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Monitoring of Seal Bay and other pinniped populations on Kangaroo Island: 2017/18

Simon D Goldsworthy, Peter D Shaughnessy, Jonathan Smart, Alice Mackay, Frederic Bailleul, Sarah-Lena Reinhold, Melanie Stonnill and Kym Lashmar

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SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

May 2019

Report to the Department for Environment and Water

SOUTH AUSTRALIA

Government of South Australia
Department for Environment and Water

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Primary Industries and Regions SA

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EXECUTIVE SUMMARY

Seal populations are a key biodiversity feature of Kangaroo Island. It is the only location where breeding populations of all three of Australia's (mainland) resident seal species co-occur, including the largest population of long-nosed fur seal (LNFS), and one of the largest breeding sites for the threatened Australian sea lion (ASL). Seals are one of the premier tourism attractions on Kangaroo Island and they underpin a regional multimillion dollar tourism industry. Populations of seals on Kangaroo Island have been monitored for about 30 years. This report provides an update on the status and trends in abundance of the ASL population at Seal Bay and Seal Slide, following the 2017/18 breeding season; and of the LNFS population following the 2017/18 breeding season in the Cape Gantheaume Wilderness Protection Area, which contains the largest seal population in Australia.

The 2017/18 ASL breeding season commenced at Seal Bay on 31 October 2017. The median pupping date was 12 February 2018 (sd = 48 days), with 90% of births occurring over 157 days (5 months), between 26 November 2017 and 1 May 2018. Pup production for the breeding season, based on the cumulative number of births, was estimated to be 232. Trend estimates for nine breeding seasons between 2004 and 2017/18 indicate that pup production at Seal Bay is declining by 1.6% per year, or -2.3% per breeding season.

The maximum count of live ASL pups was 110. Pup mortality for the season was 32.5%. Maximum counts of live pups are now available for 23 consecutive breeding seasons (1985 to 2017/18). Trend estimates are similar to those for pup production, and indicate that over the last 34 years, live pup counts have been declining by 1.5% per year, or 2.2% per breeding season.

A microchipping program commenced at Seal Bay in 2002, with the aim of monitoring population vital rates (survival and reproductive success). A total of 163 pups were microchipped during the 2017/18 breeding season. Microchip scanning efforts directed towards breeding females resulted in ~90% of all (232) females that pupped in the 2017/18 breeding season at Seal Bay being scanned, of which 61% (141) had a microchip (and hence known age). With the exception of two 4.5 year-old females, recruitment to the breeding population commenced at age 6 (14 females born in the 2011/12 breeding season) with the oldest known-age females being 15 years old (born in the 2002/03 breeding season, coinciding with the beginning of the microchipping program).

ASL pup production at Seal Slide was estimated to be 14 for the 2017/18 breeding season. Trend analyses suggests that pup abundance at Seal Slide is increasing by about 1% per year, or 1.5% per breeding season, however, given the low pup abundance there is high uncertainty in these trends.

The estimate of pup abundance of LNFS for the whole Cape Gantheaume Wilderness Protection Area (CGWPA) in the 2017/18 breeding season was 5,820 (95% CL 5,776 – 5,865). This is an increase of 20.6% compared with the previous breeding season (4,825). Since January 1989, estimated LNFS pup production within the CGWPA has increased by a factor of 12.7 (from 458 to 5,820) and at an annual rate of 8.7% per year (n = 30 seasons). However, it is clear that growth in this population is no longer exponential. Pup production has grown by 3.8% per year over the last decade, but by only 2.6% per year over the last five years. Pup production at the new colony at Cape Linois has increased exponentially at 97.1% per year over the last five years.

A review of monitoring approaches for Kangaroo Island pinnipeds was undertaken. It recognised that the current monitoring program for the ASL population at Seal Bay is delivering important information on pup production and population vital rates that are important to the management of the species and human interactions at the site. The Seal Bay monitoring also provides information essential to informing conservation and management programs for the species. Monitoring of pup production at the Seal Slide should be continued, and consideration should also be given to monitoring the Cape Bouguer and North Casuarina breeding sites.

The 30-year annual time series on LNFS pup production at the Cape Gantheaume WPA has provided a record of post-sealing recovery for the largest population of the species in Australia and the largest seal colony. However, the resources to maintain this comprehensive survey annually are considerable, and as it and other major colonies approach capacity, further growth in LNFS populations will occur at new and emerging sites, which are not currently being systematically monitored. It is recommended that annual monitoring efforts be redirected to the Cape Linois colony, which requires a fraction of the resourcing to survey and is growing rapidly. This could provide capacity to alternately monitor other sites on Kangaroo Island or elsewhere in the State, to provide a more comprehensive monitoring program for the species abundance in South Australia. Consideration should also be given to monitoring the emerging population of Australian fur seals on North Casuarina Island.

Keywords: Australian sea lion, Long-nosed fur seal, pup production, population status, trends in abundance.

1 INTRODUCTION

Seals are one of the premier tourism attractions on Kangaroo Island (KI) and they underpin a regional multimillion dollar tourism industry, the centrepiece of which is the Australian sea lion (ASL, *Neophoca cinerea*) population in the Seal Bay Conservation Park. Information on the status and trends in abundance of the Seal Bay ASL population is essential for ensuring that ongoing tourism activities and developments are undertaken sustainably and in a way that does not impact natural population processes (Department of Sustainability Environment Water Population and Communities 2013). The information is also needed to provide long-term economic security to the regional tourism industry that is directly or indirectly dependent on Seal Bay (Department for Environment and Water (DEW), Commercial Tour Operators, regional tourism businesses). This is especially pertinent given that ASL are a listed threatened species under the *Environment Protection and Biodiversity Act 1999* (EPBC Act), and endangered under the International Union for the Conservation of Nature (IUCN) Redlist (Goldsworthy 2015). Based on a recent comprehensive State-wide census, the South Australian population is estimated to be declining by ~3% per year, and by almost 25% over the last decade or so (Goldsworthy *et al.* 2015b). Seal Bay forms a critical monitoring site for ASL and is the only location where the species' population vital rates (survival and reproductive rates) are being monitored (Goldsworthy *et al.* 2015a). Such data are important to assess the performance of mitigation measures (fishery closures and bycatch trigger limits) introduced by the Australian Government to protect ASL from bycatch in gillnet fisheries (Australian Fisheries Management Authority 2015).

In contrast to ASL, the rapid recovery of long-nosed fur seal (LNFS, *Arctocephalus forsteri*) and recent colonisation and growth of Australian fur seal (*Arctocephalus pusillus dorifierus*) populations in South Australia has created public concern from some fisheries and ecotourism sectors, and knowledge of their status and trends in abundance is important to assist DEW in species management decisions. The last 27 years have seen a 3.5 fold increase in the population of LNFS in South Australia (SA), which now number ~100,000 individuals (Shaughnessy *et al.* 2015). LNFS pup production in the Cape Gantheaume Wilderness Protection Area (CGWPA) on KI has been monitored annually each January since 1989 (Goldsworthy *et al.* 2015a, Shaughnessy and Goldsworthy 2015). Over this period pup production has increased from ~450 to 5,300, which is equivalent to a ~10% increase per year (Shaughnessy and Goldsworthy 2015).

This project is the third consecutive three-year program to monitor the status and trends in abundance of Kangaroo Island pinniped populations supported by the DEW. The first two extended from 2010 to 2012 and from 2013 to 2015. The current project extends the monitoring from 2015 to 2018. Its aims are to:

1. maintain monitoring of Australian sea lion pup production during the 2016 and 2017/18 breeding seasons at Seal Bay and the Seal Slide, Kangaroo Island;
2. maintain monitoring of population, survival and reproductive success of Australian sea lions between 2015 and 2018 at Seal Bay;
3. provide detailed reports on population dynamics and trends subsequent to the 2016 and 2017/18 breeding seasons;
4. maintain the annual monitoring of long-nosed fur seal pup production in the Cape Gantheaume Wilderness Protection Area over three consecutive breeding seasons (2015/16, 2016/17 and 2017/18), and provide reports on their status and trends in abundance; and
5. provide a final report at the end of the program including an assessment of ongoing seal population monitoring needs for the Kangaroo Island region.

This report provides details on monitoring of the 2017/18 ASL breeding season at Seal Bay and the 2017/18 LNFS survey in the CGWPA. As the final report for this project, it also addresses aim 5 and provides an assessment of ongoing seal population monitoring needs for the Kangaroo Island region.

2 METHODS

2.1 Australian sea lions

2.1.1 Field sites

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

Government Gazette, December 7, 1972, pp. 2543-2544) for the "purposes of conserving the native animals on that portion of the Seal Bay Conservation Park described". The ASL colony known as the Seal Slide (36.028°S, 137.539°E) is located in the CGWPA, on the south-east coast of Kangaroo Island. The colony can be accessed by 4WD vehicle.

2.1.2 Pup production and population growth estimates

At Seal Bay, 64 surveys were conducted between 31 October 2017 and 9 August 2018. Two methods were used to estimate pup abundance: direct counts of live and dead pups, and the cumulative count of new births and deaths throughout the colony based on repeat (usually twice-weekly) surveys (Goldsworthy *et al.* 2008, 2011). The latter is the main method of estimating pup production and we refer to it as the estimate based on the cumulative number of births. It can also be determined from the number of microchipped pups plus cumulative dead (not microchipped) pups at the end of the breeding season.

Previously, mark-recapture methods using the Petersen estimate were also used to estimate pup production, using pups that had been clip-marked during the microchipping process. However, we are now aware that clip-marks applied to pups in their brown lanugo may not be readily detectable once these pups have moulted. The loss of marks violates the assumptions of the Petersen estimate (Caughley 1977), and has likely led to over-estimates of pup abundance in some breeding seasons. Therefore, the Petersen estimate is no longer used to estimate pup abundance at Seal Bay.

The mortality rate of pups was calculated as the number of cumulative dead pups at the end of the breeding season, divided by the overall estimate of pup production. The median date of birth and the period over which 90% of births occurred were determined using a modified probit analysis of cumulative pup production data (Caughley 1977).

The methodology to survey the Seal Slide followed that described by Goldsworthy et al. (2007b) for small colonies and is referred to as the cumulative mark and count (CMC) method.

To estimate tends in abundance, we used the method developed by Johnson and Fritz (2014). It uses a Bayesian modelling and Markov Chain Monte Carlo method, and a hierarchical model to make inferences of trends in abundance. Analyses were undertaken using the R package 'agTrend' (Johnson and Fritz 2014). The agTrend analyses produce plots of abundance trends, with a line fitted to the median of the posterior predictive counts bounded by the 90% highest probability density credible interval. Where there are >10 observations, a Generalised Additive Model (GAM) is used, where there are 6 to 10 observations, a General Linear Model (GLM) is fitted to the data and where there are <6 observations, a GLM with intercept only is fitted (Johnson and Fritz 2014).

2.1.3 Seal Bay - microchipping and demography program

Pups older than two-months and un-attended by an adult female were captured by hand, weighed in a canvas bag using a spring balance to the nearest 0.1 kg, and then sexed and measured (standard length - nose to tail to the nearest ± 0.5 cm). Each pup was externally marked by clipping the fur across the rump (Figure 3) and a Passive Integrated Transponder tag (PIT tag: TIRIS™ RFID 23 mm) was subcutaneously implanted using a sterile single-use needle. PIT tags (microchips) were inserted in the clipped area, parallel to the spine and close to the tail to minimise the effect of gravitation.

During the breeding season and between breeding seasons, hand-held scanning of animals (using Aleis Model 9030 readers; and Allflex RS320 EID ‘boom’ readers) was undertaken regularly throughout the colony. To successfully identify seals with a microchip, the Radio Frequency Identification (RFID) reader was held near the animal within a distance of 10 cm from the insertion site (rump) (Figure 3). Mother-pup pairs were also targeted throughout the breeding season to assess the tagged status of the pups and identify if the mother had been microchipped. In addition to monitoring during the breeding season, all available sea lions were scanned over 3 days at approximately two-month intervals to monitor individual survival. All scanning data were entered in real time into a purposely developed data management app (Seal Bay ASL Monitoring V2) developed using the Fulcrum software (https://web.fulcrumapp.com) and operated on a handheld device.

Seal Bay Demographic analysis

Capture-history matrices were constructed from the re-sight histories of individual sea lions over eleven cohorts. Re-sights were grouped into 32, 6-month intervals (Summer/Autumn: December to May and Winter/Spring: June to November) extending from December 2002 to November 2018. These capture matrices were used as input files for the capture–mark–recapture (CMR) program MARK (White and Burnham 1999) to estimate survival and capture probabilities. MARK provides survival (Φ) and recapture (p) estimates under the Cormack–Jolly–Seber (CJS) model (Cormack 1964, Jolly 1965, Seber 1965) and under several models that appear as special cases of the CJS model (Lebreton *et al.* 1992). Parametric goodness-of-fit (GOF) tests within MARK were used to test whether the CJS model assumptions were met (Burnham *et al.* 1987, Lebreton *et al.* 1992). This bootstrap procedure simulates encounter histories that exactly meet the CJS model assumptions. These simulated data were compared to the field data for compliance with the CJS model assumptions (White and Burnham 1999). To test the main hypothesis (e.g. effect of sex, age and cohort on survival), the c2 likelihood ratio test (LRT) statistics within program MARK were used (White and Burnham 1999). Analyses were undertaken in RMark.

Figure 1. Map of Seal Bay breeding colony of Australian sea lions, on Kangaroo Island, extended to Bay 2 (EPA 2) of the Eastern Prohibited Area (EPA). The Western Prohibited Area (WPA), Main Beach and EPA comprise the main areas of the site.

Figure 2. Main sector boundaries used in the mark-recapture procedures at Cape Gantheaume and Berris Point long-nosed fur seal sub-colonies in the Cape Gantheaume Wilderness Protection Area.

Figure 3. An Australian sea lion brown pup with clipped rump, which indicates that it has been microchipped (above); and typical scanning attempt of a resting Australian sea lion at Sea Bay using an Allflex RS320 EID ‘boom’ reader (below).

2.2 Fur seal surveys

2.2.1 Field sites

The CGWPA contains two large sub-colonies of LNFS: Berris Point and Cape Gantheaume (Figure 2). The Berris Point sub-colony is divided into three sectors referred to as ‘North’, ‘Middle’ and ‘South’ separated by deep channels extending through the schist to the base of the limestone slopes. The Cape Gantheaume sub-colony is also separated into sectors as described by Shaughnessy (2011). In addition, there are several small aggregations of LNFS that form part of the Cape Gantheaume sub-colony: (i) 0.5 km west of the Cape Gantheaume headland on small sandy beaches at the base of limestone cliffs, (ii) in the bay immediately north-east of the Cape Gantheaume sub-colony, known locally as ‘Little Weirs Cove’ (iii) a small site 1 km east of the northern sector of Berris colony, (iv) a small but rapidly increasing sub-colony at Cape Linois in the north-east part of the CGWPA, and (v) further north-east, a small group at The Veranda (near D’Estrees Bay).

2.2.2 Direct counting

Numbers of LNFS in small aggregations were counted by one or two members of the survey team while walking through the aggregation; these are referred to as 'direct counts' to distinguish them from the mark-resight estimates.

2.2.3 Mark-resight estimation - marking

In the main sub-colonies, LNFS pups were marked by clipping the black natal hair (lanugo) on the top of their heads between the eyes and down toward the nose with curved surgical scissors to reveal the light grey underfur. This clip provides a temporary mark, in that the natal hair is shed between March and April, when the adult-type pelage emerges. Pups were marked by a team of people with one person acting as scribe to record the number marked. Effort was made to apply marks uniformly throughout each sector of the colony (~50% of pups present).

2.2.4 Mark-resight estimation - recapturing

The ‘recapturing’ of pups was undertaken by visual resighting, and did not require physically handling them. Resights were conducted by individuals walking through the colony and visually scanning pups' heads to identify them as either ‘marked’ (clip-marked) or ‘clear’ (unmarked). Information was recorded on tally-counters, one in each hand, with one to record marked pups and the other to record clear pups. At the completion of each sector, data were recorded in a field notebook and tally-counters were reset to zero. Between nine and 13 resights were conducted of each colony sector by individuals, typically 10-15 minutes apart. Resights were undertaken between 1 and 5 days after pups had been marked to enhance the potential for mixing of marked and clear pups.

By distributing marks and conducting resight sessions uniformly throughout each colony sector, the sampling process at resighting is assumed to be random with respect to the marking process. This is an important assumption of mark-recapture estimation (Caughley 1977). The sampling was done without replacement; that is, care was taken to avoid recording pups more than once during each resight session. The percentage of marked pups in a sector or a colony was calculated using the number of pups marked and the mark-resight estimate of live pups.

2.2.5 Dead pups

The number of pups found dead was recorded when pups were marked and also during resight sessions. Dead pups were spray painted or covered with large rocks to indicate that they had already been counted in order to avoid re-counting. Dead pups counted during resight sessions were recorded as 'marked' or 'clear'. Dead marked pups were subtracted from the total number of marked pups (M) at risk of being resighted (see below).

2.2.6 Calculation of pup abundance using mark-recapture estimates

The estimate of pup numbers (N) was calculated using a variation of the Petersen method (Seber 1982), with the formula

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

where M is the number of marked pups available for resighting during recapture sessions (minus any dead marked pups sighted during recapture sessions), n is the total number of pups examined in the recapture (resight) sample, and m is the number of marked pups in the recapture sample.

The variance of this estimate was calculated from

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

Since there were several mark-recapture estimates (N_j) for each colony, one from each recapture session, they were combined by taking the mean (N) for each colony using formulae from White and Garrott (1990, pp. 257 and 268):

$$N = \sum_{j=1}^{q} {N_j}/{q} \, ;$$

where *q* was the number of estimates for the individual colony (i.e., the number of recapture sessions). The variance of this estimate was calculated from

$$VarN = \frac{1}{q^2} \sum_{j=1}^{q} Var(N_j) \ .$$

Its standard error (s.e.) was calculated from

$$[Var(N)]^{\ 1/2} \, ;$$

(see Chapman 1952, Fowler *et al.* 1998, Kuno 1977). The 95% confidence limits were calculated from

$$N \pm (1.96 \times [Var(N)]^{\ 1/2}).$$

The Cape Gantheaume and Berris Point sub-colonies were divided into several sectors, and pup numbers were calculated for each sector by the above method. An estimate for the whole sub-colony was obtained by summing the estimates for each sector. The variance of that combined estimate was obtained by summing the variances of each sector, and the standard error was calculated by taking the square root of the summed variances.

For each colony, the number of dead pups was added to the estimate of the number of live pups to give the overall estimate of pup numbers in a colony. Means for mark-recapture estimates are presented as ± standard error (s.e.).

