1. INTRODUCTION

The global threat to biodiversity has spurred the world’s governments to develop a suite of policy initiatives such as the UN Convention on Biological Diversity (CBD) and the Sustainable Development Goals (UN 2019, CBD 2020). Following the recent United Nations Summit on Biodiversity (September 2020), 77 countries signed The Leaders’ Pledge for Nature, committing them to reversing biodiversity loss. While the CBD (2020) was adopted in 1992, the Sustainable Development Goals (2015) provide the backbone for global action to reverse this trend. Since 1980, the IUCN Red List has provided a standardized framework to document the extinction risk posed by declining populations of species. The IUCN (2019) Red List of Threatened Species is the authoritative list of the world’s threatened species, which includes over 40,000 species. It is a key resource for conservation planning and management, and is widely used by governments, NGOs, and academia. It is also a key tool for identifying gaps in our understanding of species’ status and trends, which can guide future research and conservation efforts.

ABSTRACT: Australian sea lions Neophoca cinerea are endemic to Australia, with their contemporary distribution restricted to South Australia (SA) and Western Australia (WA). Monitoring of the species has proved challenging due to prolonged breeding events that occur non-annually and asynchronously across their range. The most recent available data from 80 extant breeding sites (48 in SA, 32 in WA) enabled us to estimate the species-wide pup abundance to be 2739, with 82% (2246) in SA and 18% (493) in WA, mostly based on surveys conducted between 2014 and 2019. We evaluated 1776 individual site-surveys undertaken between 1970 and 2019 and identified admissible time-series data from 30 breeding sites, which revealed that pup abundance declined on average by 2.0% yr\(^{-1}\) (range 9.9% decline to 1.7% growth yr\(^{-1}\)). The overall reduction in pup abundance over 3 generations (42.3 yr) was estimated to be 64%, with over 98% of Monte Carlo simulations producing a decline >50% over a 3-generation period, providing strong evidence that the species meets IUCN ‘Endangered’ criteria (decline ≥50% and ≤80%). The population is much smaller than previously estimated and is declining. There is a strong cline in regional abundances (increasing from west to east), with marked within-region heterogeneity in breeding site pup abundances and trends. Results from this study should improve consistency in the assessment of the species and create greater certainty among stakeholders about its conservation status.

To facilitate species management and recovery, we prioritise key data gaps and identify factors to improve population monitoring.

KEY WORDS: Australian sea lion · Declining population · Endangered species · IUCN Red List Criteria · South Australia · Western Australia

Simon D. Goldsworthy\(^{1,2,*}\), Peter D. Shaughnessy\(^{1,3}\), Alice I. Mackay\(^{1}\), Frederic Bailleul\(^{1}\), Dirk Holman\(^{4}\), Andrew D. Lowther\(^{5}\), Brad Page\(^{6}\), Kelly Waples\(^{7}\), Holly Raudino\(^{7}\), Simon Bryars\(^{8}\), Tim Anderson\(^{9}\)

\(^{1}\)South Australian Research and Development Institute, West Beach, South Australia 5024, Australia
\(^{2}\)School of Biological Sciences, The University of Adelaide, Adelaide, South Australia 5005, Australia
\(^{3}\)South Australian Museum, North Terrace, Adelaide, South Australia 5000, Australia
\(^{4}\)Department for Environment and Water, Port Lincoln, South Australia 5666, Australia
\(^{5}\)Norwegian Polar Institute, Frøysletet, 9296 Tromsø, Norway
\(^{6}\)Department of Primary Industries and Regions, Urrbrae, South Australia 5064, Australia
\(^{7}\)Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia 6151, Australia
\(^{8}\)Department for Environment and Water, Adelaide, South Australia 5000, Australia
\(^{9}\)Helifarm, Ceduna, South Australia 5690, Australia
loss by 2030 (Leaders’ Pledge for Nature 2020). The International Union for the Conservation of Nature (IUCN) Red List represents the largest standardised database of the status, trends and threats to global biodiversity, and provides a critical indicator of the health of the world’s biodiversity against which the success of policy initiatives (including those listed above) can be measured (IUCN Standards and Petitions Committee 2019).

