerous Reef

Live and dead pup surveys

Estimates of pup numbers (live and dead) by direct counting are available for 14 seasons from 1975 to 2009-10, and range from 248 to 585 with an average of 402 (sd = 111) (Table 4, Figure 3).

Because dead pups were not counted in the 1994-95 season, the number of live pups in that season has been used to estimate the total number of births (Table 4, see Shaughnessy 2005c). Using the maximum live-pup counts and numbers of cumulative dead pups over these 14 breeding seasons (1975 to 2009-10) as an index of pup production, the number of pups born at Dangerous Reef has increased at an exponential rate of r = 0.026 or 2.65% per breeding season (~ 1.5 years) or r= 0.017 or 1.76% per year, although the trend is not significant ($F_{1,13}$ = 10.604, P = 0.069, R^2 = 0.469).

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 3). 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). Counting that ended in the fourth month of a pupping season is therefore likely to underestimate pup production. Data for the 1994/95 season were incomplete because there were no counts of dead pups and total births were adjusted for mortality based on the averages from the three preceding summer breeding seasons (Table 4). The most accurate pup count data have therefore been collected since 1996, with the exception of 1997/98. Analyses of data from the nine pupping seasons from 1996 (excluding 1997/98), indicate that pup counts have increased at r = 0.038 or 3.9% per breeding season, equivalent to r = 0.025 or 2.6% per year, with this trend being statistically significant ($F_{1,8}$ = 7.486, P = 0.029, R^2 = 0.517) (Figure 3).

Despite variable and often high rates of pup mortality between season, the maximum direct count of live pups (maximum pup count – cumulative dead pups at the maximum pup count),

showed a significant increase over 10 seasons from 1996 (r = 0.057, 5.9%) and years (r = 0.038, 3.9%) using data collected since 1996 ($F_{1,9}$ = 5.61, P = 0.045, R^2 = 0.427) (Figure 3).

Mark-recapture surveys

Petersen estimates plus the cumulative number of dead pups have been used to determine pup numbers over six breeding seasons between 1999 and 2009/10 (Table 3). Trend data for the six seasons show an increase between seasons of r = 0.034 or 3.4% per season, which is equivalent to r = 0.022 or 2.3% increase per year (Figure 2). With the drop in pup numbers in the 2008 and 2009/10 breeding seasons, and with the limited time series of the mark-recapture data set, this trend is not significant (for both linear regressions $F_{1,5}$ = 0.936, P = 0.388, R^2 = 0.436).

Cumulative pup production

Estimates of pup production based on the cumulative pup production method are only available for three consecutive breeding seasons (2006/07, 2008, 2009/10): 831, 541 and 715 (Table 5). Data from more breeding seasons are required before trends in abundance can be accurately assessed using this method.

English Island

English Island pup counts

English Island was surveyed on one occasion, 5 December 2009. On this visit 37 live pups (11 black, 26 brown) and 2 dead pups were observed. This gives a total estimate of 39 pups for the 2009/10 season.

Trends in abundance at English Island

Australian sea lion pup abundance has now been surveyed at English Island over seven breeding seasons. From1998 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. 2009c), and in 2008, a minimum of 23 pups were reported (Goldsworthy et al. 2009a). The estimate for the 2009/10 breeding season, based on a single survey, was 39 pups. Previous surveys have been confounded by the issue of pups dispersing to English Island from Dangerous Reef during the breeding season, as well as high variability in survey effort across breeding seasons. However, based on historical surveys the trend in pup abundance for this colony is positive.

Table 1. Summary of details of abundance estimates of Australian sea lion pups at Dangerous Reef in the 2009-10 breeding season: counts, tagging, cumulative mortalities and various direct count and mark-recapture and cumulative pup production abundance estimates, during four visits (sessions) between September 2009 and March 2010.