2.2.7 Trends in pup abundance

Trends in abundance were calculated using linear regression of the natural logarithm of the mean estimate of pup numbers against year. This gives an exponential rate of increase, which has been demonstrated for LNFS on Kangaroo Island (Shaughnessy *et al.* 1995) and for other species. The intrinsic rate of increase (r) is the slope of the regression line. It can be expressed as a percentage rate of growth (λ) as follows:

$$\lambda = (e^{r} - 1) \times 100.$$

As indicated in section 2.1.2, we used the method developed by Johnson and Fritz (2014) to estimate trends in abundance of fur seal colonies.

2.2.8 Pup weight and length

A sample of pups was weighed using scales (20 kg range) suspended from a surveyor's tripod. Pups were sexed, placed in a weighing sling (an adjustable looped rope placed around the neck and under one fore-flipper) and weighed, their standard length (straight–line distance between tip of nose and tip of tail) was then measured using a 1 m ruler. A small clip of fur was removed from each pup's rump to indicate it had been weighed before it was returned to its place of capture.

3 RESULTS AND DISCUSSION

3.1 Seal Bay

3.1.1 Pup production and population growth

Results of the surveys for pup births and deaths undertaken during the 2017/18 breeding season at Seal Bay are presented in Table 1 and Figure 4. The breeding season commenced with the first pup birth on 31 October 2017. The last pup birth occurred on 9 August 2018. Based on these observations, the duration of the breeding season was approximately nine months. A probit analysis of the cumulative number of births, estimated the median pupping date to be 12 February 2018 (sd = 48 days), with 90% of births occurring over 157 days (5.2 months), between 26 November 2017 and 1 May 2018 (Table 2).

Variation in the chronology of breeding across the last 11 breeding seasons is presented in Figures 5 and 6. The mean breeding interval (period between successive median pupping dates) for eleven consecutive breeding seasons since the 2002/03 breeding season was 545 days (range 541 - 553, sd = 4.7) or 17.9 months (range 17.8 - 18.2, sd = 0.2) (from data in Table 2, Figure 5).

The pup production estimate based on the cumulative number of births recorded for the 2017/18 breeding season at Seal Bay was 231 (Table 1). However, as the sum of the total number of microchipped pups and cumulative pup deaths of unchipped pups was 232 (163 + 69 = 232), this gives a minimum pup production for the 2017/18 breeding season of 232 pups (Table 1, Figure 4).

Most pups were born in the Main Beach/Road Reserve areas west of the area accessed by the public (112 pups, 48%) and in the EPA (69 pups, 30%), with 33 pups (14%) reported for the WPA and 17 pups (7%) for Pup Cove (Figure 1, Figure 7). As Pup Cove could only be surveyed from along the cliff-line at various vantage points, the number of cumulative births for this area may be an under-estimate. Trends in the distribution of observed births over the last eight breeding seasons indicate a progressive increase in the proportion of births in the Main Beach/Road Reserve areas, and a concomitant decrease in the proportion of births in the WPA and Pup Cove areas, indicative of an eastward geographic shift in the distribution of births (Figure 7).

The maximum direct count of live pups was 110 on 12 April 2018, when the cumulative number of dead pups was 62. The cumulative number of pup deaths to the end of the breeding season was 75 on 12 July 2018 (Table 1).

3.1.2 Trends in maximum live-pup counts, estimated pup production and mortality

Trends in direct counts of the maximum number of live pups counted throughout a breeding season extend over 23 consecutive breeding seasons between 1985 and 2017/18 (Figure 8 and 9). The maximum live pup count for the 2017/18 breeding season (110) is relatively low and is in part a consequence of the high pup mortality recorded for the breeding season (see below). A regression model fitted to the median of the posterior predictive counts bounded by the 90% highest probability density credible interval indicates that live pup counts at Seal Bay have been declining over the last 34 years at an average of 1.46% per year (range -2.72 to -0.28), or 2.19% per breeding season (range -4.08 to -0.42) (Figure 9).

The trend in estimated pup production based on the cumulative number of births/minimum pup birth estimates for nine breeding seasons between 2004 and 2017/18 are presented in Figures 8 and 9. A regression model fitted to the median of the posterior predictive counts bounded by the 90% highest probability density credible interval indicates a change in pup production of -1.55% per year (range -2.61 to -0.38), or -2.33% per breeding season (range -3.9 to -0.57) (Figure 9). The live pup count trends show a very similar rate of decline to the estimated pup production trends.

Based on a pup production estimate of 232 pups for the 2017/18 breeding season at Seal Bay, and a total of 75 cumulative pup deaths at the end of the breeding season, the mortality rate for the breeding season was estimated to be 32.3% (Table 2, Figure 10). Breeding season mortality rate can be estimated for nine of the last 11 breeding seasons. Mean breeding seasons mortality was 27.1% (sd = 7.8); it has varied between 17.9% and 41.8%, and oscillated between the low and high end of that range in consecutive seasons, with 2017/18 being a high mortality season (Figure 8). Pup mortality is relatively low in winter/spring breeding seasons, averaging 21.8% (sd = 3.4, n = 5), while pup mortality is relatively high in summer/autumn breeding seasons, averaging 33.7% (sd = 5.8, n = 4) (from Table 2). There was no significant trend in breeding season pup mortality over time (Figure 8), but there was a strong negative relationship between pup mortality and maximum live pup counts (Figure 11).

Pup production estimation has been important in determining that declines in live pup counts over the last 23 breeding seasons reflect real declines in pup production, and not changes in pup mortality rate.

Table 1. Summary of surveys of Australian sea lion pups at Seal Bay during the 2017/18 breeding season undertaken for new births and dead pups, cumulative births and deaths, and direct counts of brown pups (BP), moulted pups (MP) and total live pups.

Survey	Date	Survey	New	New	Cummulative				Counts	
No.		day	Births	Dead	Born	Dead	Alive	BP	MP	Total live
1	31-Oct-17	0	1	1	1	1	0	0	0	0
2	02-Nov-17	2	1	1	2	2	0	0	0	0
3	09-Nov-17	9	0	0	2	2	0	0	0	0
4	16-Nov-17	16	0	0	2	2	0	0	0	0
5	23-Nov-17	23	1	0	3	2	1	1	0	1
6	30-Nov-17	30	2	0	5	2	3	3	0	3
7	07-Dec-17	37	5	1	10	3	7	7	0	7
8	11-Dec-17	41	3	1	13	4	9	7	0	7
9	14-Dec-17	44	3	1	16	5	11	7	0	7
10	18-Dec-17	48	3	0	19	5	14	10	0	10
11	21-Dec-17	51	3	0	22	5	17	12	0	12
12	26-Dec-17	56	8	0	30	5	25	14	0	14
13	28-Dec-17	58	10	1	40	6	34	28	0	28
14	31-Dec-17	61	7	0	47	6	41	27	0	27
15	04-Jan-18	65	5	3	52	9	43	30	0	30
16	08-Jan-18	69	14	5	66	14	52	50	0	50
17	11-Jan-18	72	6	1	72	15	57	36	0	36
18	15-Jan-18	76	9	1	81	16	65	49	0	49
19	19-Jan-18	80	4	4	85	20	65	45	0	45
20	22-Jan-18	83	10	3	95	23	72	48	0	48
21	25-Jan-18	86	8	2	103	25	78	47	0	47
22	29-Jan-18	90	11	1	114	26	88	67	0	67
23	01-Feb-18	93	9	2	123	28	95	62	0	62
24	06-Feb-18	98	7	5	130	33	97	65	0	65
25	08-Feb-18	100	5	2	135	35	100	75	0	75
26	13-Feb-18	105	5	2	140	37	103	64	0	64
27	16-Feb-18	108	9	1	149	38	111	73	0	73
28	19-Feb-18	111	6	1	155	39	116	82	0	82
29	22-Feb-18	114	6	2	161	41	120	97	0	97
30	26-Feb-18	118	2	1	163	42	121	86	0	86
31	01-Mar-18	121	6	3	169	45	124	88	0	88
32	05-Mar-18	125	3	1	172	46	126	92	0	92
33	08-Mar-18	128	5	0	177	46	131	82	0	82
34	13-Mar-18	133	9	2	186	48	138	105	0	105
35	16-Mar-18	136	6	0	192	48	144	100	0	100
36	19-Mar-18	139	2	4	194	52	142	91	0	91
37	22-Mar-18	142	3	2	197	54	143	93	0	93
38	26-Mar-18	146	2	3	199	57	142	96	0	96
39	29-Mar-18	149	5	1	204	58	146	102	0	102
40	03-Apr-18	154	3	3	207	61	146	94	0	94
41	06-Apr-18	157	1	0	208	61	147	105	0	105
42	09-Apr-18	160	2	0	210	61	149	106	0	106
43	12-Apr-18	163	2	1	212	62	150	110	0	110
44	16-Apr-18	167	1	1	213	63	150	92	0	92
45	19-Apr-18	170	0	1	213	64	149	1	0	1
46	19-Apr-18	170	1	0	214	64	150	100	0	100
47	23-Apr-18	174	0	1	214	65	149	85	0	85
48	26-Apr-18	177	1	0	215	65	150	96	5	101
49	02-May-18	183	0	2	215	67	148	80	2	82
50	05-May-18	186	2	0	217	67	150	112	0	112
51	07-May-18	188	1	0	218	67	151	107	0	107
52	10-May-18	191	0	0	218	67	151	94	0	94
53	17-May-18	198	2	1	220	68	152	89	0	89
54	21-May-18	202	0	0	220	68	152	109	1	110
55	24-May-18	205	0	0	220	68	152	84	0	84
56	28-May-18	209	1	1	221	69	152	88	0	88
57	31-May-18	212	2	0	223	69	154	78	6	84
58	07-Jun-18	219	0	1	223	70	153	75	7	82
59	14-Jun-18	226	1	1	224	71	153	63	2	65
60	21-Jun-18	233	3	2	227	73	154	91	2	93
61	28-Jun-18	240	1	0	228	73	155	76	13	89
62	12-Jul-18	254	1	2	229	75	154			
63	26-Jul-18	268	1	0	230	75	155	50	48	98
64	09-Aug-18	282	1	0	231	75	156	27	47	74

Table 2. Summary of the timing and duration of 11 consecutive breeding seasons of the Australian sea lion at Seal Bay, and pup abundance estimates including cumulative births and deaths; maximum live pup count; total numbers of microchipped pups and minimum pup production (microchipped + cumulative pup deaths); and the overall estimate of pup production. Estimated mortality rate is also included. Comparative data for the 2002/03, 2004 and 2005/06 breeding seasons are from McIntosh *et al*. (2006) and McIntosh *et al*. (2012) unless otherwise indicated. Data for the 2007, 2008/09, 2010, 2011/12, 2013, 2014/15 and 2016 breeding seasons are from Goldsworthy *et al.* (2008, 2010, 2011, 2013, 2014, 2015a and 2017). Data from the 2017/18 season is from this report. Note: Overall, estimates of pup production for some seasons may differ from previous reports because mark-recapture methods are no longer included as part of the estimation procedure.

	2002-03	2004	2005-06	2007	2008/09	2010	2011/12	2013	2014/15	2016	2017/18
Month breeding season commenced	Dec-02	Jun-04	Dec-05	May-07	Oct-08	May-10	Oct-11	Mar-13	Aug-14	May-16	Oct-17
Duration of breeding season (months)	9	7	6	7	7	9	8	12	12	8	9
Median pupping date	13-Mar-03	5-Sep-04	28-Feb-06	27-Aug-07	24-Feb-09	28-Aug-10	21-Feb-12	25-Aug-13	1-Mar-15	28-Aug-16	12-Feb-18
± s.d. (days)	42	39	36	36	41	46	48	47	53	53	48
90% births (5%- 95%)	2 Jan—21 May[1]	3 Jul -1 Nov	4 Jan-18 Apr	28 Jun- 26 Oct	18 Dec-3 May	14 June-11 Nov	5 Dec -9 May	8 June - 11 Nov	3 Dec - 27 May	1 Jun - 24 Nov	26 Nov - 1 May
90% births (days)	139	121	104	120	136	150	156	156	175	176	157
Maximum live pup count	122	148	125	154	122	119	84	99	103	163	110
At months since beginning of BS	6	7	6	6	7	6	6	4	12	6	6
Max live pup count + cumulative dead[2]	185	208	197	198	197	180	166	126	170	192	172
Cumulative births	-	200	207	245	268	259	249	259	239	240	231
Cumulative pup deaths total	73	70	75	51	88	66	104	54	67	43	75
Chipped										10	6
Unchipped										33	69
Mortality rate		25.7%		20.1%	32.8%	24.7%	41.8%	20.8%	28.0%	17.9%	32.3%
Total pups micro-chipped	148	202	144	203	161	201	118	161	153	201	163
Minimum pup production[3]	221	272	219	254	249	267	222	215	220	234	232
Overall estimate of pup production	-	272	-	254	268	267	249	259	239	240	232

[1]Shaughnessy *et al*. (2006).

[2]at time of maximum live count.

[3]total microchipped + cumulative dead at end of the breeding season (less dead microchipped pups).

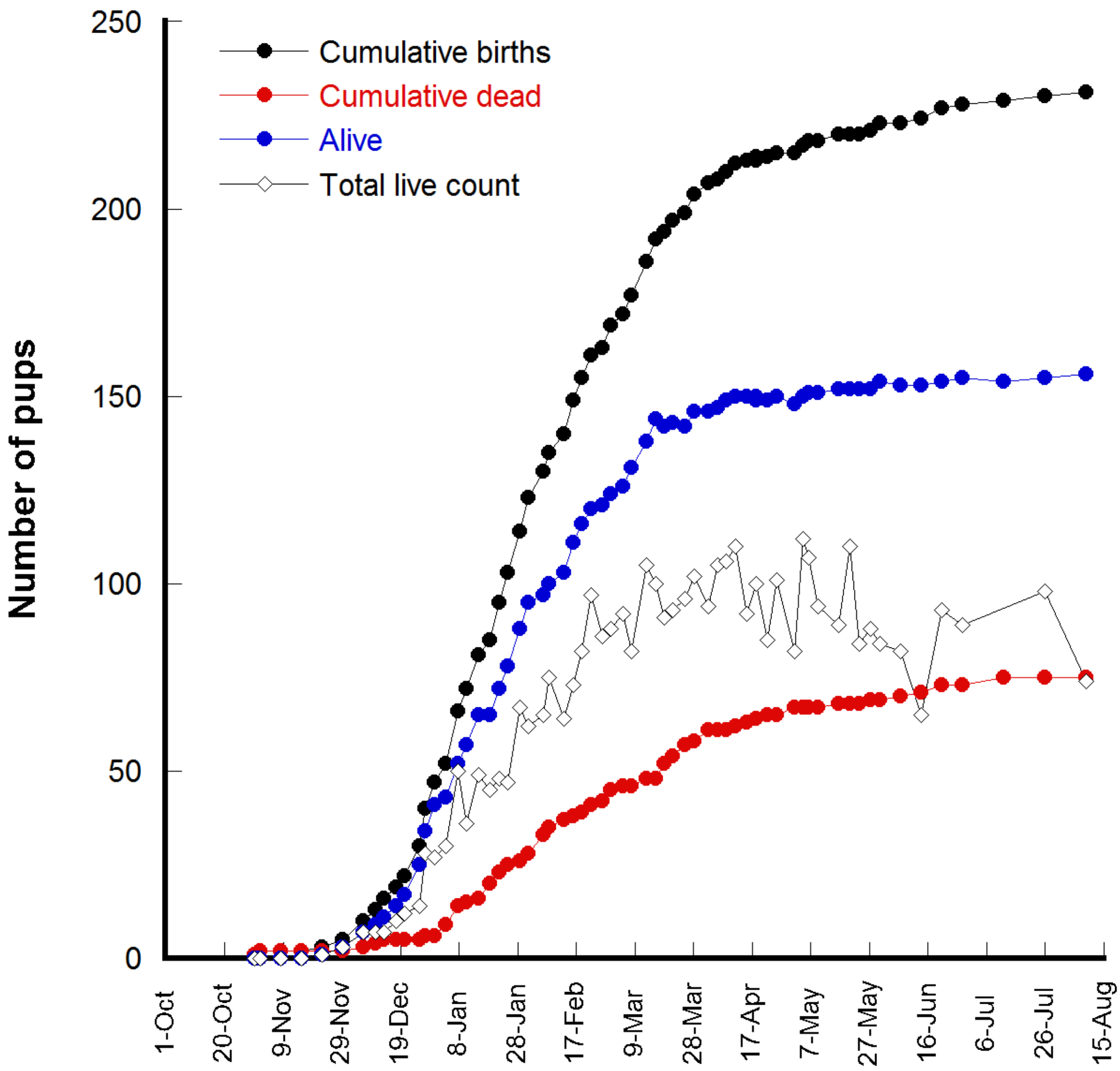

Figure 4. Changes in the number of cumulative pup births, cumulative pup deaths, minimum number of pups alive (cumulative alive), and number of live pups counted during surveys of Australian sea lion pups at Seal Bay between 31 October 2017 and 9 August 2018.