Marine mammals have been previously characterised as disproportionately threatened and data poor (Kovacs et al. 2012), with almost one-third of all seal species threatened. Sea lions are 1 of 2 groups of otariid (eared) seals, and comprise 8 taxa (6 species and 2 subspecies) (Committee on Taxonomy 2020). The distribution of these taxa is centred on the Pacific Rim. Globally, sea lions are facing significant conservation and management challenges, with many species in low abundance or facing declines throughout parts or all of their ranges. Sea lions generally forage demersally and mostly occur in near-coastal and continental shelf waters, leaving them vulnerable to increased interactions with human activities such as direct and indirect interactions with fisheries, climate change, extreme weather events (e.g. El Niño), entanglement in marine debris and disease (Kovacs et al. 2012). Given this increased vulnerability, it is unsurprising that the IUCN Red List assesses 75% of all sea lion taxa at a Near Threatened or higher category (Japanese sea lion Zalophus japonicus: Extinct; Australian sea lion Neophoca cinerea, New Zealand sea lion Phocarctos hookeri, Galapagos sea lion Z. wolffbaeki and western Steller sea lion Eumetopias jubatus jubatus jubatus: Endangered; eastern Steller sea lion E. j. monteriensis: Near Threatened; Californian sea lion Zalophus californianus and South American sea lion Otaria bryonya: Least Concern). Even for those species listed as Least Concern, some subpopulations have undergone major declines. The Gulf of California subpopulation of Z. californianus has undergone a 65% decline since 1991 (Adame et al. 2020), and the Falkland Islands subpopulation of O. bryonya is estimated to have declined by 95% since the 1930s (Thompson et al. 2005, Baylis et al. 2015).

The Australian sea lion (ASL) was subject to sealing in the late 18th and early 19th century, resulting in a reduction in population size and extirpation from locations within and beyond its current range (Ling 1999, Stuart 2018). Its extant breeding distribution is restricted to islands off South Australia (SA) and Western Australia (WA), with the exception of a number of small mainland breeding sites at the base of cliffs. Known threats to species recovery include fisheries interactions (especially bycatch in demersal gillnet and rock lobster fisheries), entanglement in marine debris and disease (Page et al. 2004, Goldsworthy & Page 2007, Goldsworthy et al. 2010, Hamer et al. 2013, Marcus et al. 2014, 2015).

Unlike all other pinnipeds, ASLs have a non-annual breeding cycle of about 17−18 mo, with the longest gestation period of any pinniped (up to 14 mo, Gales & Costa 1997). Breeding is protracted (4−12 mo in duration, depending on pup production), can occur at any time of the year and is asynchronous across its range (i.e. adjacent breeding sites can breed at different times) (Kirkwood & Goldsworthy 2013). Mechanisms suggested to maintain asynchronous breeding are thought to be extreme philopatry and population sub-structuring, effectively making most breeding sites closed subpopulations (Campbell et al. 2008b, Lowther et al. 2012).

There is evidence of significant declines in abundance across parts of the ASL’s range (Goldsworthy et al. 2015), with total population estimates ranging between 10 000 and 15 000 (based on multipliers of pup production) (Goldsworthy et al. 2009a, 2015, Shaughnessy et al. 2011). Because of the species’ unusual breeding biology, and the unpredictable timing and duration of breeding seasons among breeding sites, there has been limited reliable or useable data available to assess its status and investigate long-term population trends with confidence or certainty (Shaughnessy et al. 2011, Goldsworthy et al. 2015).

Despite the fact that the ASL has been listed as Endangered under the IUCN Red List since 2008 (Goldsworthy & Gales 2008, Goldsworthy 2015), the species has been listed as ‘vulnerable’ under Australia’s Commonwealth and State environment legislation (Environment Protection and Biodiversity Conservation Act of 1999 [EPBC Act]; SA National Parks and Wildlife Act of 1972; WA Biodiversity Conservation Act of 2016), even though a common assessment method using the IUCN criteria and thresholds has been applied in these jurisdictions. Different interpretations on past (limited) data and the marked variability in breeding site status and trends in abundance across its range have contributed to differences in the assessment of the species’ conservation status (Woinarski et al. 2014). ASLs were recently (23 December 2020) uplisted to ‘endangered’ under the EPBC Act (Threatened Species Scientific Committee 2020). Consistency in the assessment of ASLs under the IUCN Red List and the Australian EPBC Act will reduce confusion among stakeholders about the status of this species. This consistency, plus an improved ability to detect changes in abundance, will underpin
the development of a more cohesive and targeted policy and management framework for the recovery of the ASL.

With these issues in mind, the overarching goal of our study was to undertake a comprehensive species-wide assessment of the status of the ASL. Specifically, our aims were to (1) compile all historic ASL pup abundance time-series data; (2) evaluate and extract useable data; (3) assess the status and trends in abundance across breeding sites, subregions and metapopulations; and (4) identify and prioritise key data gaps and important factors to improve future population monitoring.

2. METHODS

2.1. Source data

The number of pups produced in a breeding season is a commonly used index of abundance for pinniped populations because pups form the only age-class that is easily identifiable (black/brown lanugo), and most pups are ashore at the end of the breeding season and available for counting prior to moulting and dispersing. Although the relationship between pup production and the total population size is variable, depending on the status of the population (increasing, decreasing, stable), comparing pup counts can be a reliable indicator of population growth (Berkson & DeMaster 1985).