Session	**1**	**2**	**3**	**4**
Date	**18-Sep**	**5-Dec**	**26-Jan**	**13-Mar**
Cumulative marked	52	181	230	230
Maximum unmarked counted	60	161	112	87
Maximum count (live)	136	392	324	212
Cumulative dead (unmarked)	19	40	50	56
Cumulative dead (marked)	0	3	3	13
Total cumulative dead	19	43	53	69
Maximum count (live) + cumulative dead	155	435	377	281
Cumulative marked + dead (unmarked) + max unmarked	131	382	392	373
Petersen Estimate (live)	139	445	417	293
Petersen Estimate Lower – Upper CL	130-148	422-468	383-444	272-315
(No. recapture estimates)	9	6	8	6
Petersen Estimate (live) + cumulative dead	158	488	470	362
Lower – Upper CL	149-167	465-511	436-497	341-384
Apparent survival (φ) between sessions		0.750	0.673	0.673
Estimated pup production between sessions		370	141	46
Lower – Upper CL		353-386	124-153	46-50
Estimated cumulative pup production	158	528	669	715
Lower – Upper CL	149-167	502-533	626-706	672-755

Table 2. Details of Petersen mark-recapture procedures undertaken at Dangerous Reef between September 2009 and March 2010. 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	V	%	CV	Nlo	Nup
Session 1											
18-Sep	1	52	76	32	123	10	97	42%			
18-Sep	2	52	88	32	142	12	143	36%			
18-Sep	3	52	41	21	100	11	124	51%			
18-Sep	4	52	92	32	148	13	160	35%			
18-Sep	5	52	87	29	154	15	223	33%			
18-Sep	6	52	77	21	187	25	645	27%			
18-Sep	7	52	98	45	113	4	20	46%			
18-Sep	8	52	88	33	138	11	122	38%			
18-Sep	9	52	91	32	147	12	155	35%			
				Mean	**139**	**5**		**38%**	**3.3%**	**130**	**148**
Session 2											
5-Dec	1	168	267	108	415	18	331	40%			
5-Dec	2	168	196	72	455	32	1005	37%			
5-Dec	3	168	185	65	475	36	1331	35%			
5-Dec	4	168	249	88	474	28	763	35%			
5-Dec	5	168	194	73	444	30	922	38%			
5-Dec	6	168	183	75	408	27	702	41%			
				Mean	**445**	**12**		38%	**2.7%**	**422**	**468**
Session 3											
26-Jan	1	162	170	63	435	33	1109	37%			
26-Jan	2	162	170	59	464	38	1451	35%			
26-Jan	3	162	151	61	399	30	930	40%			
26-Jan	4	162	183	71	416	28	808	39%			
26-Jan	5	162	128	50	411	37	1358	39%			
26-Jan	6	162	142	64	358	25	639	45%			
26-Jan	7	162	174	66	425	31	969	38%			
26-Jan	8	162	157	59	428	34	1184	38%			
				Mean	**417**	**11**		**39%**	**3.7%**	**383**	**444**
Session 4											
13-Mar	1	109	150	63	259	16	250	42%			
13-Mar	2	109	120	40	324	32	1041	33%			
13-Mar	3	109	126	51	268	21	424	40%			
13-Mar	4	109	124	38	352	37	1380	31%			
13-Mar	5	109	113	48	255	20	414	42%			
13-Mar	6	109	115	41	303	29	846	36%			
				Mean	**293**	**11**		37%	**3.8%**	**272**	**315**

Table 3. Summary of mark-recapture estimates of the abundance of Australian sea lion pups at Dangerous Reef over six breeding seasons, highlighting comparison between mark-recapture estimates and direct counts of live pups. For the 2006-07 season comparisons between methods can be made for two of the three mark-recapture estimates.

Date (breeding season)	Max. direct count (inc. dead)	Direct count of pups	Mark-recapture estimate of pups	Comparison[1]	95% confidence interval	No. month since pupping commenced to		Source
						Max count	Mark-recapture estimate	
July 1999 (1999)	383	240	285	1.19	1.12 - 1.25	4	4	(Shaughnessy & Dennis 1999)
Jan 2004 2003-04)	499	333	423	1.27	1.21 - 1.31	5.5	5	(Shaughnessy 2004)
July 2005 (2005)	585	272	326	1.20	1.15 to 1.25	6	6	(Shaughnessy 2005a)
Nov 2006 (2006-07)	397	330	436	1.32	1.26 - 1.38	4	4	(Goldsworthy et al. 2007b)
Jan 2007 (2006-07)	575	495	629	1.27	1.12 - 1.42	6	6	(Goldsworthy et al. 2007b)
Aug 2008 (2008)	537	210	289	1.38	1.31 - 1.45	6-7	6-7	(Goldsworthy et al. 2009b)
Dec 2009 (2009-10)	435	392	488	1.24	1.19-1.30	6	6	This report