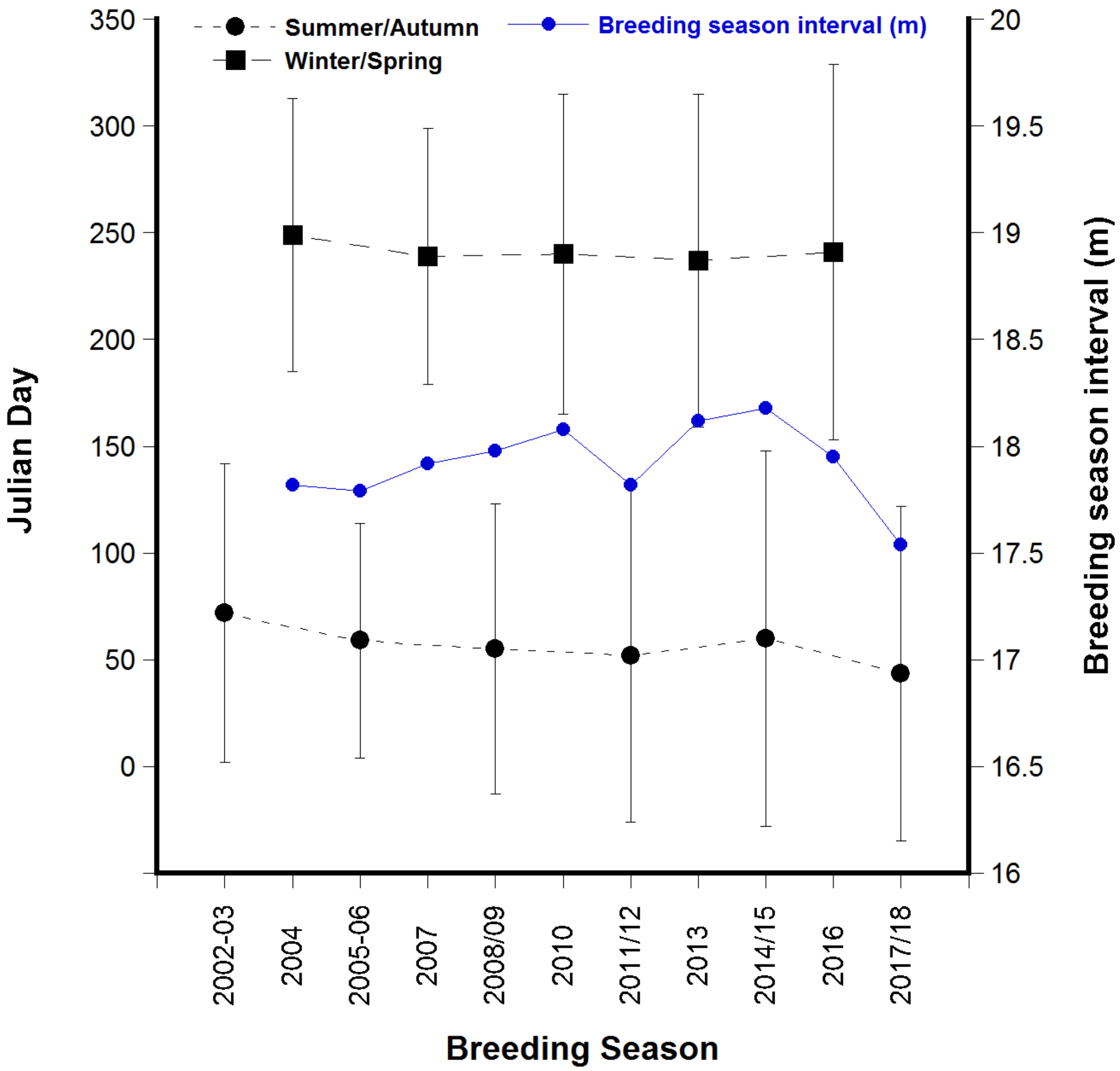

Figure 5. Variation in the breeding season phenology of Australian sea lions at Seal Bay across 11 consecutive breeding seasons, 2002/03 to 2017/18. Black circles (summer/autumn breeding seasons) and squares (winter/spring breeding seasons) indicate median pupping dates. Error bars represent the spread of 90% of births (5-95%) based on the probit analyses of cumulative pup births**.** The alternating pattern of summer/autumn and winter/spring breeding seasons is apparent.

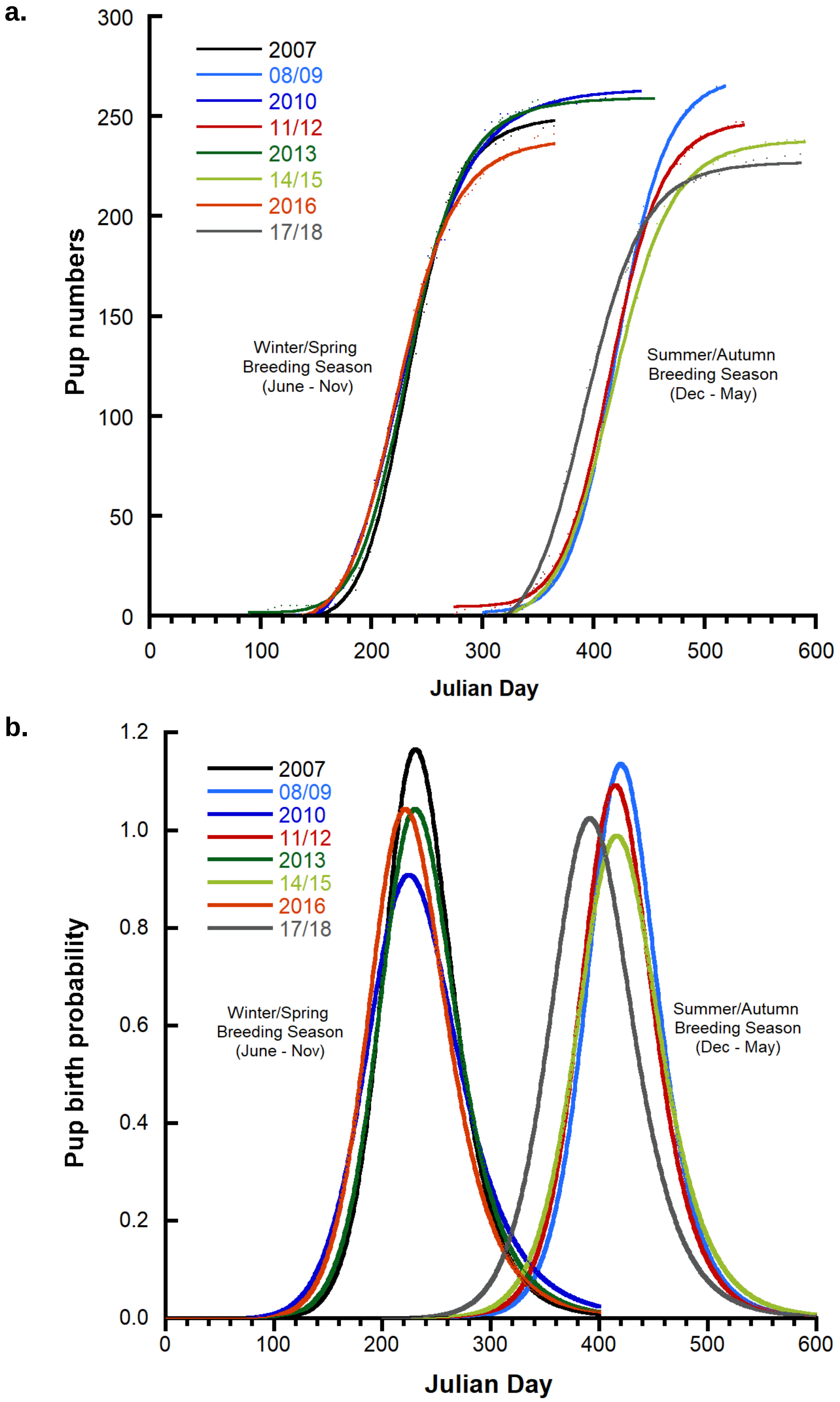

Figure 6. Distribution of cumulative births (a) and probability distributions (b) of Australian sea lions pups at Seal Bay in each of the last eight breeding seasons, 2007 to 2017/18. Julian day begins at 1 on January 1st of each breeding season. The figure demonstrates different ways of visualising the timing and distribution pup births across the different winter/spring and summer/autumn breeding seasons.

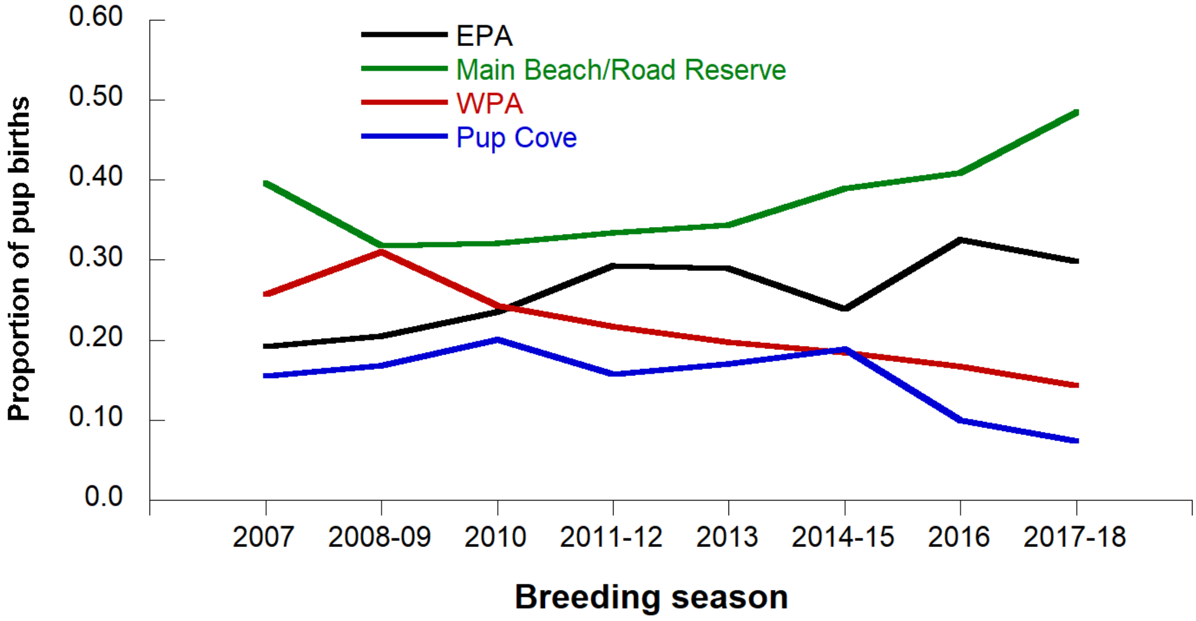

Figure 7. Geographic shifts in the distribution of Australian sea lion pup births over eight consecutive breeding seasons at Seal Bay.

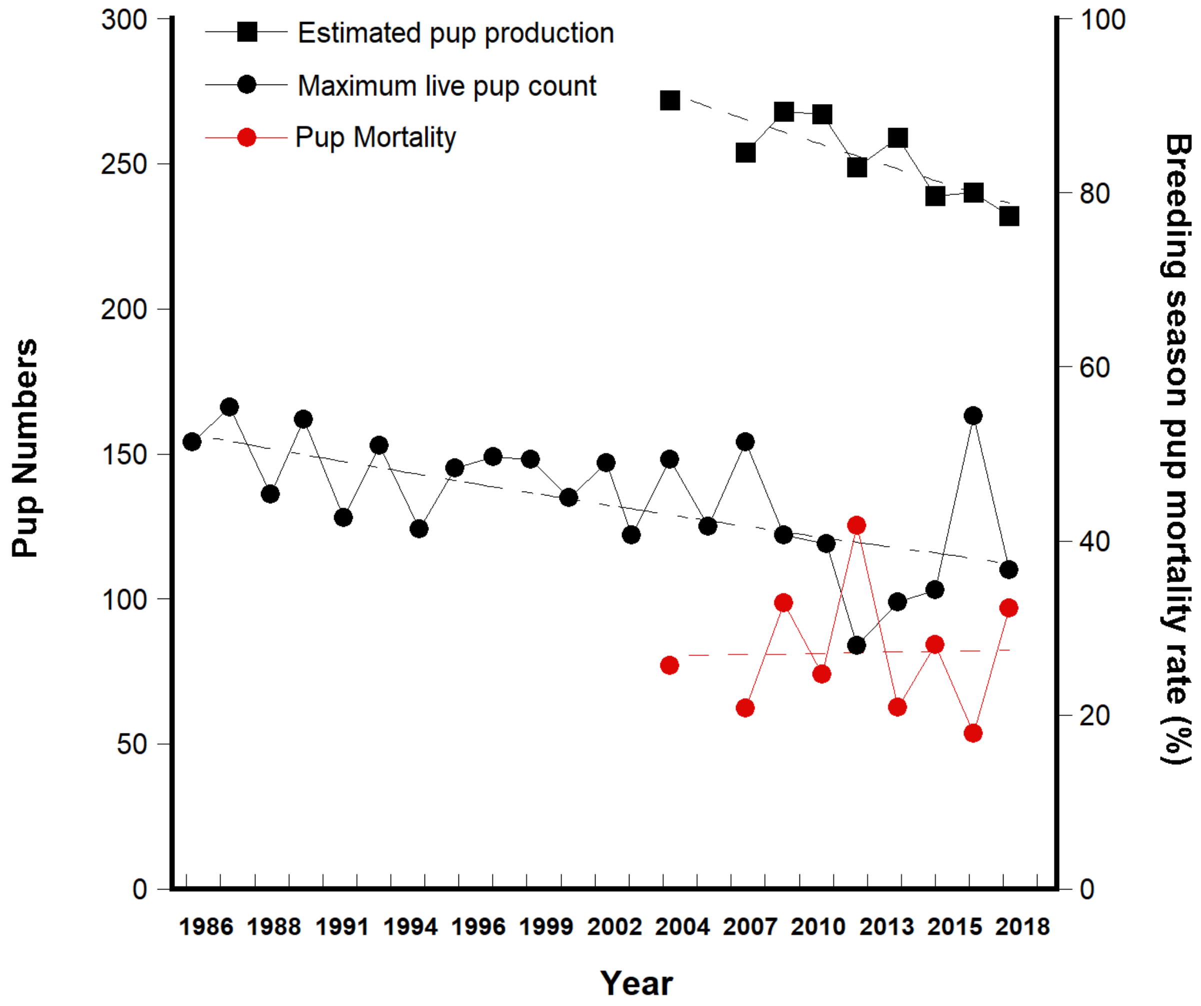

Figure 8. Trends in the abundance of Australian sea lion pups at Seal Bay based on maximum live pup counts for 23 breeding seasons between 1985 and 2017/18. Trends in estimated pup production and breeding season pup mortality rate are presented for nine of the last eleven breeding seasons. Exponential regression curves are fitted to pup numbers, while a linear regression is fitted to pup mortality data.

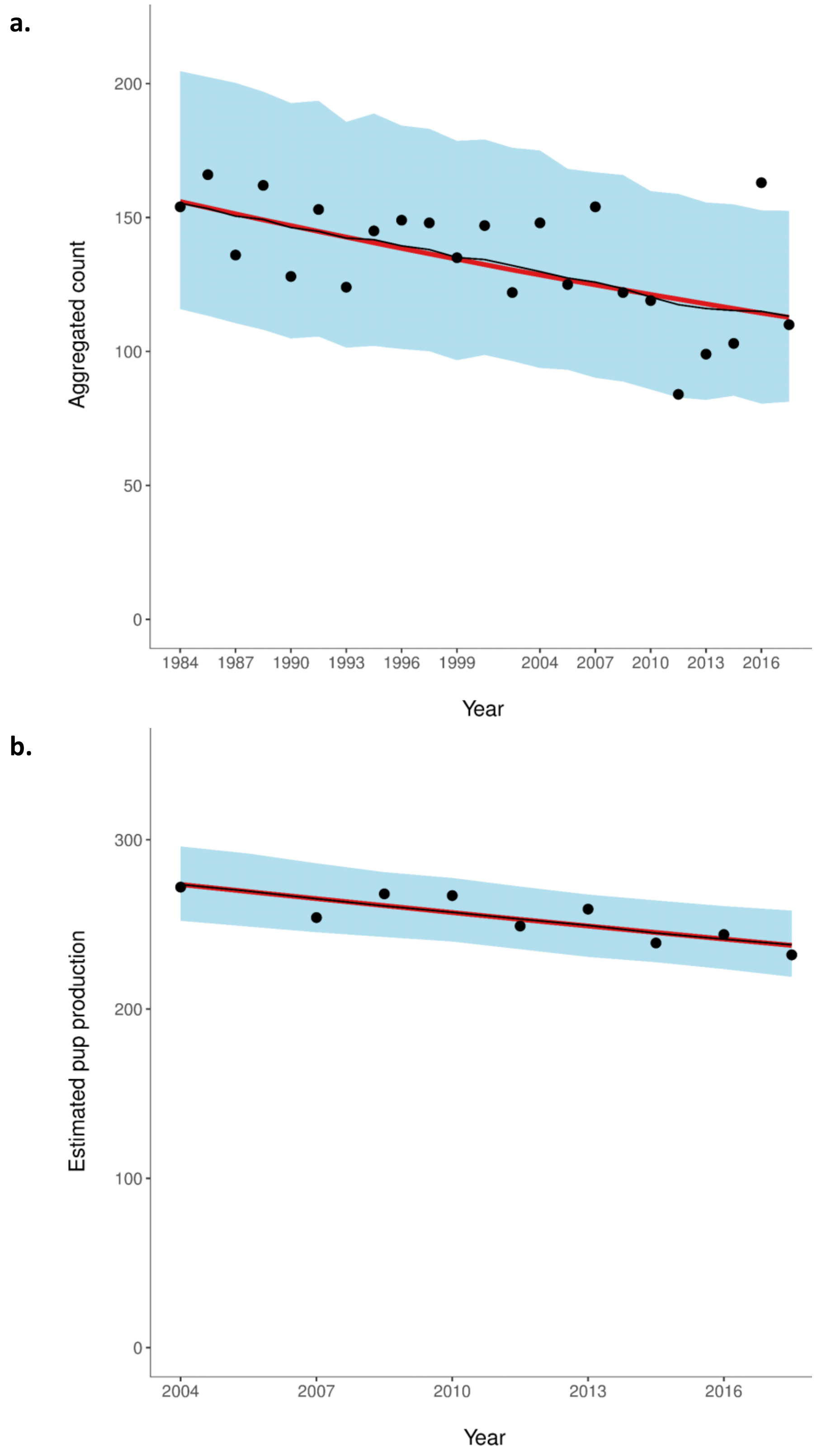

Figure 9. Trend in the abundance of Australian sea lion pups at Seal Bay based on a) maximum live pup counts for 23 breeding seasons between 1985 and 2017/18, and b) the estimated pup production for nine breeding seasons between 2004 and 2017/18. The blue envelope is the 90% highest probability density credible intervals. The red line is the fitted least-squares predictive trend and the black line is the median of the posterior predictive counts.