A total of 1776 individual site surveys for all known ASL breeding sites in SA and WA between 1970 and 2019 were collated. Pup abundance counts have been obtained from ground, aerial, boat, cliff-top and, more recently, drone surveys. Four main methods were used: (1) standard ground counts of live and dead (or cumulative dead) pups; (2) adjusted ground counts where a known number of marked (or tagged) pups can be added to the maximum count of live and dead (or cumulative dead) unmarked pups; (3) mark–recapture using the Petersen estimate; and (4) cumulative pup production based on either twice-weekly surveys of cumulative births (Seal Bay population), or from estimates of net pup production between successive mark–recapture surveys (Goldsworthy et al. 2015).

As the standard ground count is the default/basic survey method, these data form the basis to all time series analysis in this assessment. The only exception is for the Bunda Cliffs breeding sites, where cliff-top counts were used, as none of the sites are accessible on foot. Where multiple surveys have been conducted within a breeding season, individual surveys have included the cumulative number of dead pups. Dead pups are typically marked within surveys to avoid double counting. Most surveys include details on the number of live pups present in different pelage categories. This information is critical for estimating survey timing relative to the stage of the breeding season, as the pelage categories provide a proxy for pup age: black mate-guarded (pups whose mothers are mate-guarded by an adult male are aged 0–10 d), black (post-mate-guarded pups, 1–4 wk), brown (pups approximately 4–16 wk), moulting (pups ~16–20 wk) and moulted (pups >20 wk).

2.2. Evaluation and identification of comparable surveys

The duration of ASL breeding seasons varies relative to the pup production of a given breeding site. For breeding sites that produce <150 pups, the breeding season typically lasts 4–5 mo, and a single survey is adequate if conducted at the right time, as the maximum count of pups occurs at the end of the breeding season. The end of the breeding season is indicated by an absence (or low numbers) of mate-guarded or black pups and the presence of some moulting pups. Fully moulted pups are rarely recorded at the end of the breeding season for breeding sites that produce <150 pups.

For breeding sites producing >150 pups (Seal Bay, The Pages, Dangerous Reef), the breeding season may extend between 6 and 9+ mo in duration, and it is usual for fully moulted pups to be present alongside newborn (black) pups. For these sites, the peak in pup numbers usually occurs well before the end of the breeding season, due to a decrease in detectability as moulted pups become more aquatic (i.e. foraging at sea, dispersing). Multiple within-season surveys are often undertaken at larger breeding sites to increase the likelihood of counting at the ‘peak’ in pup numbers.

To evaluate if surveys provided data collected at a similar stage of breeding (i.e. admissible data) and hence suitable for time-series analysis, the distribution of pups in the 3 main pelage categories (black, brown, moulted) relative to the size of the breeding population was assessed. Additional observations (notes) made by observers on the timing of the survey relative to the stage of the breeding season were also considered. Two or more surveys of a given site in different breeding seasons were evaluated to be
‘comparable’ if they were made at a similar time within each breeding season. A challenge with assessing the data of many early surveys is that categories of pups based on pelage were either not recorded (‘unclassed’), or recorded inconsistently (e.g. brown pups in early moult were sometimes classed as moulted pups), or were recorded differently from recent surveys. For example, ‘black mate-guarded’ and ‘black’ pups have only been regularly recorded in SA surveys since ~2007; prior to this, they were recorded as ‘brown’ pups.

Surveys were excluded from time-series analyses, if they were assessed to be: ‘Early’ (undertaken prior to, or early in the breeding season); ‘Late’ (undertaken well after the breeding season had ended); ‘Unknown’ (timing relative to the breeding season could not be evaluated); ‘Incomplete’ (evidence of inconsistent survey effort, i.e. parts of islands not surveyed where breeding may have taken place); or ‘Incursions’ (evidence that the timing of breeding of neighbouring breeding sites occurred earlier or was similar to the breeding site being surveyed; pup counts could be confounded [inflated] if there was significant movement of pups between sites, e.g. tagged Dangerous Reef pups sighted at Lewis, English and Albatross Islands; Nicolas Baudin Island pups sighted at Jones Island; Shaughnessy et al. 2005, Goldsworthy et al. 2008, 2009b, 2014).