[1] Mark-recapture estimate divided by Direct count

Table 4. Estimated number of births of Australian sea lions at Dangerous Reef, South Australia for 14 pupping seasons between 1975 and 2009-10. Data are collated from Dennis (2005), Shaughnessy and Dennis (2001) and (2003), Shaughnessy (2004) and (2005b), Goldsworthy et al. (2007a), Goldsworthy (2009b) 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 et al. (2005).

Pupping season	Cumulative dead pups at max. pup count [a]	Max. pup count [b]	Pup mortality (%)	Month of max. live count since pupping began	Max. cumulative dead pup
1975	73	356	20.5	5	73
1976-77	26	262	9.9	4	26
1990	55	260	21.2	4	55
1994-95	-	354 [c]	not estimated	6.5	
1996	110	363	30.3	-	110
1997-98	38	248	15.3	4	43
1999	161	383 [d]	42.0	4	165
2000-01	90	393	22.9	7	90
2002	190	426 [e]	44.6	6	190
2003-04	93	499 [f]	18.6	5	100
2005	182	585 [g]	31.1	5	274
2006-07	80	575 [h]	13.9	6	88
2008	231	537	43.0	6-7	231
2009-10	43	435	9.9	6	69

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

Table 5. Comparison of the estimated number of births of Australian sea lions at Dangerous Reef, South Australia for 3 breeding seasons between 2006-07 and 2009-10 based on Petersen estimates and cumulative pup production methods. Estimates of pup mortality for these breeding seasons based on cumulative pup production methods are also presented.

Breeding season	Method of estimating pup production			
	Petersen estimate plus cumulative dead (±CL)	Cumulative pup production (±CL)	Pup mortality based on cumulative pup production estimates	Comparison[1]
2006-07	764 (693-858)	831 (751-912)	10.6%	1.09
2008	520 (506-535)	541 (518-563)	42.7%	1.04
2009-10	488 (465-511)	715 (672-755)	9.6%	1.87