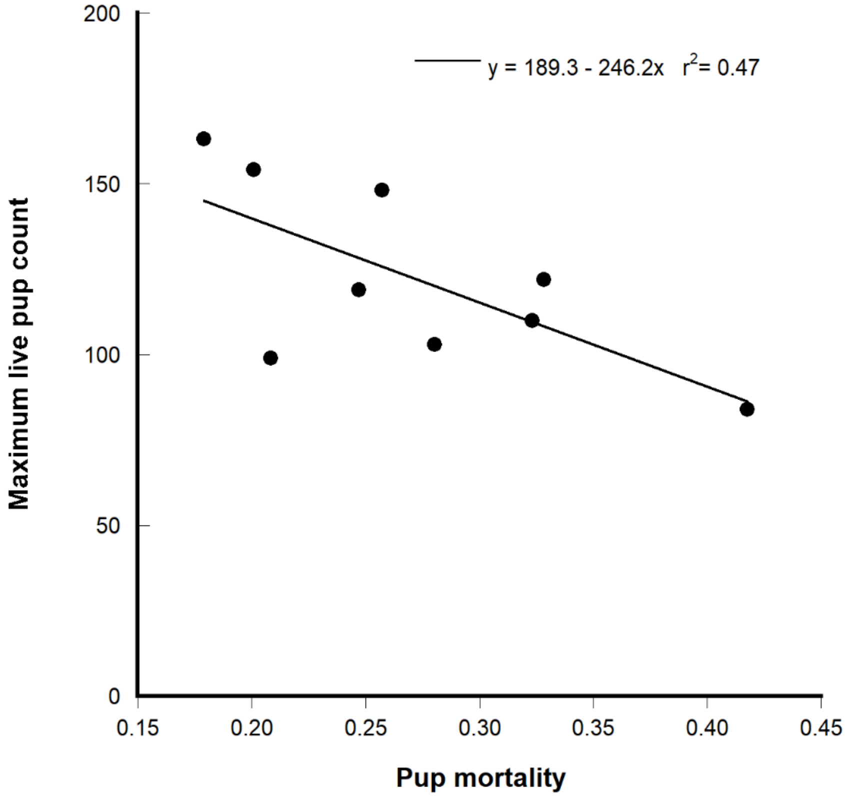

Figure 10. Relationship between the estimated breeding season pup mortality and maximum live pup count for nine breeding seasons between 2007 and 2017/18.

3.1.3 Seal Bay - microchipping and demography program

Population scanning and microchipping

Between February 2013 and August 2018, a total of 10,491 individual scans have been undertaken at Seal Bay (Figure 11a). An average 68% of scanned animals were microchipped, however the proportion of scanned animals with microchips has steadily increased over time as new cohorts of microchipped pups have been added to the population each breeding season. The proportion microchipped has increased from around 57% in 2013 to 80% in 2018 (Figure 11b). This suggests that ~80% of the total Seal Bay ASL population is ≤15 years of age, and that we should reach close to 100% of animals microchipped by the end of 2022 (i.e. in three breeding seasons time), assuming similar efforts to microchip pups in the 2019, 2020/21 and 2022 breeding seasons.

A total of 163 pups were microchipped by the end of the 2017/18 breeding season; six of these were recorded as dead by the end of the breeding season (Table 1).

Age distribution of breeding females

Since the 2011/12 breeding season, scanning of breeding females to monitor reproductive rates has been conducted more assiduously. This has involved attempts to scan as many females as possible during the peri-natal period (when females are mate-guarded) and later in order to identify known-age females and to monitor age-specific and seasonal variation in birth rates (births per female per breeding season).

Of the 231 recorded births in the 2017/18 breeding season, 201 (87%) females were scanned within or just outside of the peri-natal period, leaving 30 (13%) un-scanned. Of the un-scanned females, 13 were within the main colony area, while 17 were inaccessible (either in Pup Cove or EPA Bays 4 and 5). At least seven of these unscanned females were microchipped, as they were later scanned in the main colony area with older pups (known as ‘Discovery scans’). Locations of the birth sites of these females are uncertain. It is possible that additional non-chipped females that pupped outside of the main colony area were scanned outside of the peri-natal period, but as they are unidentifiable, the number of non-chipped females in the remaining ~23 un-scanned females is unknown. This gives a minimum total of 208 (201+7) females (90% of the 231 females recorded to have pupped) that were scanned during the 2017/18 breeding season; of these 141 (61%) were microchipped (i.e. of known age).

The age distribution of the 141 microchipped breeding females that are known to have pupped during the 2017/18 breeding season at Seal Bay is presented in Table 3 and Figure 12. With the exception of two 4.5 year-old females, recruitment to the adult (reproductive) population commenced at age 6 (14 females born in the 2011/12 breeding season), with the oldest known-age females being 15 years old (born in the 2002/03 breeding season, coinciding with the beginning of the microchipping program) (Table 3). The age distributions of known-aged female ASL recorded in the last five breeding seasons (2011/12, 2013, 2014/15, 2016 and 2017/18) are presented in Figure 12 along with the pooled distributions for all five breeding seasons. Although this data set is still somewhat limited, there is an apparent difference in the age distribution of breeding females in summer/autumn and winter/spring breeding seasons. In the two winter/spring breeding seasons (2016 and 2013), the recruitment of 6 year-old females into the breeding population is pronounced, while it is diminished in the summer/autumn breeding seasons (2017/18, 2014/15, and 2011/12) (Figure 12).

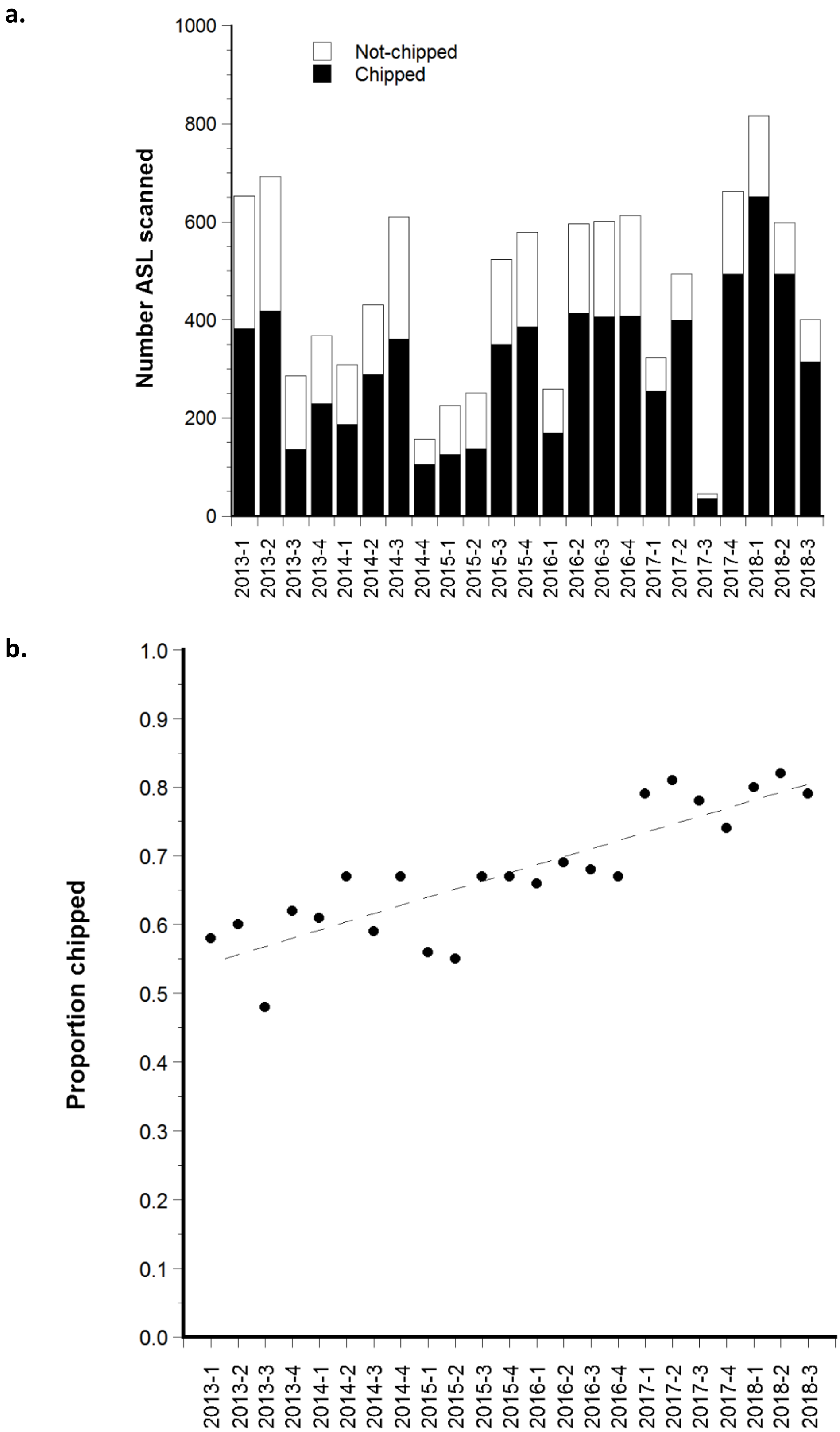

Figure 11. Microchip scanning effort of the Australian sea lion population at Seal Bay summarised into the quarterly (3 month) periods between 2013 and 2018 (a), indicating the total number scanned (chipped and not chipped). The proportion of scanned individuals that were microchipped is also presented (b).

Table 3. The age distribution of 141 microchipped females known to have pupped during the 2017/18 breeding season at Seal Bay. The cohort (season of birth) associated with each age-class is included. Known parity data includes information on the number and percentage of females where parity (1st to 5th birth) is known. Minimum parity data are presented for females from older cohorts (2004 or earlier) where first parity may not have been recorded, where 3rd+, 4th+ and 5th+ parity refer to the minimum number of known births.

Female Age	Cohort	No. Females	Known parity					Minimum parity		
			1st	2nd	3rd	4th	5th	3rd+	4th+	5th+
0	2017/18	0	-	-	-	-	-	-	-	-
1.5	2016	0	-	-	-	-	-	-		
3	2014/15	0	-	-	-	-	-	-	-	-
4.5	2013	2	2 (100%)	-	-	-	-	-	-	-
6	2011/12	14	13 (92.9%)	1 (7.1%)	-	-	-	-	-	-
7.5	2010	25	6 (24%)	18 (72%)	1 (4%)	-	-	-	-	-
9	2008/09	19	3 (15.8%)	11 (57.9%)	4 (21.1%)	1 (5.3%)	-	-	-	-
10.5	2007	34	3 (8.8%)	16 (47.1%)	8 (23.5%)	7 (20.6%)	-	-	-	-
12	2005/06	20	-	4 (20%)	6 (30%)	8 (40%)	2 (10%)	-	-	-
13.5	2004	22	1 (4.5%)	3 (13.6%)	4 (18.2%)	3 (13.6%)	-	6 (27.3%)	3 (13.6%)	2 (9.1%)
15	2002/03	5	-	-	1 (20%)	2 (40%)	-	1 (20%)	-	1 (20%)
	No.	**141**	**28 (19.9%)**	**53 (37.6%)**	**24 (17.0%)**	**21 (14.9%)**	**2 (1.4%)**	**7 (5%)**	**3 (2.1%)**	**3 (2.1%)**

Table 4. Pooled age and known parity data available for 328 adult female Australian sea lions from the Seal Bay population obtained across five consecutive breeding seasons (2011/12, 2013, 2014/15, 2016 and 2017/18). As the microchipping program commenced in the 2002/03 breeding season, no data are available for females >15 years of age.

	Parity				
Age (y)	**1st**	**2nd**	**3rd**	**4th**	**5th**
0	-	-	-	-	-
1.5	-	-	-	-	-
3	-	-	-	-	-
4.5	9 (5.6%)	-	-	-	-
6	81 (50.3%)	4 (3.8%)	-	-	-
7.5	40 (24.8%)	42 (40%)	2 (4.8%)	-	-
9	21 (13%)	33 (31.4%)	14 (33.3%)	1 (5.6%)	-
10.5	8 (5%)	22 (21%)	20 (47.6%)	9 (50%)	-
12	-	4 (3.8%)	6 (14.3%)	8 (44.4%)	2 (100%)
13.5	1 (0.6%)	-	-	-	-
15	1 (0.6%)	-	-	-	-
No.	161	105	42	18	2

Table 5. Inter-birth interval for 167 adult females from the Seal Bay Australian sea lion population, obtained across five consecutive breeding seasons (2011/12, 2013, 2014/15, 2016 and 2017/18).

	Inter-birth interval			
Years	**1st-2nd**	**2nd-3rd**	**3rd-4th**	**4th-5th**
1.5	82 (78.1%)	35 (83.3%)	18 (100%)	2 (100%)
3	20 (19%)	7 (16.7%)	0 (0%)	0 (0%)
4.5	3 (2.9%)	0 (0%)	0 (0%)	0 (0%)
6	-	-	-	-
No.	105	42	18	2

Age of primiparous and multiparous females

Age and parity (number of times a female has given birth) data for the 141 known-aged females that gave birth in the 2017/18 breeding season are presented in Table 3. Age and parity data are also presented for 328 births recorded over five consecutive breeding seasons (2011/12, 2013, 2014/15, 2016, 2017/18) (Figure 13, Table 4). Given the maximum age of female in the study was 15 years, the upper range of parity estimates is likely to be underestimated. Age at first parity had a large range, from 4.5 to 15 years, with most females having their first pup at age 6 (50%), 7.5 (25%) or 9 (13%) (Figure 13a, Table 3). Age of second parity ranged from 6 to 12 years, with most females having the second pup at 7.5 (40%), 9 (31%), and 10.5 (21%) years (Figure 13b, Table 3). Age at third parity ranged from 7.5 to 12 years, with most females having their third pup at age 9 (33%), 10.5 (48%) and 12 (14%) (Figure 13c, Table 3). Age at 4th parity ranged from 9 to 12 years, with most females having their fourth pup at age 10.5 (50%) and 12 (44%) (Figure 13d, Table 3). Of two females in the microchipped population known to have given birth to five pups, both were aged 12 years (Figure 13e, Table 3).

Inter-birth interval

Details on the interval between births is provided in Table 5. Based on 167 known inter-birth intervals, the majority of females (82%) pupped every 1.5 year (i.e. in consecutive breeding seasons), while 16% had an inter-birth interval of 3 years (i.e. every second breeding season), and 2% had an inter-birth interval of 4.5 years. The inter-birth interval between the 1st and 2nd pups was mostly1.5 years (78%), with some females having an inter-birth interval of 3 (19%) and 4.5 (3%) years. The inter-birth interval between the 2nd and 3rd pup was 1.5 years (83%) for most females, with some (17%) having an inter-birth interval of 3 years. The inter-birth interval between the 3rd and 4th, and 4th and 5th pup was 1.5 years (100%), although the sample sizes are small.

Birth rates

Estimates of birth rate were based on the age distribution of 490 known-aged breeding females across five consecutive breeding seasons (2011/12, 2013, 2014/15, 2016, 2017/18), and on the minimum number of females known to be alive in each age-class for each breeding season, derived from microchip re-sight data. The estimated birth rate was just 0.06 (sd = 0.04, n = 5) for 4.5 year-old females, but was 0.58 (sd = 0.30, n = 5) for 6 year-old females, indicating that primiparity is most typically at age 6 years, while births at 4.5 years are atypical. Estimated birth rate increased from 6 to 10.5 years where it peaked at 0.70 (sd = 0.28, n = 4), then declined thereafter (Figure 14). Birth rates of females of a given age pupping in summer/autumn and winter/spring breeding seasons appear to be similar (Figure 14). This suggests that apparent differences in the number of females giving birth at age 6 in summer/autumn and winter/spring breeding seasons, reflects a difference in their survival.

The mean birth rate of adult females between 6 and 15 years of age across the five breeding seasons was 0.62 (sd = 0.23, n = 25). Given that the number of breeding seasons of data available for older cohorts is very limited, data presented here is intended to be indicative, and estimates will improve as more breeding seasons and older cohorts of females are sampled.

Survival rates

Survival (Φ) and recapture (ρ) probability estimates using the Cormack–Jolly–Seber (CJS) approach produced a range of models demonstrating that recapture (ρ) and survival (Φ) probabilities increased with age, but showed marked variability between cohorts (Figures 15 and 16). Recapture probability varied considerably as a function of time, due in part to changes in re-sight effort over time (Figure 17). In general survival to age 1.5 was low, averaging 0.57 (range 0.46 – 0.70), but it increased thereafter. Juvenile survival (1.5 to 4.5 years) averaged 0.93 (range 0.90 – 0.96), and adult survival averaged 0.94 (0.90 – 0.96). The data for younger cohorts are sparse and therefore difficult to model.

There was evidence that cohort survival to 1.5 years (which approximates weaning age) varied across the ten cohorts. It was generally higher for older cohorts compared to younger cohorts (Figure 17). Part of this result is likely to be an artefact of recapture probability increasing with age, as the oldest cohort has a total of 15 years of re-sights while the youngest (2016) has less than two (Figure 17). The was a clear pattern of alternating pup survival between winter/spring and summer/autumn cohorts, with winter/spring cohorts having relative high survival and summer/autumn cohorts having lower survival (Figure 17). This is consistent with higher breeding season pup mortality in summer/autumn breeding seasons (Figure 8).

Several fundamental life-history parameters, or vital rates, are required to understand population dynamics, including production, survival, fecundity and dispersal. Age specific survival rates are considered one of the best indicators of population change in pinnipeds (Pistorius *et al.* 1999). The population ecology and demography of ASL are poorly understood and are likely to differ in many respects from all other ‘typical’ annual and synchronous breeding pinnipeds. As such the life history study of ASL at Seal Bay provides critical information for this unique pinniped. Estimates of age-specific survival, recruitment and fecundity will be used to develop better demographic models for the species. Understanding survival and recruitment are critical to understanding and managing the population at Seal Bay. Such information will improve population viability analyses (PVA) developed for the species and help understanding the ultimate reasons why populations are in decline. They can also be used to assess the likely consequences of different conservation and management actions, and recovery times.

3.2 Seal Slide

3.2.1 ASL pup abundance

Ground counts were undertaken at Seal Slide 27 January 2018 when seven pups were counted (1 black mate-guarded, and 6 brown) and on 17 May 2018 when 14 pups were counted (7 brown, 6 moulted, 1 dead). Four pups were microchipped on 27 January 2018 and a further five pups were microchipped on 17 May 2018, bringing the total microchipped to nine. The minimum pup production estimate for the 207/18 breeding season is therefore 14.

Estimates of pup abundance at the Seal Slide with a high degree of confidence are now available for the last 11 breeding seasons since 2002/03 (Table 6, Figure 18). A regression model fitted to the median of the posterior predictive counts between 2002/03 and 2017/18 breeding season suggests that pup abundance at Seal Slide is increasing by about 0.95% per year (range -3.24 to 7.37), or 1.45% per breeding season (range -4.86 to 11.06). However, the credible range of these estimates is large indicating high uncertainty in the current trends of pup abundance at this site (Figure 18).

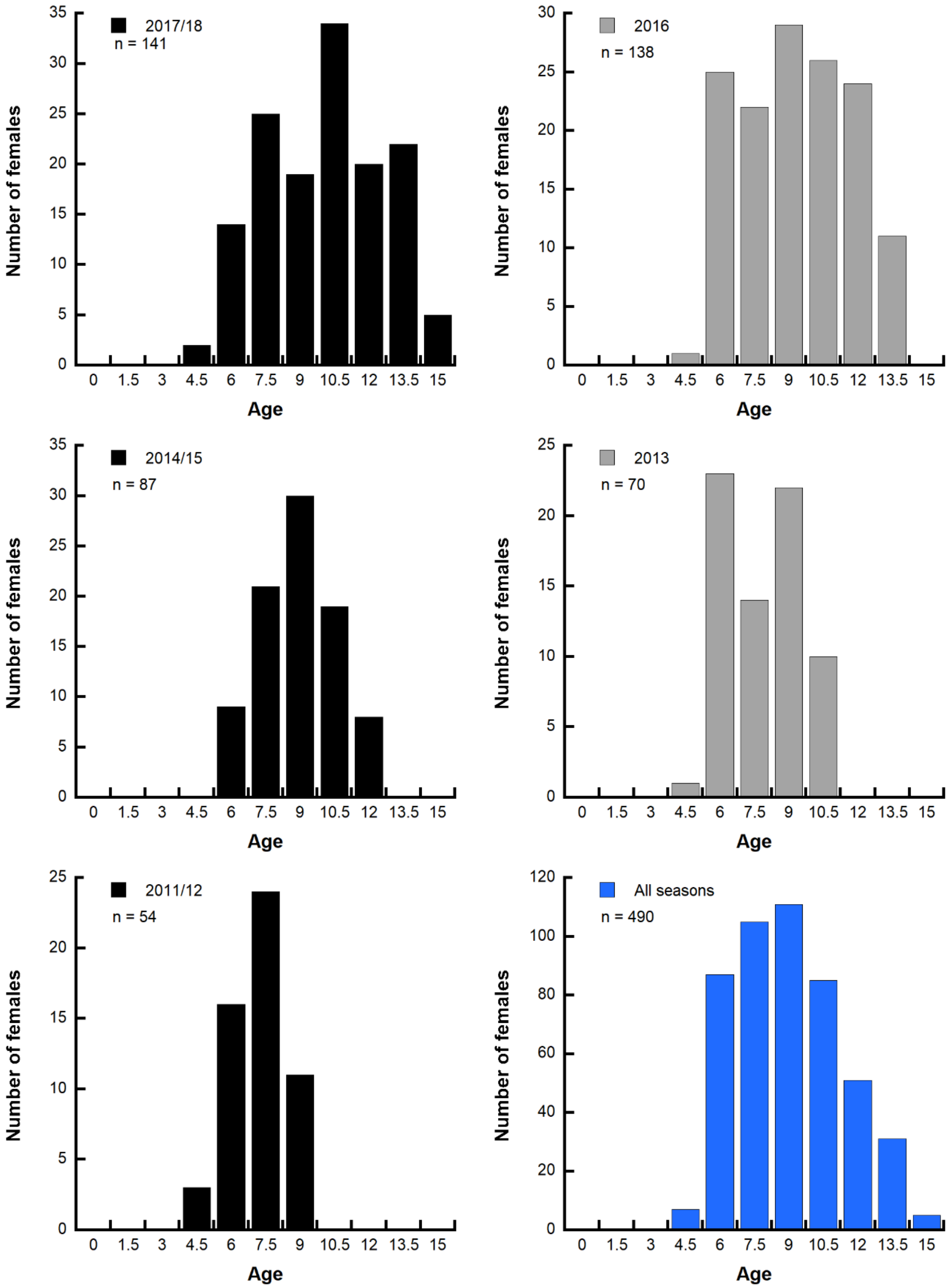

Figure 12. Age distribution of known-age Australian sea lion females that pupped at Seal Bay in the 2011/12, 2013, 2014/15, 2016 and 2017/18 breeding seasons. Seasons with black bars represent summer/autumn, while grey bars reflect winter/spring breeding season. The pooled age-distribution across the last five breeding seasons (All seasons) is also presented (blue bars). Note that microchipping commenced in the 2002/03 breeding season, so the oldest known-aged females were 15 years in 2017/18, and no data are available for females >15 years of age.

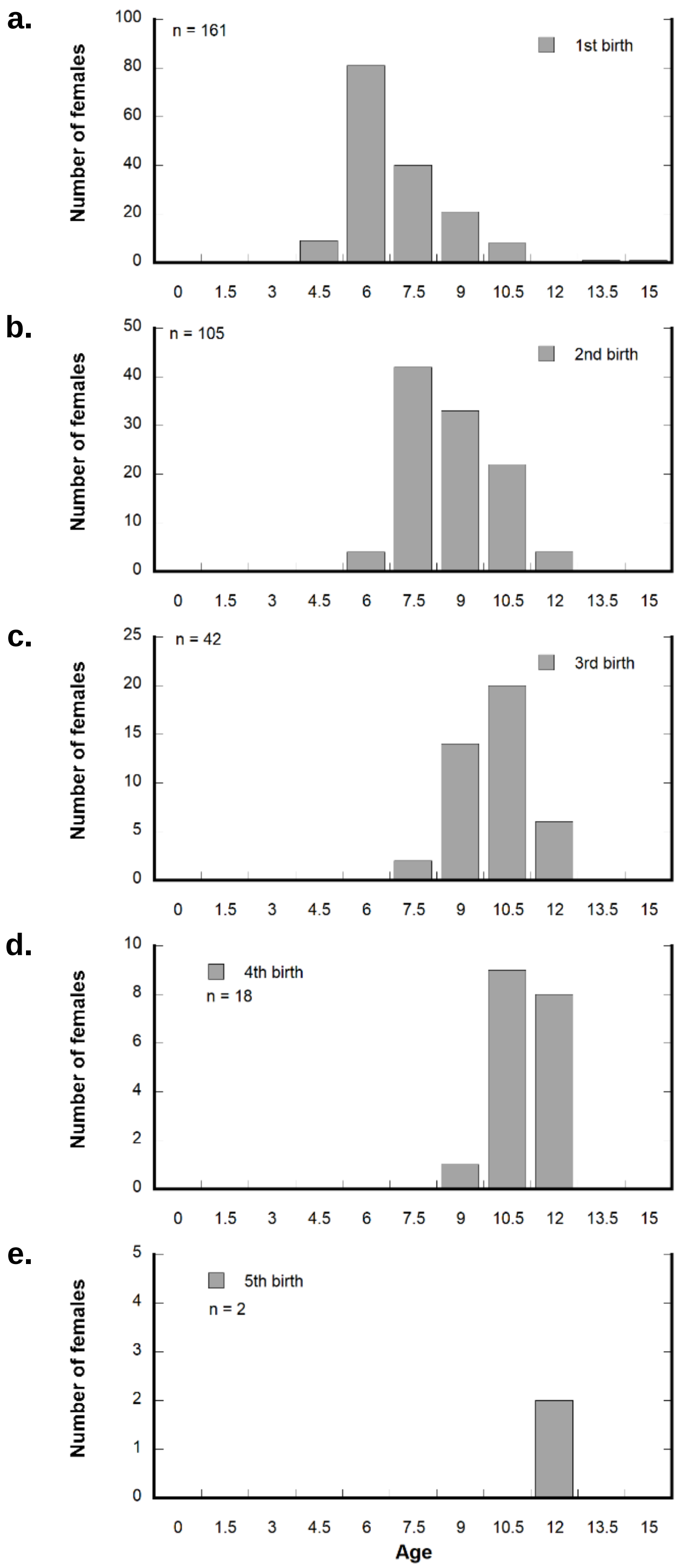

Figure 13. Age related parity distribution of known-age Australian sea lion females that pupped at Seal Bay in the 2011/12, 2013, 2014/15, 2016 and 2017/18 breeding seasons. Note that microchipping commenced in the 2002/03 breeding season, so the oldest known-aged females were 15 years in 2017/18, and no data are available for females >15 years of age.

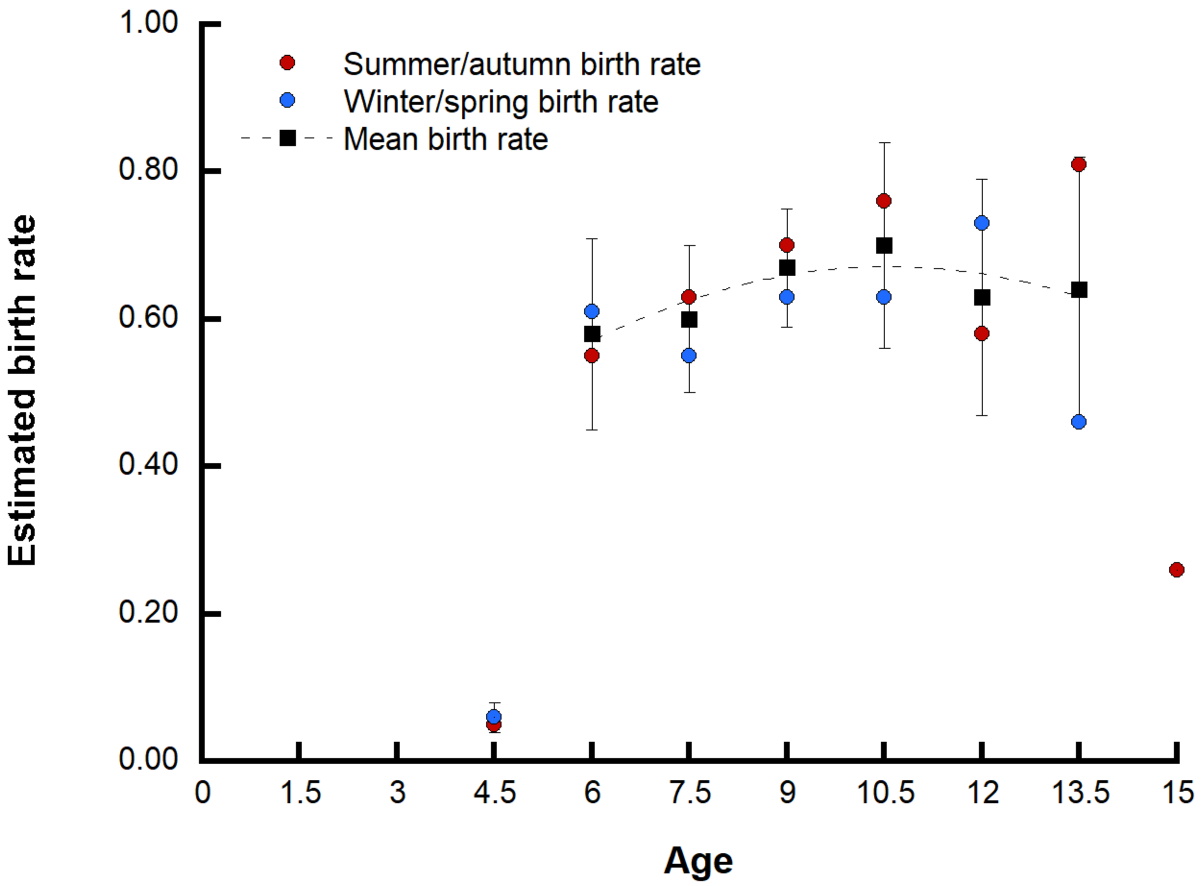

Figure 14. Estimated birth rate of known-age Australian sea lion females that pupped at Seal Bay in the 2011/12, 2013, 2014/15, 2016 and 2017/18 breeding seasons. Note that microchipping commenced in the 2002/03 breeding season, so the oldest known-aged females were 15 years in 2017/18, and no data are available for females >15 years of age.

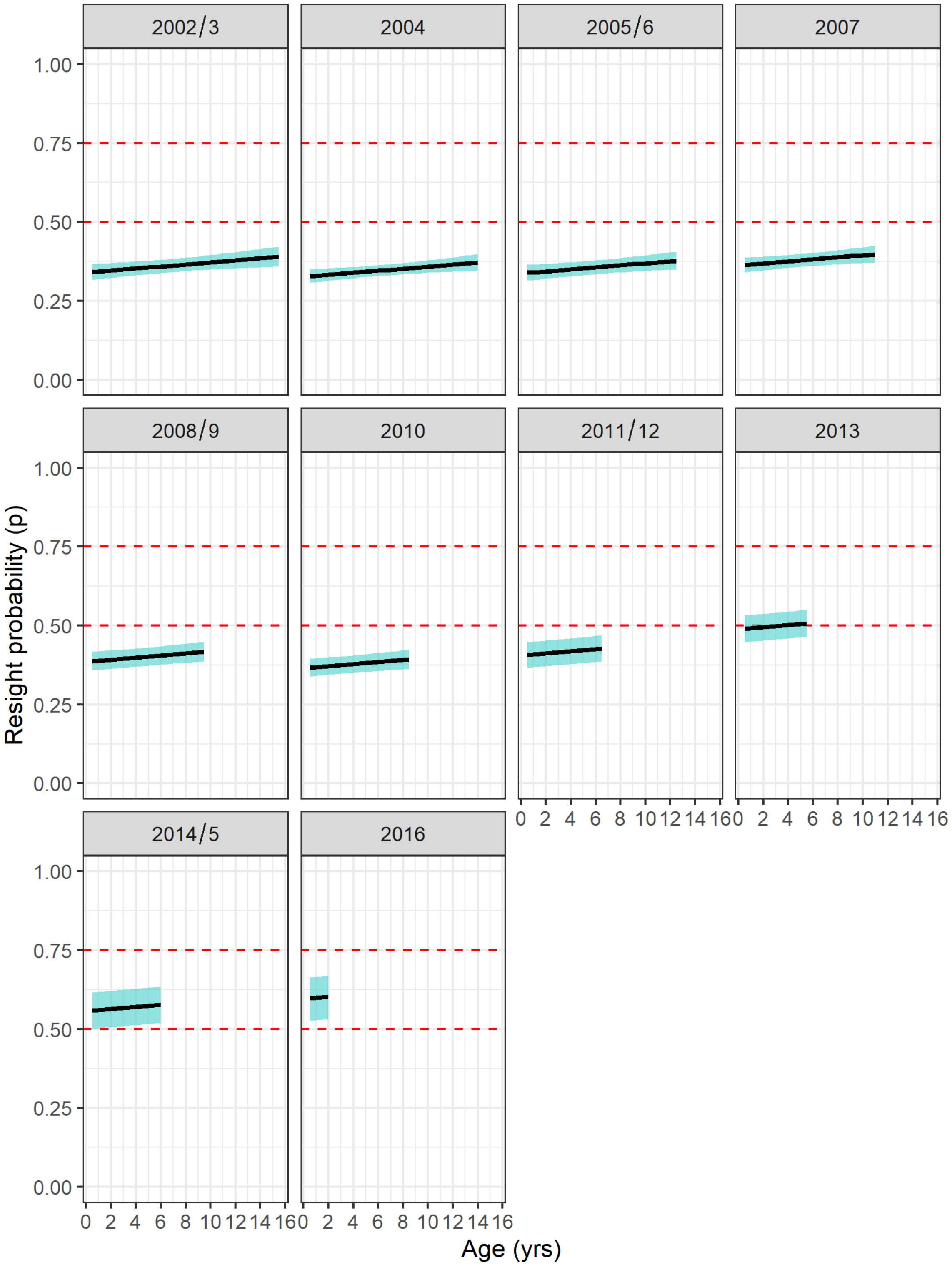

Figure 15. Resight probability by age for ten cohorts (2002/03 to 2016) of known-age (microchipped) Australian sea lions in the Seal Bay population.

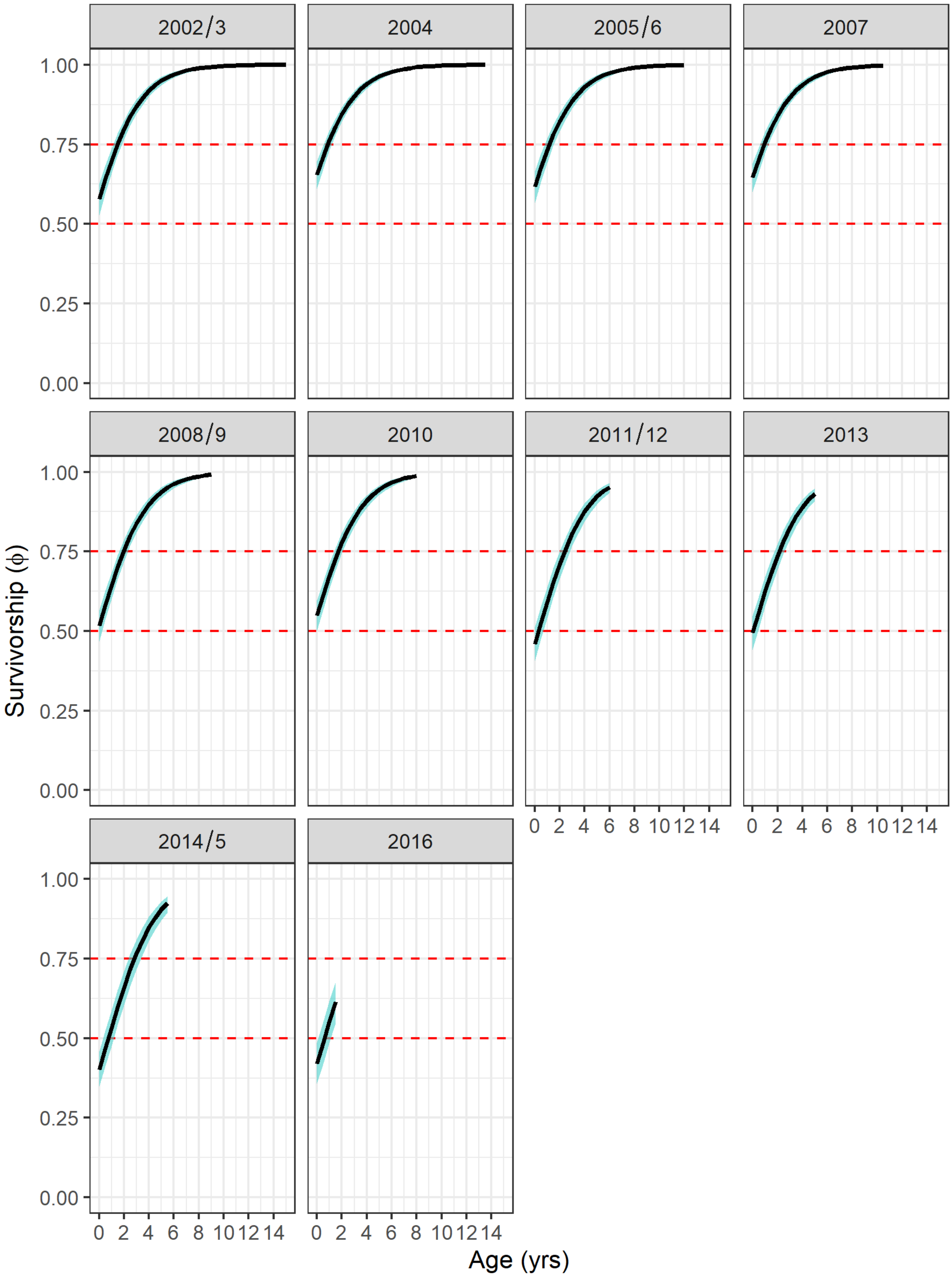

Figure 16. Estimated cohort survivorship as a function of age for ten consecutive (microchipped) Australian sea lion cohorts in the Seal Bay population.