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

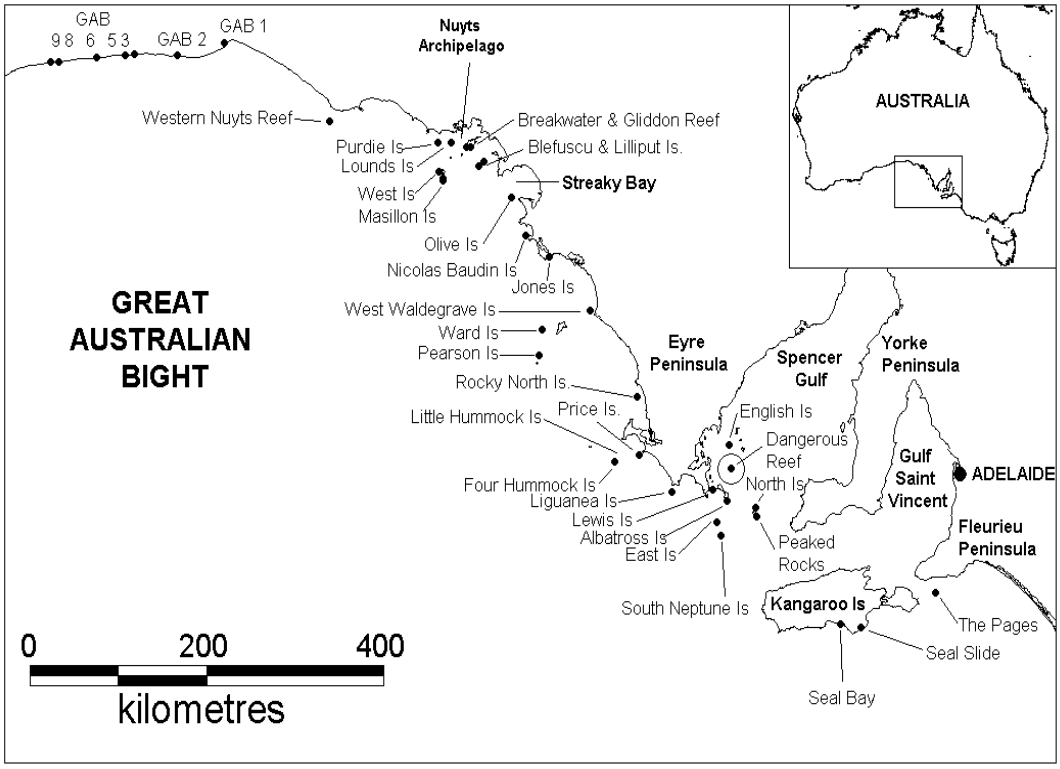

Figure 1. Location of Dangerous Reef and English Island in southern Spencer Gulf, relative to other Australian sea lion colonies in South Australia.

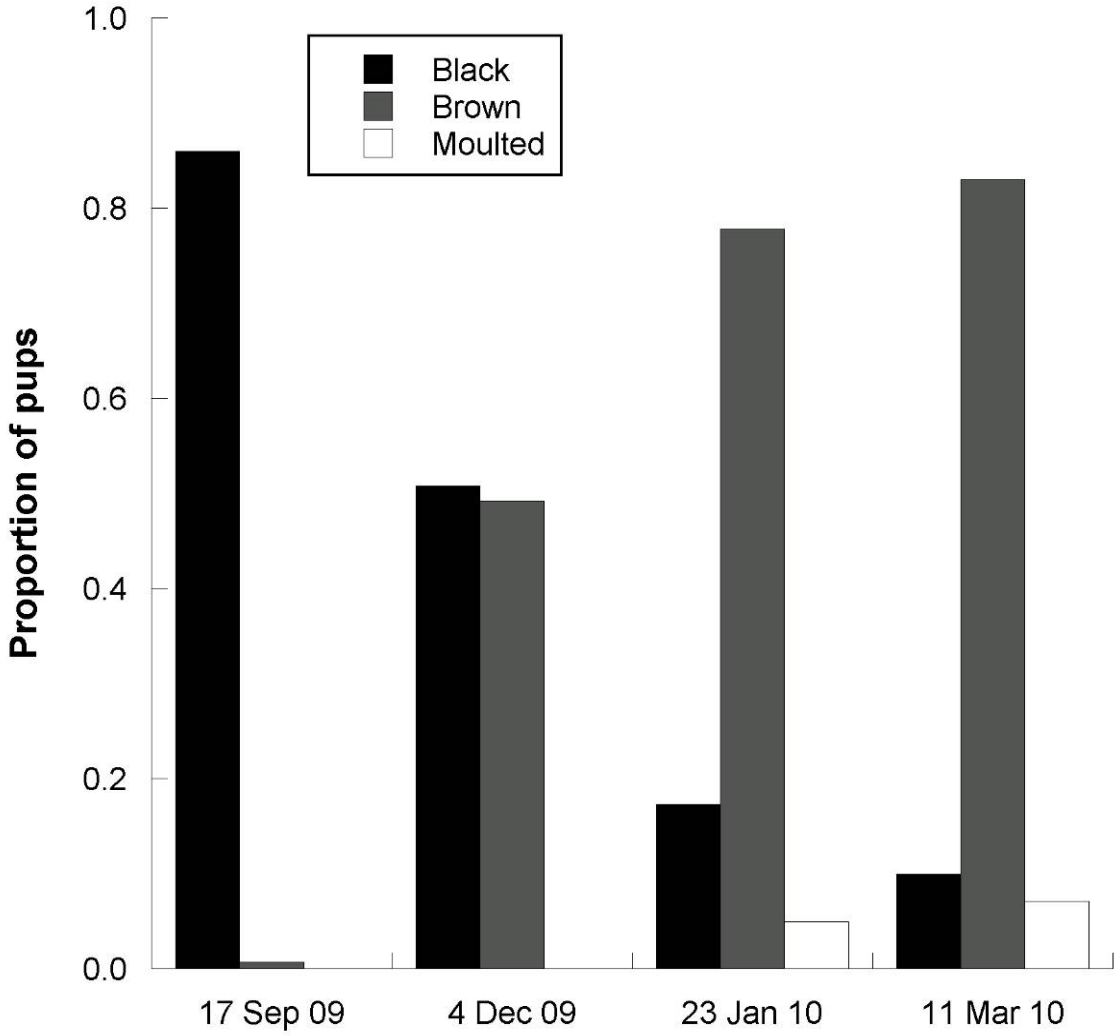

Figure 2. Proportions of Australian sea lion pups classified in three categories (black, brown and moulted) counted during four surveys at Dangerous Reef in the 2009-10 breeding season.