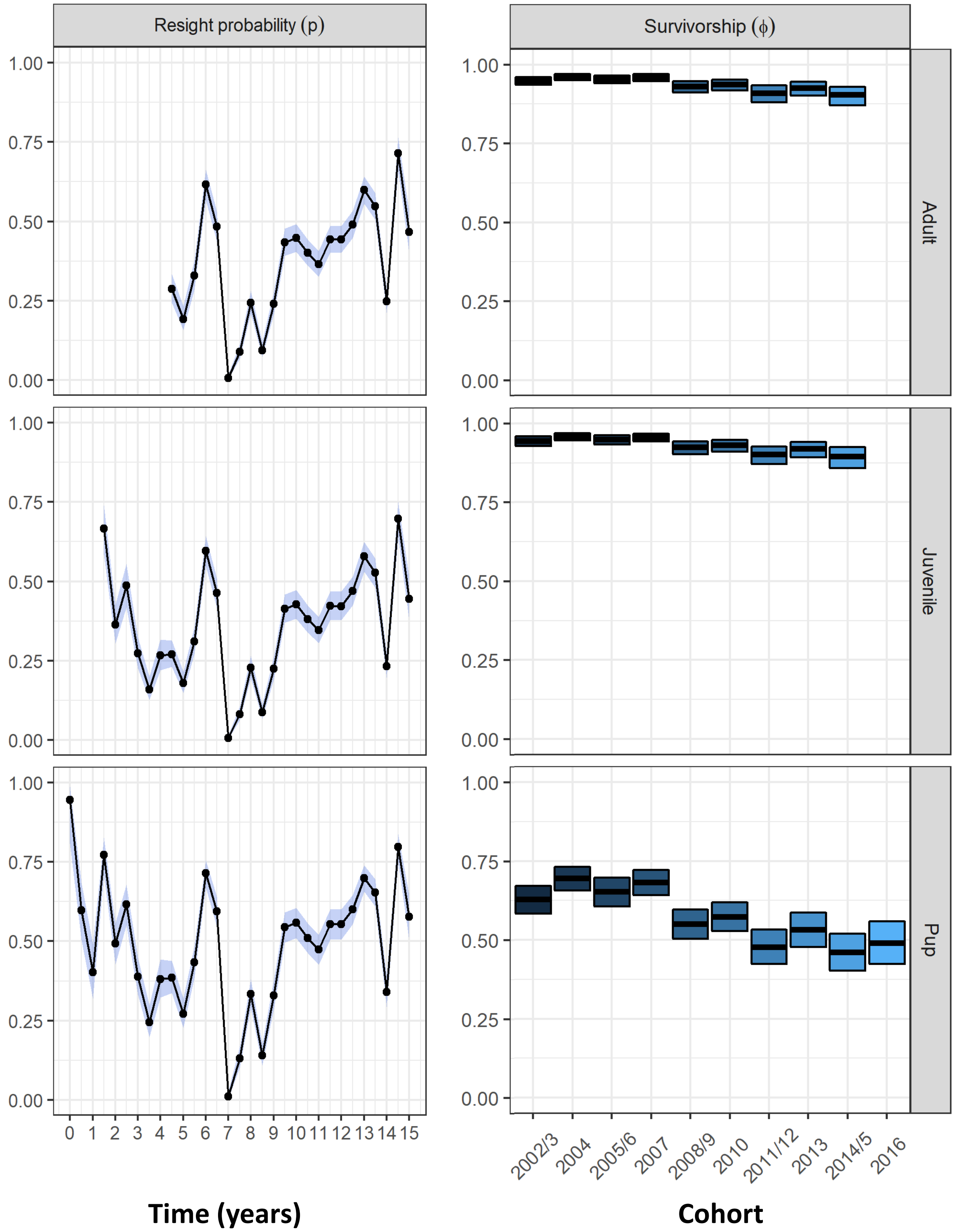

Figure 17. Variation in resight probability of microchipped Australian sea lions in the Seal Bay population as a function of time (year) and stage (left), and cohort specific survival as a function of stage (pups 0 to 1.5 years, juveniles 1.5 to 4.5 years and adults >4.5 years) (right).

Table 6. Estimates of abundance of Australian sea lion pups at the Seal Slide, Kangaroo Island over 11 breeding seasons from 2002/03 to 2017/18.

Breeding season	Estimate of pup numbers	Source
2002/03	9	Shaughnessy *et al*. (2009)
2004	11	Shaughnessy *et al*. (2009
2005/06	10	Goldsworthy *et al.* (2007)
2007	15	Goldsworthy *et al.* (2008)
2008/09	12	Goldsworthy *et al.* (2010)
2010	10	Goldsworthy *et al.* (2011)
2011/12	13	Goldsworthy *et al.* (2013)
2013	10	Goldsworthy *et al.* (2014)
2014/15	8	Goldsworthy *et al.* (2015a)
2016	15	Goldsworthy *et al.* (2017)
2017/18	14	This report

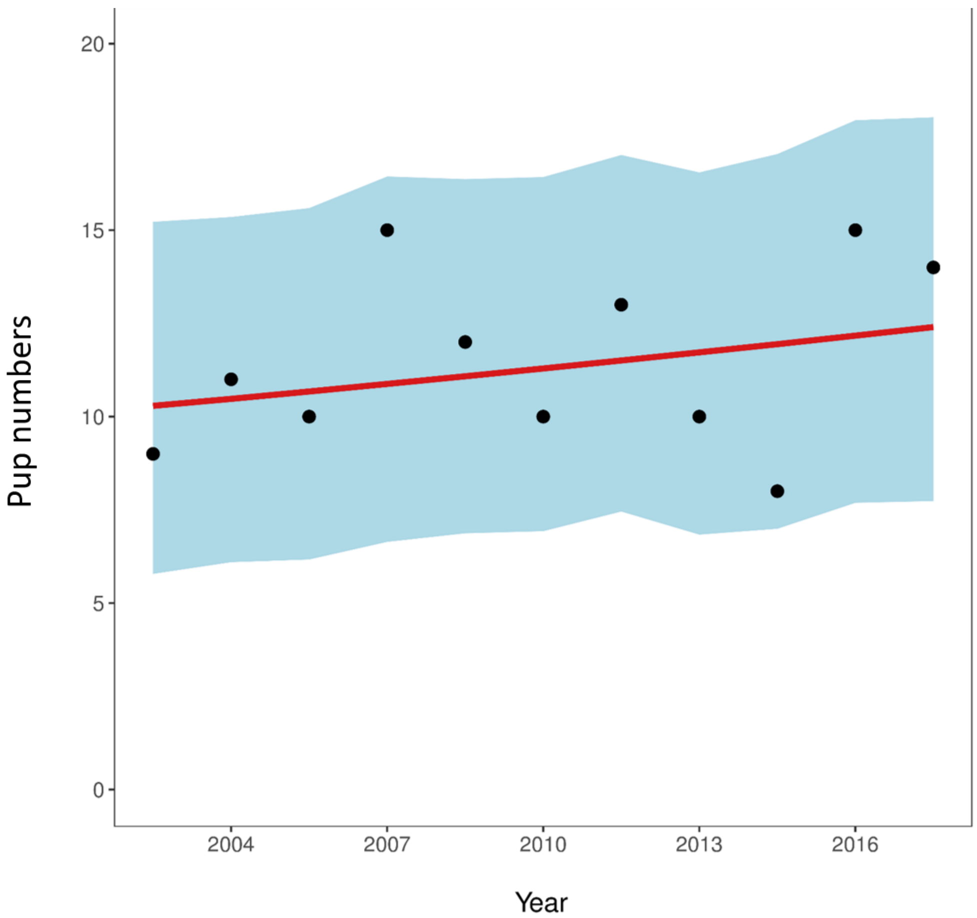

Figure 18. Trends in the estimated Australian sea lion pup production at the Seal Slide (Kangaroo Island), over eleven consecutive breeding seasons (2002/03 to 2017/18). The blue envelope is the 90% highest probability density credible intervals. The red line is the fitted least-squares predictive trend of pup counts and the black line is the median of the posterior predictive counts.

3.3 Fur seal surveys

3.3.1 Pup marking

For the survey of LNFS in January 2018 in the CGWPA, a total of 3,586 pups were marked: 288 at Cape Linois, 695 across three sectors at Berris Point and 2,603 across seven sectors at Cape Gantheaume (Table 7).

3.3.2 Pup abundance estimates

In the Cape Gantheaume sub-colony (which includes Little Weirs Cove), the mean proportion of marked pups in the resight sessions was 0.63. The estimated number of pups in the colony was 4,144 (95% CL 4,107 – 4,181). This estimate includes 68 dead pups (1.6%) (Table7).

At the Berris Point sub-colony, the mean proportion of marked pups was 0.61. The estimated number of pups in the sub-colony was 1,144 (95% CL 1,124 – 1,164). This estimate includes 23 dead pups (2.0%) (Table 7).

At the Cape Linois sub-colony, the mean proportion of marked pups was 0.54 and the estimated number of pups in the sub-colony was 532 (95% CL 518 – 546). This estimate includes four pups counted at The Veranda and 1 dead pup at Cape Linois (0.2%) (Table 7).

The estimate of pup abundance for the entire CGWPA for the 2017/18 breeding season was 5,820 (95% CL 5,776 – 5,865), the proportion of marked pups was 0.62 and 1.6% of pups were found dead (Table 4). The estimate represents an increase of 20.6% compared with the previous breeding season (4,825; 95% CL 4,865 – 4,942) (Goldsworthy *et al.* 2017).

3.3.3 Trends in pup abundance

For the Cape Gantheaume sub-colony, estimates of pup numbers increased from January 1989 to January 2018 (Table 8, Figures 19 and 20). Growth rates in the sub-colony have declined from 3.4% (2.4 to 4.6) per year over the last decade to 2.7% (-0.5 to 5.7) over the last five years (Table 9).

The Berris Point sub-colony was established in 1996/97 and grew rapidly throughout the 2000s, peaking at 1,344 pups in the 2013/14 breeding season. Much of this increase was likely to have been sustained through immigration from the Cape Gantheaume sub-colony. Average growth in the Berris Point sub-colony has declined from 2.4% (1.4 to 3.4) per year over the last 10 years, to -2.1% (-4.7 to 0.5) per year over the last five years (Table 9, Figures 19 and 20).

At the Cape Linois sub-colony, the first breeding record was in 2001/02 when a single pup was sighted. Over the last nine years, pup numbers have increased rapidly from 6 to 532. Pup production over the last 10 years has grown at an extraordinary rate of 83.3% (75.8 to 94.7) per year, to 97.1% (80.1 to 110.9) per year over the last five years (Table 9, Figures 19 and 20).

Since January 1989, pup numbers within the entire CGWPA have increased by a factor of 12.7 (from 458 to 5,820). Overall, this increase has been at an average exponential rate of r = 0.083, equivalent to 8.7% per annum (n = 30 seasons, r^2 = 0.86) (Figure 21). There appear to be two phases to the recovery of fur seals in the CGWPA. The first was between January 1989 and 1998 when the population increased at an average exponential rate of r = 0.159, equivalent to 17.2% per annum (r^2 = 0.99). The second phase was between January 1999 and 2018 when the population increased more erratically and at the lower exponential rate of r = 0.056, equivalent to an average of 5.8% per annum (r^2 = 0.84) (Figure 22).

The 2018 breeding season represents only the second breeding season since 1989 where pup production exceeded 5,000 for the entire CGWPA. The previous breeding season was 2014 (5,333), four breeding seasons earlier. Part of the marked increase in pup production in the 2018 breeding season may be related to strong recruitment of females born in the 2014 breeding season, as the earliest age that LNFS females give birth is four (McKenzie *et al.* 2007).

Most of the growth in the LNFS population in the CGWPA over the last decade has been due to the marked growth in the Cape Linois sub-colony. The combined pup production at the Cape Gantheaume and Berris Point sub colonies has only increased by 2% per year (r = 0.0195), whereas Cape Linois has increased by 93.7% per year (r = 0.6613) over the same period. In fact, for the Cape Gantheaume and Berris Point sub colonies, if one removes the two exceptional high pup production seasons (2014 = 5,333 and 2018 = 5,820) and one season of very low pup production (2010 = 3,472), pup production has been effectively stable over the last 10 breeding seasons (r = -0.00168, -0.2%/year), averaging 4,700.

These results suggest that there is limited capacity for continued growth in LNFS abundance within the established sub-colonies in the CGWPA, and that continued growth in abundance is largely a reflection of the establishment and rapid growth of new colonies (Cape Linois).

3.3.4 Pup mortality

The number of pups found dead was recorded when pups were marked and also during resight sessions a few days later. In January 2018, a total of 92 dead fur seal pups were recorded at sub-colonies in the CGWPA. This represents 1.6% of the 5,820 pups estimated at these sites (Table 7). It should be considered an underestimate because some of the dead pups would have been overlooked, including some that might have been washed out to sea or into rock pools, or taken by scavengers (Shaughnessy and Goldsworthy 2015).

Changes in annual estimates of pup mortality of LNFS pups in the CGWPA are presented in Figure 23. It shows a gradual increase in pup mortality as the LNFS population in the CGWPA has grown, suggesting the influence of density dependent factors. However, there is also marked inter-annual variability in the estimated mortality rates of pups, which are likely to reflect environmental factors such as food availability (Figure 23).

3.3.5 Pup weight and length

A total of 110 pups were weighed at Cape Gantheaume on 27 January 2018 (Table 10): males and females weighed 7.37 kg and 6.37 kg on average, and were 70.8 cm and 67.6 cm in length, respectively. Fluctuations in the mass of male and female pups over 30 consecutive years show a steady decline in average mass since the late 1990s (Figure 24a). Annual deviations from mean male and female mass (mass anomaly) indicate two main periods, one of above average mass from the early 1990s to the mid-2000s, and one of below average from 2006 onwards (Figure 24b). The earlier period corresponds to the period of major growth in CGWPA colonies. Between 1994 and 2015, pup production increased from one breeding season to the next in 11 out of 12 breeding seasons, with an average inter-breeding season increase in pup production of 13.1%. In contrast, between 2006 and 2018, pup production increased from one breeding season to the next 7 times, and decreased 6 times out of a total of 13 breeding seasons, and the average inter-breeding season increase in pup production had reduced to 5.2%.

Changes in the mass of pups appear to correspond to changes in relative population growth rates, suggesting that density dependent factors that have reduced population growth rates, have also resulted in a general decline in pup mass and an overall increase in pup mortality as the population has grown and approaches carrying capacity. However, broader environmental changes such as in ENSO or Southern Annular Mode (SAM) that can affect ocean production and food availability to predators may have also contributed to changes in population growth, pup mass and mortality.

4.3 Future monitoring priorities

Monitoring of pinniped populations on Kangaroo Island has been occurring since the 1980s. For both the Australian sea lion and long-nosed and Australian fur seals, the focus of monitoring has been estimating pup production and determining trends in abundance.

4.3.1 Australian sea lions

Seal Bay

A history of research activity and monitoring of the Australian sea lion population at Seal Bay, including the development of the current monitoring framework, are detailed in Goldsworthy et al. (2007a). The core developments of the current program implemented in 2003 was the estimation of breeding season pup production and mortality rates, and an expansion of the microchipping program. Since 2003, the core program has remained relatively unchanged, but some the methods to achieve them have been improved. The introduction of the Fulcrum app as a data collection and database tool has led to significant improvements in data acquisition and efficiency. Increasing effort to report reproductive histories over the last four breeding seasons is now providing dividends for estimating birth rates and fecundity, and more regular resighting effort has improved survival estimates.

The current monitoring program is working well. Its continuation is essential as it provides critical information on the status and health of the population that is needed to ensure tourism activities are sustainable, and to assess the success of conservation and management actions to mitigate threats and enable the recovery of the species and all subpopulations (i.e. actions as set out in the Australian sea lion Recovery Plan, Department of Sustainability Environment Water Population and Communities 2013). It also provides fundamental life history data that cannot be collected at other sites because of difficulties with accessibility. Such data will be essential in the development of new conservation and management initiatives for the species.

Monitoring of minor sites

In additional to Seal Bay, there are known to be an additional five small ASL breeding sites on Kangaroo Island (Shaughnessy *et al.* 2009). These include the Seal Slide, Black Point, Cave Point, Cape Bouguer, and North Casuarina Island. Of these, the Seal Slide has been most frequently monitored, with pup numbers ranging from 8 to 15 over the last 11 breeding seasons (this report). The most comprehensive surveys of North Casuarina Island and Cape Bouguer were undertaken as part of the 2014/15 State-wide ASL survey, with 11 and 9 pups recorded, respectively (Goldsworthy *et al.* 2015b). Earlier surveys have recorded fewer pups at these sites, but many of these were undertaken outside the peak of the breeding season (Shaughnessy *et al.* 2009). A single pup has been observed at Black Point on three occasions (1986, 2002, 2005), but it is not clear if any of these were actually born there (i.e. it is possible they moved from the Seal Slide or Seal Bay). At Cave Point, three dead pups were recorded in 1990 and a single dead pup was sighted in 1993. No live pups have been recorded since (Shaughnessy *et al.* 2009).

It appears, therefore, that Seal Slide, North Casuarina Island, and Cape Bouguer are all established breeding colonies of a similar size. Although Seal Slide is currently being monitored regularly, North Casuarina Island and Cape Bouguer are not. Consideration should be given to obtaining more regular assessments of pup abundance at these sites. Remote cameras (4G network) could be utilised to monitor signs of breeding activity, so that survey timing can be planned to coincide with the breeding season.

4.3.2 Long-nosed fur seals

Long-term time series data on pup production in the CGWPA LNFS colony is the longest for any seal colony in Australia, and provides one of the best records of post-sealing population recovery. The fact that this population has grown to become the largest for the species in Australia, and the largest seal colony in Australia, is serendipitous. However, as the CGWPA population has grown, the logistics of monitoring and the time to survey the population have also grown. A total of 28 people participated in the January 2018 survey; 27 were involved in clipping pups over two days, and 16 of these were involved in the subsequent resights. The survey took 6 days to complete. Although this survey indicated that the Cape Gantheaume colony is still growing slowly (2.7%/year over last 5 years), its growth is small compared to that of the Cape Linois colony (97%/year over last 5 years). These results, plus those of the 2014 State-wide survey, indicate that as most of the main breeding sites reach capacity, further growth in LNFS population is being achieved by the establishment and growth of new, emerging colonies (Shaughnessy *et al.* 2015).

After 30 consecutive annual surveys in the CGWPA, we need to consider the value of continuing to maintain annual surveys there, versus adjusting the monitoring program so that it enables other sites to be periodically surveyed, especially emerging sites (like Cape Linois) where population growth may be rapid. In considering this question, we need to ensure that annual monitoring continues at least at one site in the CGWPA, so that annual variation and relative pup production can be compared. This is important as previous surveys have shown that colonies in SA usually show the same yearly residual trends, i.e. good, poor and average years. For sites surveyed infrequently, it's important to be able to evaluate pup production relative to sites where annual monitoring occurs. For example, during the last State-wide survey in 2014, LNFS pup production in the CGWPA showed a 15% increase from the previous breeding season, indicating that for all other sites surveyed, pup production estimates reflected a very strong breeding season. With the establishment of the Cape Linois colony, we now have a LNFS colony that is very accessible, and relatively easy to survey that could potentially be used as an annual monitoring site, instead of undertaking annual surveys of the entire LNFS population in the CGWPA. Cape Linois is easily accessible by 4WD (~20 minute drive from D'Estrees Bay), and can be surveyed in two, half-day trips (i.e. with one overnight stay at D'Estrees Bay). This approach can potentially free up resources and time that could be allocated to surveying sites that have not been monitored regularly, including new and emerging sites.

New analysis methods such as agTrend are capable of estimating regional trends in abundance where sites may be sampled unevenly over space and time (Johnson and Fritz 2014). As such, an approach where one site is monitored annually and where other sites may not be monitored at concurrent times, provides an opportunity to undertake greater regional monitoring of abundance, without risking the loss of annual signals in relative pup production. This provides greater flexibility to adjust monitoring effort with available resources. For example, alternating between monitoring the smaller emerging LNFS sites on Kangaroo Island in one year (Paisley Island, Cape Kersaint, Cave Point, Cape Hart), with surveying the major breeding sites at Cape du Couedic or Cape Gantheaume in other years. It also provides flexibility to undertake surveys at non-Kangaroo Island colonies in other years. Ultimately, management priorities will shape future monitoring strategies for the species.

4.3.3 Australian fur seals

The Australian fur seal population is centred on the Bass Strait islands in Victoria and Tasmania (Kirkwood and Goldsworthy 2013). A breeding colony has established at North Casuarina Island off Cape du Couedic, with 11 pups recorded there in 2006/07, 29 pups in 2007/08, 80 pups in 2011/12, and 76 pups in 2013/14 (Shaughnessy *et al.* 2014, Shaughnessy *et al.* 2010). Based on population growth of this species in Bass Strait over the last 30 years, the population in South Australia is also likely to increase (McIntosh *et al.* 2018b), and monitoring of it also need to be considered. Helicopter provides the only safe access to North Casuarina Island, making it a challenging site for regular monitoring. However, recent application of drones to monitor Australian fur seals pup production at a Victorian colony (McIntosh *et al.* 2018a), suggests this method may be suitable for locations like North Casuarina Island, which is only 400m off Cape du Couedic and therefore is readily accessible by a suitable drone. This may provide a cost-effective way to monitor changes in the abundance of Australian fur seals at this site.

4 CONCLUSION

This project aimed to provide DEW with information on the status and trends in abundance of the ASL population at Seal Bay and the Seal Slide, and the LNFS population in the Cape Gantheaume Wilderness Protection Area (CGWPA). Seal Bay and Cape Gantheaume represent the most well studied populations for each species, respectively. These studies are therefore of critical importance for informing both State and National Governments on conservation and management policy for these protected marine species. In addition, seals form an integral part of the Kangaroo Island ecotourism industry. In 2011/12, of the 193,975 visitors to Kangaroo Island, 67% viewed ASL at Seal Bay and 79% of visitors viewed LNFS at Admirals Arch (information from the South Australian Tourism Commission). Hence, knowledge on the status and health of these seal species is relevant to ensure long-term sustainability of this important eco-tourism industry.

The ASL pup production estimate for Seal Bay for the 2017/18 breeding season was 232, the lowest since estimation of pup production commenced in 2004. Trends in estimated pup production available for nine of the last ten breeding seasons between 2004 and 2017/18 indicate there has been a decline of 1.6% per year (range -2.6 to -0.4%), or 2.3% per breeding season (range -3.9 to -0.6%).

The maximum direct count of live pups at Seal Bay for the 2017/18 breeding season was 110. Analysis of trends in live pup counts over 23 consecutive breeding seasons between 1985 and 2017/18 were similar to those for pup production, indicating a decline of 1.5% per year (range -2.7 to -0.3%), or 2.2% per breeding season (range -4.1 to -0.4%).

At the Seal Slide, the estimate of pup production for the 2016 breeding season was 14. Pup abundance there has been increasing by about 1% per year (range -3.2 to 7.4%), or 1.5% per breeding season (range -4.9 to 11.1%), although the credible range is large indicating high uncertainty in the current trends.

In the CGWPA, the LNFS pup production estimate for the 2017/18 breeding season was 5,820 (95% CL 5,776 – 5,865), an increase of 20.6% compared with the previous breeding season (4,904). The part of the colony increasing most rapidly was at Cape Linois, where the estimate for 2017/18 was 532 pups, up from 343 in the 2016/17 season.

Since January 1989, pup numbers within the CGWPA have increased over the 30 breeding seasons by a factor of 12.7 (from 458 to 5,820). This increase has been at an average exponential rate of r = 0.083, equivalent to 8.7% per annum. Over the last decade, overall growth in pup production in the

CGWPA has declined to 3.8% per year and over the last five years, the rate of change has only been -2.6% per year. The long nosed fur seal colony in the CGWPA remains the largest colony for the species in Australia.

A review of monitoring approaches for Kangaroo Island pinnipeds was undertaken. It recognised that the current monitoring program for the ASL population at Seal Bay is delivering important information on pup production and population vital rates that are intrinsically important to the management of the species and human interactions at the site, and also provide important information essential to informing conservation and management programs for the species. Monitoring of pup production at the Seal Slide should be continued, and consideration should also be given to monitoring the Cape Bouguer and North Casuarina breeding sites. The 30-year annual time series on LNFS pup production at the CGWPA has provided a remarkable record of post-sealing recovery for the largest population of the species in Australia and the largest seal colony. However, the resources to maintain this comprehensive survey annually are considerable, and as it and other major colonies approach capacity, further growth in LNFS populations will occur at new and emerging sites, which are not currently being systematically monitored. It is recommended that annual monitoring efforts be redirected to the Cape Linois colony, which requires a fraction of the resourcing to survey and is growing rapidly. This could provide capacity to alternate monitoring at other sites on Kangaroo Island or elsewhere in the State, to provide a more comprehensive monitoring program for the species abundance in South Australia. The emerging population of Australian fur seals on North Casuarina Island has the potential to grow further. Consideration should be given to monitoring this population; the application of drones to monitor this near-shore island should be explored further, as the technology has proven to be suitable for monitoring the species at some sites in Victoria.

Table 7. Estimates of abundance of long-nosed fur seal pups at breeding colonies in the Cape Gantheaume Wilderness Protection Area, Kangaroo Island in January 2018. Survey methods: count = direct count; MR = mark-resight estimate.

Site (& survey method)	Date marked or counted	Date of resight	Live count	No. pups marked	No. pups dead	No. resight estimates	Overall Estimate	95% CL	% pups marked	% pups dead
Cape Linois										
Cape Linois (MR)	22-Jan-18	27-Jan-18	-	288	1	11	528	514-542	54.5%	0.2%
The Veranda	27-Jan-18		4	-	0	-	4	-	-	-
Subtotal Cape Linois			-	**288**	**1**		**532**	**518-546**	**54.1%**	**0.2%**
Berris Point										
New site 1km east of Berris Nth (coun	24-Jan-17		6		0		6			
North (MR)	22-Jan-18	24-Jan-18	-	275	8	12	452	442-462	60.8%	1.8%
Middle (MR)	22-Jan-18	24-Jan-18		226	6	10	373	360-386	60.6%	1.6%
South (MR)	22-Jan-18	24-Jan-18		194	9	9	313	301-325	62.0%	2.9%
Subtotal Berris Point				**695**	**23**		**1144**	**1124-1164**	**60.7%**	**2.0%**
Cape Gantheaume										
Little Weirs East (count)	25-Jan-18	-	27	-	0	-	27	-	-	-
Little Weirs East (MR)	23-Jan-18	26-Jan-18	-	103	3	12	171	164-178	60.3%	1.8%
Little Weirs West (count)	26-Jan-18	-	2	-	0	-	2	-	-	-
West of Beach (count)	26-Jan-18	-	22	-	0	-	22	-	-	-
Cave (count)*	26-Jan-18	-	29	-	0	-	29	-	-	-
Sector Beach (MR)	22-Jan-18	24-Jan-18	-	500	16	12	822	803-840	60.8%	1.9%
Sector AB (MR)	23-Jan-18	25-Jan-18	-	110	2	12	165	159-171	66.5%	1.2%
Sector CDE (MR)	23-Jan-18	25-Jan-18	-	262	4	13	433	421-446	60.5%	0.9%
Sector FGH (MR)	23-Jan-18	25-Jan-18	-	298	5	13	537	520-553	55.5%	0.9%
Sector IJ (MR)	23-Jan-18	25-Jan-18	-	562	16	12	856	840-872	65.6%	1.9%
Sector KL (MR)	23-Jan-18	25-Jan-18	-	768	22	12	1080	1064-1097	71.1%	2.0%
Subtotal Cape Gantheaume				**2603**	**68**		**4144**	**4107-4181**	**62.8%**	**1.6%**
Total				**3586**	**92**		**5820**	**5776-5865**	**61.6%**	**1.6%**

Table 8. Numbers of long-nosed fur seal pups in sectors of the Cape Gantheaume sub-colony, Kangaroo Island in 30 breeding seasons to 2017-18. Dead pups are included, but the sectors Little Weirs and West of Beach are not included. Data for breeding seasons from 1990-91 to 2005-06 may differ from those of Shaughnessy et al. (2006, Table 13) because they have been revised. Data for 2017-18 are from Table 5 of this report.

	Sectors					
Year	Beach	Cave	A, B	C, D, E[a]	F to L[b]	Overall
1988-89[c,d]	0	0	233	205	19	457
1989-90[c]	0	0	237	234	54	525
1990-91	0	0	279	238	89	606
1991-92	2	0	312	310	112	736
1992-93	2	0	370	313	179	864
1993-94	22	0	380	311	225	938
1994-95	92	0	350	409	263	1114
1995-96	211	6	337	426	425	1405
1996-97	341	0	275	478	485	1579
1997-98	548	12	270	408	694	1932
1998-99	623	0	201	402	822	2048
1999-00	590	8	132	408	994	2132
2000-01	523	5	73	222	832	1655
2001-02	633	22	71	289	1117	2131
2002-03	618	33	71	310	1138	2170
2003-04	692	45	85	370	1443	2635
2004-05	750	41	92	394	1704	2980
2005-06	731	41	106	360	1883	3120
2006-07	690	41	100	314	1817	2963
2007-08	635	9	100	293	1782	2819
2008-09	804	-	107	347	2079	3337
2009-10	548	28	72	261	1671	2580
2010-11	707	28	100	319	2177	3324
2011-12	792	22	115	320	2260	3509
2012-13	723	20	116	355	2113	3327
2013-14	882	15	118	387	2353	3755
2014-15	668	-	134	317	2083	3217
2015-16	715	-	159	342	2122	3353
2016-17	664	-	151	333	2066	3214
2017-18	822	29	165	433	2473	3922

[a] Includes sector Ew each year, but did not include sector Ee until 1995-96.
[b] Includes sector Ee until 1995-96; data have been adjusted to include sector K from 1996-97 and sector L from 1999-2000.
[c] From Goldsworthy (1990, Table 8).
[d] All tagged.

Table 9. Trend estimates of growth in LNFS pup production for the three main sub-colonies of the CGWPA (Cape Gantheaume, Berris Point and Cape Linois) and for all breeding sites combined within the CGWPA, calculated using the hierarchical modelling and Bayesian inference methodology (see Johnson and Fritz 2014). Trend estimates (λ per year) are given for the posterior median of λ, and lower and upper 90% highest probability density credible intervals (CI) (in parentheses) of λ by year for the last five (2012/13-2017/18) and ten (2007/08 to 2017/18) year periods.

Site	Growth rate last 10 years (λ/yr)	Growth rate last 5 years (λ/yr)
Cape Gantheaume	3.4 (2.4 to 4.6)	2.7 (-0.5 to 5.7)
Berris Point	2.4 (1.4 to 3.4)	-2.1 (-4.7 to 0.5)
Cape Linois	83.3 (75.8 to 94.7)	97.1 (80.1 to 110.9)
Cape Gantheaume WPA	3.8 (3.2 to 4.5)	2.6 1 (1 to 4.2)

Table 10. Mass (kg) and standard length (cm) of long-nosed fur seal pups at Cape Gantheaume sub-colony, Kangaroo Island on 27 January 2018.

	January 2018	
	Male	Female
Mass (kg)		
Mean	7.37	6.37
(min – max)	4.5 – 11.25	4.15 – 9.7
Standard deviation	1.24	1.19
Standard length		
Mean	70.8	67.6
(min – max)	63.5 – 79.0	61 - 75
Standard deviation	3.16	3.69
Sample size	65	45

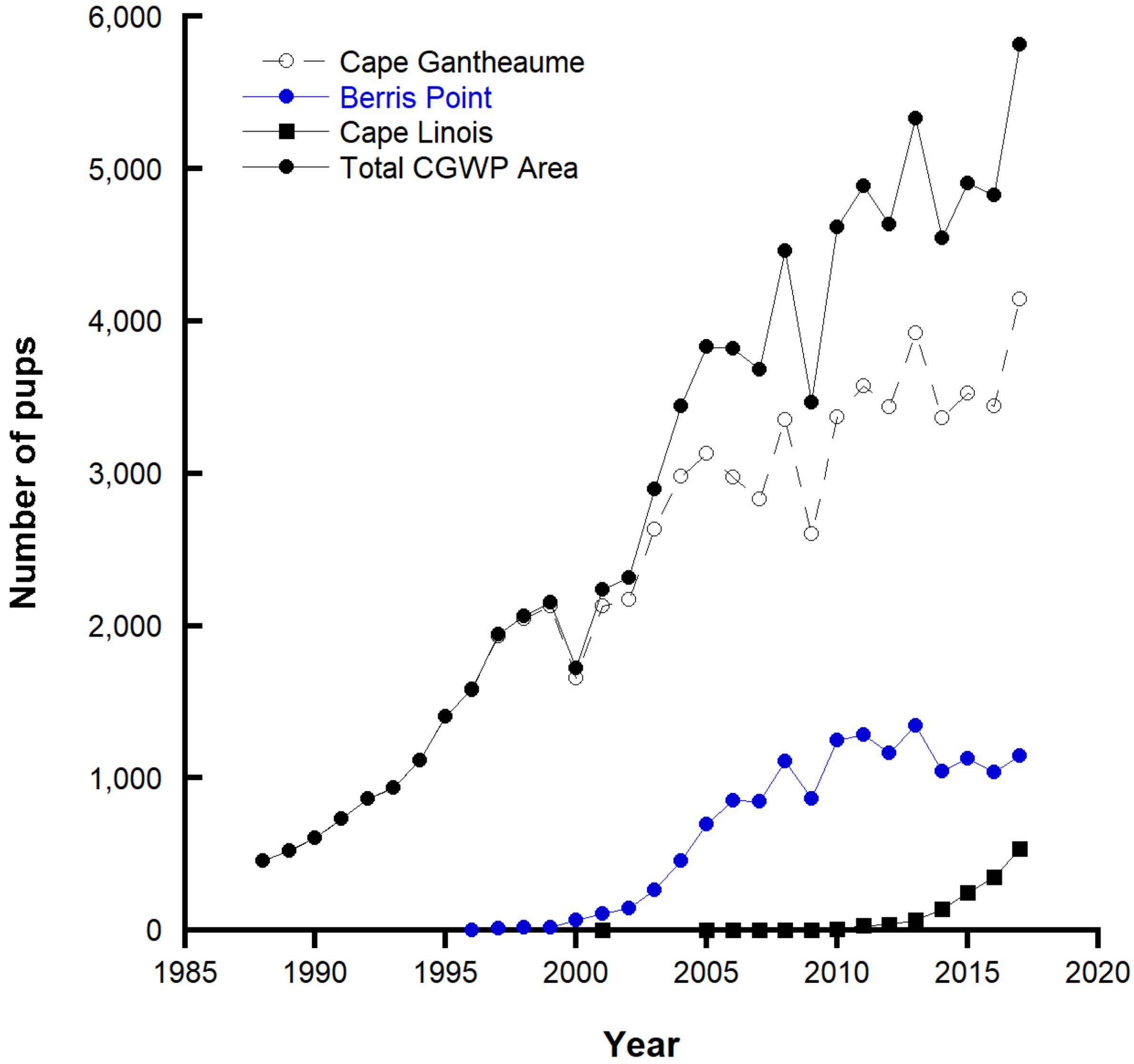

Figure 19. Annual pup production of long-nosed fur seal pups in the Cape Gantheaume Wilderness Protection Area (CGWPA) monitored each January between 1989 and 2017. Individual graphs show pup numbers for the entire CGWPA, and for the sub-colonies of Cape Gantheaume, Berris Point and Cape Linois.