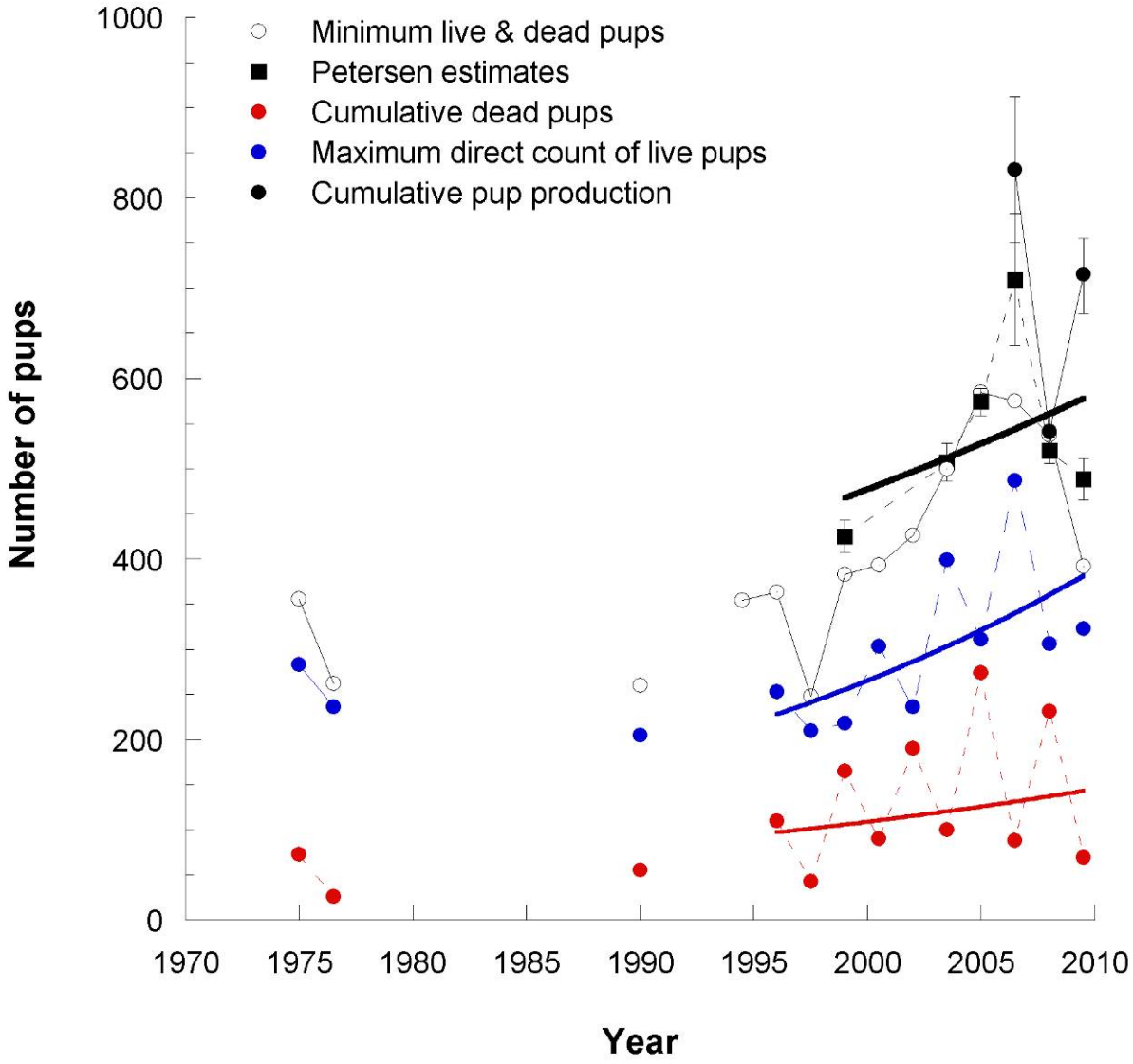

Figure 3. Trends in the abundance of Australian sea lion pups at Dangerous Reef, based upon cumulative pup production, Petersen estimates, minimum live and cumulative dead pup counts, maximum direct count of live pups, cumulative dead pups for 14 breeding season between 1975 and 2009-10. Error bars around estimates are ± 95% CL. Exponential curves are fitted to subsets of Petersen estimates, minimum live and cumulative dead pup counts.