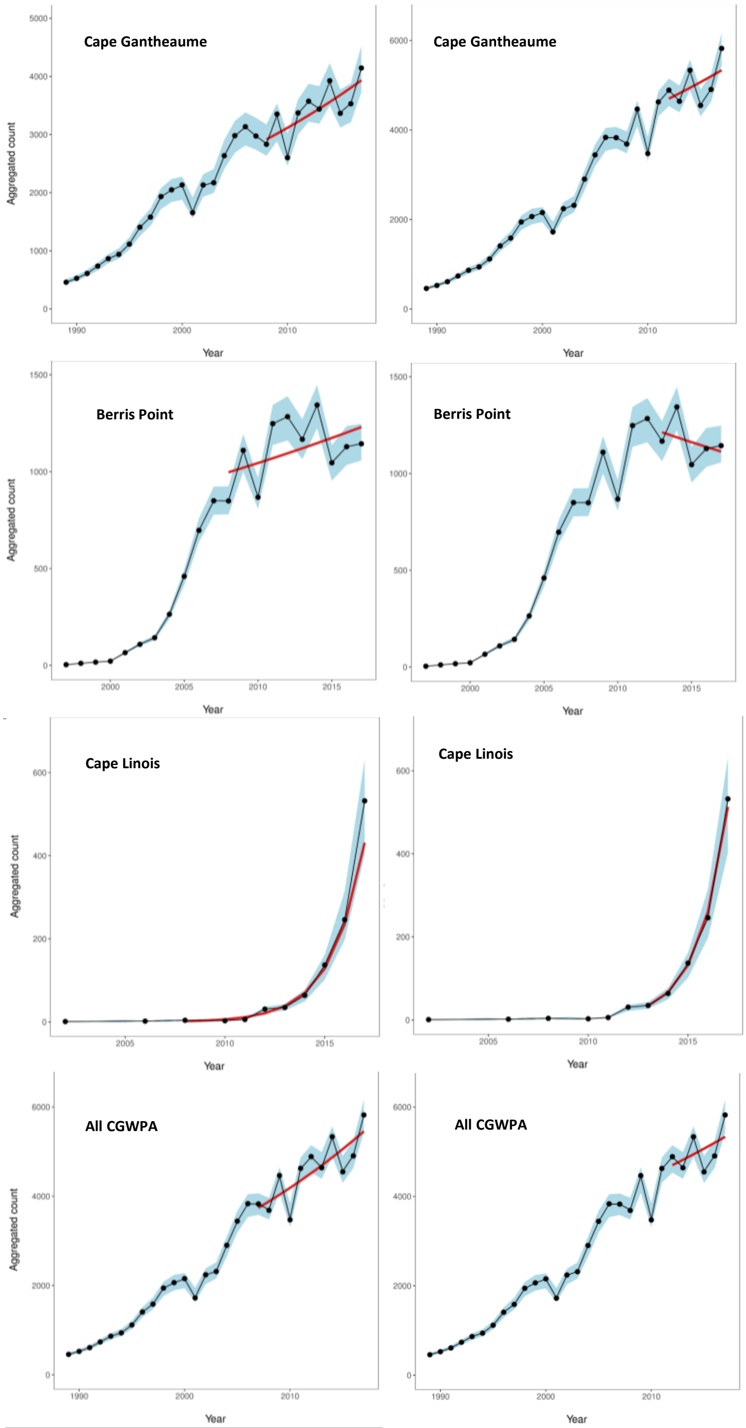

Figure 20. Estimates of LNFS pup production per year for the three main sub-colonies (Cape Gantheaume 1988/89 - 2017/18, Berris Point 1996/97 – 2017/18 and Cape Linois 2001/02 – 2017/18) and for all breeding sites combined within the CGWPA (1988/89 - 2017/18), calculated using the hierarchical modelling and Bayesian inference methodology (see Johnson and Fritz 2014). The blue envelope is the 90% highest probability density credible intervals. The red line is the fitted least-squares predictive trend for the last 10 years and last 5 years, on the left hand side and right hand side, respectively.

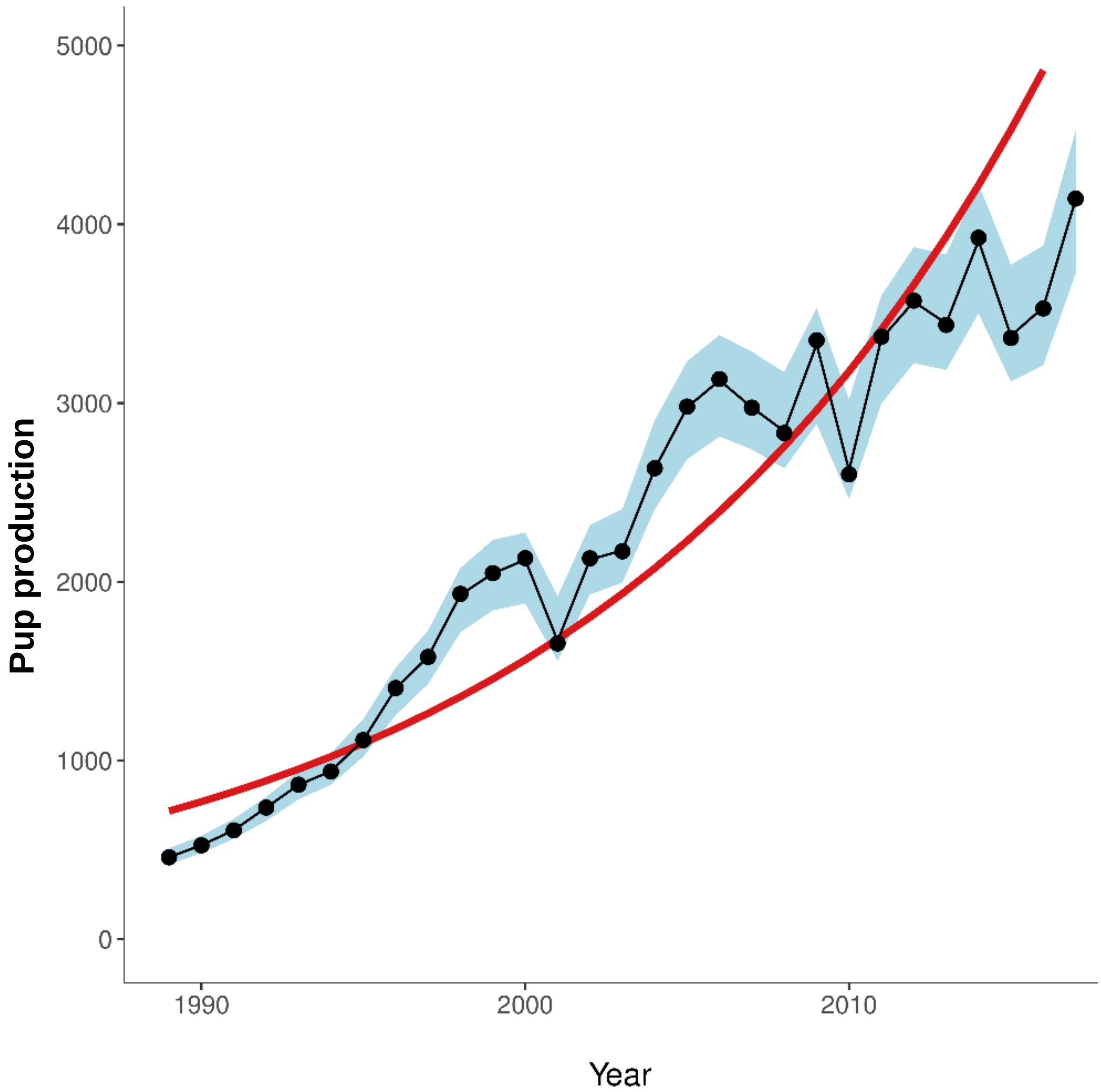

Figure 21. Annual pup production of long-nosed fur seals in the entire Cape Gantheaume Wilderness Protection Area between January 1989 and 2018. The blue envelope is the 90% highest probability density credible intervals. The red line is the fitted least-squares predictive trend for the 30 years of the study.

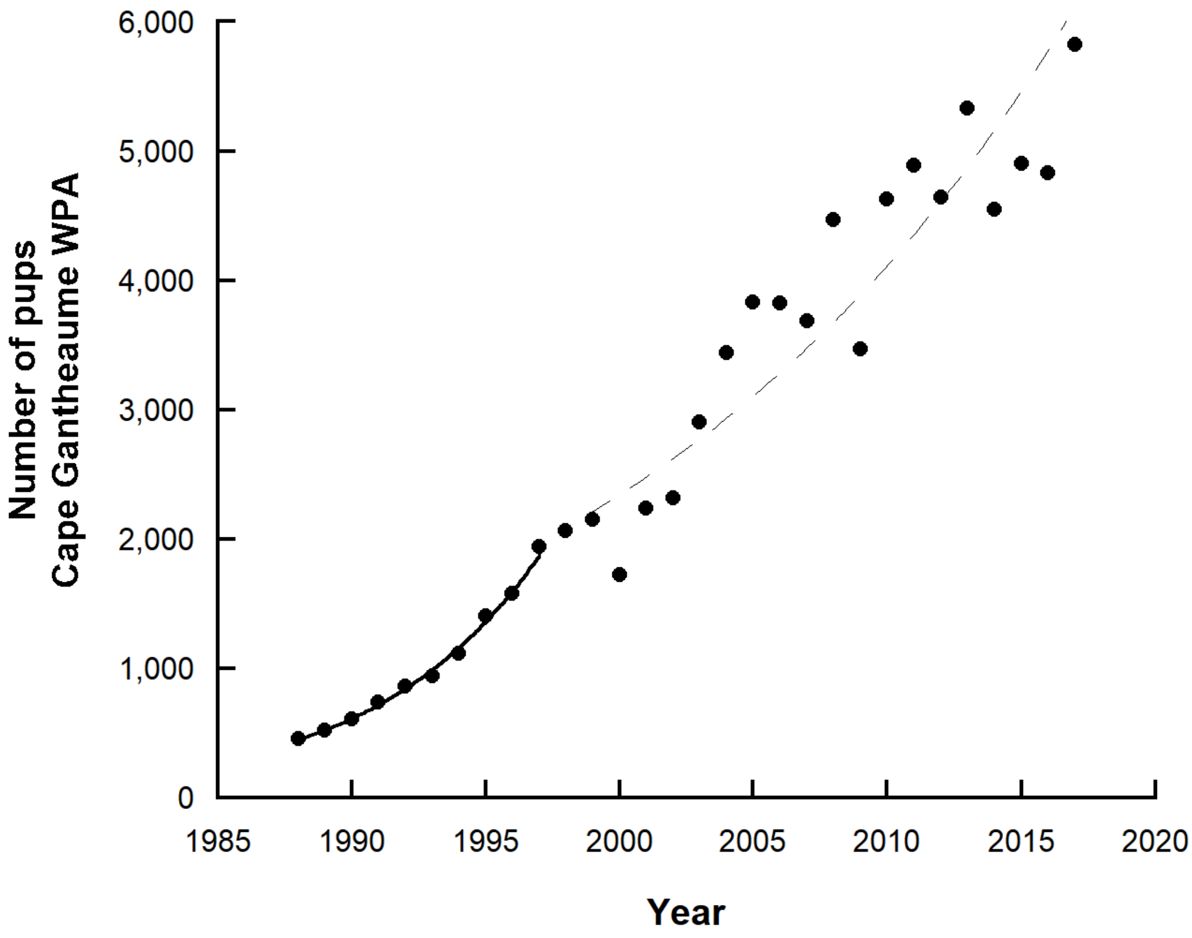

Figure 22. Changes in long-nosed fur seal (LNFS) pup production in the entire CGWPA, for the two periods of the recovery: January 1989 to 1998 (at 17.2% per annum) and January 1999 to 2018 (at 5.8% per annum).

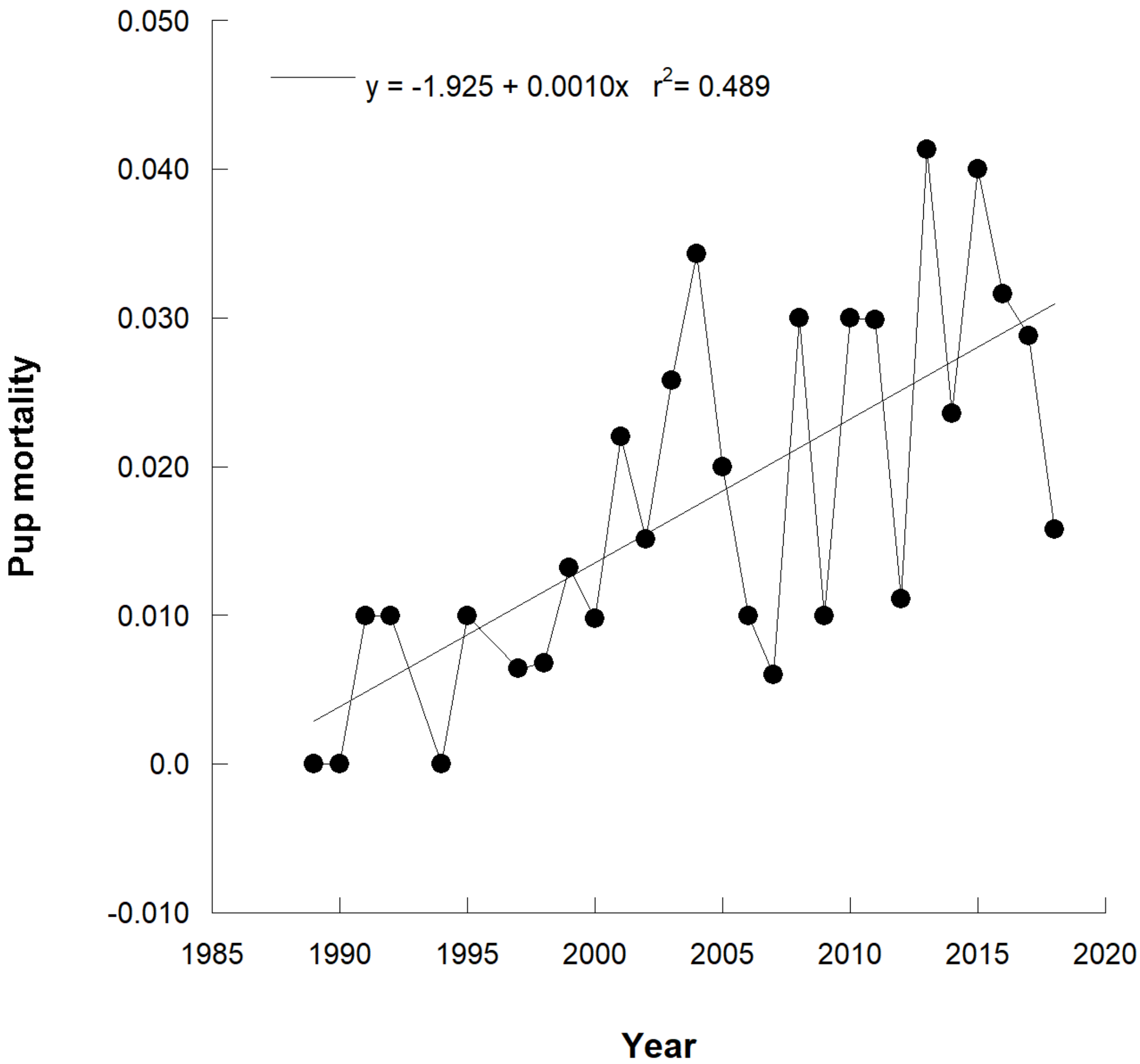

Figure 23. Changes in annual estimated mortality rate of long-nosed fur seal pups in colonies in the Cape Gantheaume Wilderness Protection Area between the 1989 and 2018 breeding seasons. Pup mortality is the total number of dead pups recorded during surveys, divided by the total estimated pup production.

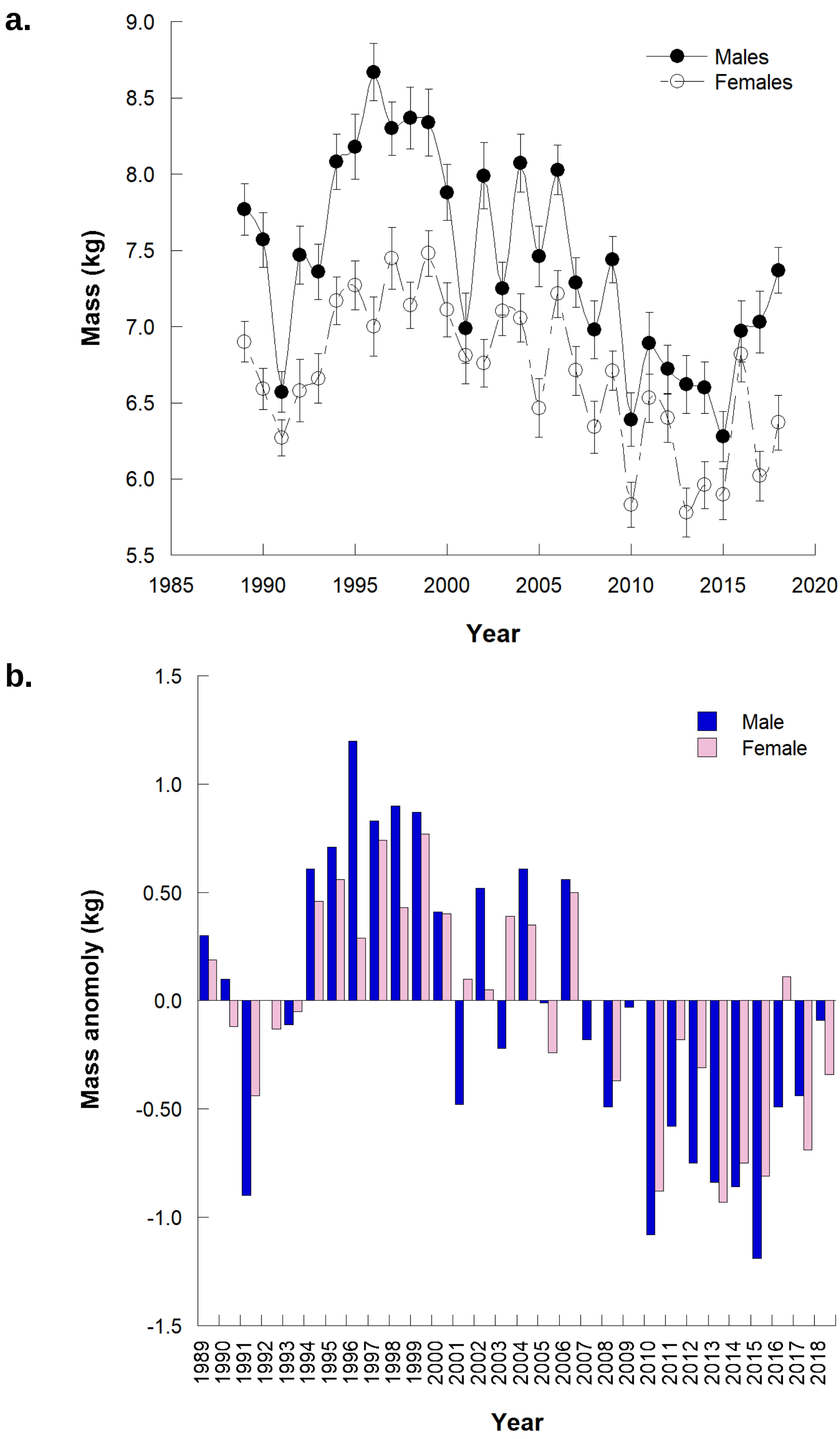

Figure 24. Changes in the mean mass (±SE) of male and female long-nosed fur seal pups weighed at Cape Gantheaume between January 1989 and 2018 (a). Annual deviations from mean male and females mass (mass anomaly) are also presented (b).

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