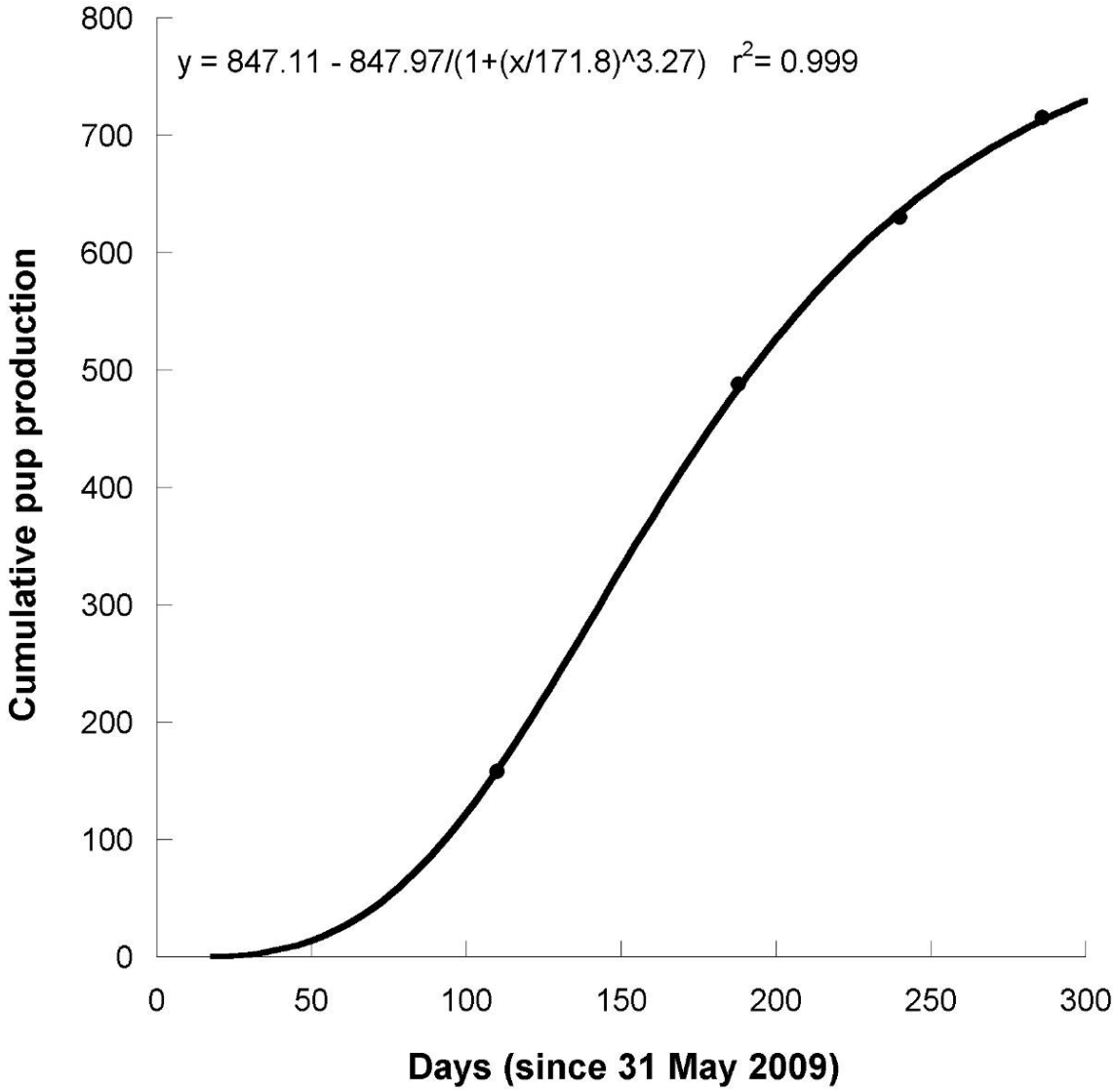

Figure 4. Estimated cumulative pup production of Australian sea lions during the 2009/10 breeding season based on estimates of pup production to 18 September 2009, and pup production between the next three survey sessions (5 December 2009, 26 January 2010 and 13 March 2010). The sigmoidal curve fitted to the data assumes that the breeding season commenced on 18 June 2009.

6 ACKNOWLEDGMENTS

We thank the Wildlife Conservation Fund (Department for Environment and Heritage) for funding the project. Transport to Dangerous Reef and English Island was provided by Protec Marine Port Lincoln (Tony Jones and Adam Kemp). We also thank Paul Rogers, Saras Kumar, Guido Parra, Andrew Lowther, Rachael Gray, and Damien Higgins for field assistance. The work was conducted under an animal ethics permit from SA Department of Environment and Natural Resources, and the PIRSA Animal Ethics Committee. We thank the Wildlife Conservation Fund for funding this project and Kate Lloyd and Peter Canty (SA Department for Environment and Heritage) for provision of SA DENR Permits. We thank Paul van Ruth and Kathryn Wiltshire for reviewing a draft of this report.

7 REFERENCES

Campbell RA, Gales NJ, Lento GM, Baker CS (2008) Islands in the sea: extreme female natal site fidelity in the Australian sea lion, *Neophoca cinerea.* Biology Letters 4:139-142

Caughley G (1977) Analysis of vertebrate populations. John Wiley & Sons Ltd, Bath, p 234

Dennis TE (2005) Australian sea lion survey (and historical) records for South Australia. Report to the Wildlife Conservation Fund, Department for Environment and Heritage, South Australia

Gales NJ, Shaughnessy PD, Dennis TE (1994) Distribution, abundance and breeding cycle of the Australian sea lion, *Neophoca cinerea* (Mammalia: Pinnipedia). Journal of Zoology, London 234:353-370

Goldsworthy SD, Lowther A, Shaughnessy PD, McIntosh RR, Page B (2007a) Assessment of pup production and the maternal investment strategies of the Australian sea lion *Neophoca cinerea* at Dangerous Reef in the 2006-07 breeding season. Report to the Department for Environment and Heritage, Wildlife Conservation Fund South Australia. Report No. SARDI Aquatic Sciences Publication Number F2007/000929-1. SARDI Research Report Series No 249

Goldsworthy SD, Page B (2007) A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries. Biological Conservation 139:269-285

Goldsworthy SD, Page B, Lowther A, Rogers P, Peters KD, Shaughnessy PD (2009a) Pup production assessment of the Australian sea lion *Neophoca cinerea* at Dangerous Reef and English Island, South Australia. Report to the Department for Environment and Heritage, Wildlife Conservation Fund Project No. 0259. SARDI Aquatic Sciences Publication Number F2009/000088-1, SARDI Research Report Series No. 338. 23pp

Goldsworthy SD, Page B, Lowther A, Rogers P, Shaughnessy PD (2009b) Pup production assessment of the Australian sea lion Neophoca cinerea at Dangerous Reef and English Island, South Australia. Report to the Department for Environment and Heritage, Wildlife Conservation Fund Project No. 0259. SARDI Aquatic Sciences Publication Number F2009/000088-1, SARDI Research Report Series No. 338. 23pp

Goldsworthy SD, Page B, Shaughnessy PD, Hamer D, Peters KD, McIntosh RR, Baylis AMM, McKenzie J (2009c) Innovative solutions for aquaculture planning and management: addressing seal interactions in the finfish aquaculture industry. SARDI Publication Number F2008/000222-1, SARDI Research Report series No. 288

Goldsworthy SD, Peters KJ, Page B (2007b) Foraging ecology and diet analysis of Australian sea lions. Final Report to the Department of the Environment and Water Resources. SARDI Aquatic Sciences Publication Number F2007/001024-1. SARDI Research Report Series No 251

Goldsworthy SD, Shaughnessy PD, Page B, Dennis TE, McIntosh RR, Hamer D, Peters KJ, Baylis AMM, Lowther A, Bradshaw CJA (2007c) Developing population monitoring protocols for Australian sea lions. Report to the Department of the

Environment and Water Resources. Report No. SARDI Aquatic Sciences Publication Number F2007/000554. SARDI Research Report Series No: 219

Kirkwood R, Gales R, Terauds A, Arnould JPY, Pemberton D, Shaughnessy PD, Mitchell AT, Gibbens J (2005) Pup production and population trends of the Australian fur seal (*Arctocephalus pusillus doriferus*). Marine Mammal Science 21:260-282

Kuno E (1977) A sequential estimation technique for capture-recapture censuses. Research in Population Ecology 18:187-194

McIntosh R, Shaughnessy PD, Goldsworthy SD (2006) Mark-recapture estimates of pup production for the Australian sea lion (*Neophoca cinerea*) at Seal Bay Conservation Park, South Australia. In: Trites AW, Atkinson SK, DeMaster DP, Fritz LW, Gelatt TS, Rea LD, Wynne KM (eds) Sea Lions of the World. Alaska Sea Grant College Program, Anchorage, Alaska, USA, p 353-367

Robinson AC, Canty P, Mooney T, Ruddock P (1996) South Australia's offshore Islands, Vol. Department of Environment and Natural Resources, Australian Heritage Commission, Canberra

Seber G (1982) The Estimation of Animal Abundance and Related Parameters., Vol. MacMillan, New York.

Shaughnessy P (2004) Population assessment of New Zealand fur seals and Australian sea lions in some South Australian breeding colonies and haul-out sites, 2003-2004. Report to Department for Environment and Heritage (South Australia)

Shaughnessy P (2005a) Australian sea lions at some colonies on the coast of Eyre Peninsula, South Australia: abundnace in 2004 and 2005. Report to Department of the Environment and Heritage, October 2005

Shaughnessy P (2005b) Population assessment of New Zealand fur seals and Australian sea lions at some colonies in South Australia, 2004-05. Report to Department for Environment and Heritage (South Australia)

Shaughnessy P, Dennis T (1999) Seal research in South Australia, 1998/1999: abundance of New Zealand fur seal pups on Kangaroo Island and Australian sea lion pups on Dangerous Reef. Report to South Australian National Parks and Wildlife, Department of Environment, Heritage and Aboriginal Affairs, October 1999

Shaughnessy P, Dennis T (2001) Research on New Zealand fur seals and Australian sea lions in South Australia, 2000-2001. Report to National Parks and Wildlife South Australia, Department for Environment and Heritage

Shaughnessy P, Dennis T (2003) Population assessment of New Zealand fur seals and Australian sea lions in some South Australian colonies, 2002-2003

Shaughnessy PD (2005c) Population assessment of New Zealand fur seals and Australian sea lions at some colonies in South Australia, 2004-05. Report to Department for Environment and Heritage (South Australia)

Shaughnessy PD, Dennis TE, Seager PG (2005) Status of Australian sea lions, *Neophoca cinerea*, and New Zealand fur seals, *Arctocephalus forsteri*, on Eyre Peninsula and the Far West Coast of South Australia. Wildlife Research 32:85-101

Shaughnessy PD, Goldsworthy SD, Libke JA (1995) Changes in the Abundance of New-Zealand Fur Seals, *Arctocephalus forsteri*, on Kangaroo Island, South Australia. Wildlife Research 22:201-215

Shaughnessy PD, McIntosh RR, Goldsworthy SD, Dennis TE, Berris M (2006) Trends in abundance of Australian sea lions, Neophoca cinerea, at Seal Bay, Kangaroo Island, South Australia. In: Trites AW, Atkinson SK, DeMaster DP, Fritz LW,

Gelatt TS, Rea LD, Wynne KM (eds) Sea Lions of the World. Alaska Sea Grant College Program, Anchorage, Alaska, USA, p 325-351

Shaughnessy PD, McKeown A (2002) Trends in abundance of New Zealand fur seal, *Arctocephalus forsteri*, at the Neptune Islands, South Australia. Wildlife Research 29:185-192

White GC, Garrott RA (1990) Analysis of Wildlife Radio-tracking Data, Vol. Academic Press: San Diego