2.3. Time-series analysis

ASL breeding sites with a time-series of pup abundance consisting of 3 or more comparable breeding seasons were used for these analyses. All sites with admissible data sets were analysed separately, except for those in the Bunda Cliffs, where site-by-site analysis of trends is challenging due to regular cliff collapses that have resulted in the loss of breeding habitat and sites over time. It is not clear what happens there when a breeding site is lost or becomes unsuitable, but presumably, some animals move to adjacent suitable habitat or to nearby established breeding sites. For these reasons, within-season surveys of pup abundance for the Bunda Cliffs breeding sites were pooled for the time-series analysis. For the pup abundance estimation, drone surveys in 2017 were used for the Bunda Cliffs region.

The change in pup numbers over time (with parts of years expressed as decimals) was estimated using regression analysis, which applied a linear regression of the natural logarithm of pup numbers against year. All analyses were undertaken in the software R, version 3.5.1 (R Core Team 2017), using the package ‘lme4’ (Bates et al. 2015).

The exponential rate of change (r) (slope of the regression line) was expressed as a percentage rate of growth ($\lambda$) as:

$$\lambda = 100(e^r - 1)$$

An exponential decline was assessed to be the most appropriate for ASL, based on the pattern of decline observed in some subpopulations (Goldsworthy et al. 2019, 2020). In addition, as fisheries bycatch is a key threat to the species, and mortality rates (in demersal gillnet fisheries) vary as a function of ASL density, populations exposed to consistent fishing effort would be expected to show a constant proportional rate of decline (i.e. decline exponentially, Goldsworthy et al. 2010).

2.4. Assessment against IUCN Red List criteria

Assessment of the status of ASL against IUCN Red List criterion A2(a) (reduction in population size over 3 generations ≥80%: Critically Endangered, ≥50%: Endangered and ≥30%: Vulnerable) followed IUCN Red List guidelines (IUCN Standards and Petitions Committee 2019). A generation time of 14.1 yr was estimated for the species using the IUCN generation length calculator tool (https://www.iucnredlist.org/resources/generation-length-calculator) and data on observed ASL fecundity and survival from the Seal Bay ASL subpopulation, which is the only site for the species where detailed demographic data are available (Goldsworthy et al. 2020). For each breeding site, the intercept and coefficient terms from the regression were used to estimate past (1977) and present (2019) pup abundances, and from these, the overall change in pup abundance over 3 generations (42.3 yr) was estimated.

A sensitivity analysis was undertaken following IUCN Guidelines for dealing with uncertainty (IUCN Standards and Petitions Committee 2019). The probability distributions for the back and forward projected estimates of pup abundances for each subpopulation with time-series data were estimated using the mean value and the 95% CI (converted to a standard deviation) for the earliest and most recent surveys from regression analyses. Using the Monte Carlo simulation method, these probability distributions were used to provide a measure of the uncertainty around past and present abundance estimates, from which a pair of past and present breeding site pup abundance estimates were randomly selected, a
3-generation change was calculated, and the procedure was repeated 1000 times. By summing all of the past and present breeding site abundances for each simulation, the probability distribution for the reduction in ASL population size could be estimated, and from this the percentage of iterations where pup abundances had declined by more than 30% (Vulnerable) and 50% (Endangered) was determined.

Because the management of ASL falls under both state and national environmental legislation, results are primarily presented at both the whole of species (national) and state level to facilitate management, rather than at the level of region or metapopulation.

3. RESULTS

3.1. Breeding sites and pup abundance

Breeding sites for the species are distributed from The Pages Islands just off Kangaroo Island, SA, in the east, west across the southern coast of Australia and north along the west coast of WA to Easter Island in the Abrolhos Islands. The breeding range can be subdivided into 3 main and discrete regions or metapopulations: South Australia (SA), south coast WA (SC-WA) and west coast WA (WC-WA) (Fig. 1). The distance between the nearest breeding sites in the SA and SC-WA and the SC-WA and WC-WA metapopulations is >500 and >700 km, respectively (Fig. 1). There is a single breeding site at Twilight Cove (WA), between the SA and SC-WA metapopulations, >200 and >300 km from the nearest breeding sites in the SC-WA and SA metapopulations, respectively; it can be considered as a fourth, minor metapopulation (Fig. 1). Within these metapopulations, 12 regional groups of breeding sites have been identified. These are based on the 11 subregions identified by Goldsworthy et al. (2007) with their WC-WA subregion divided into 2 subregions, Jurien Bay and Abrolhos Islands. The 12 subregions identified here are: Kangaroo Island, Spencer Gulf, SW Eyre, Chain of Bays, Nuyts Archipelago, Nuyts Reef, Bunda Cliffs, Twilight Cove, Recherche Archipelago, Bremer Bay, Jurien Bay and Abrolhos Islands (Fig. 1).

A total of 80 extant ASL breeding sites (subpopulations) were identified, with 48 (60%) in SA, and 32 (40%) in WA (Table 1). There is uncertainty about the breeding status of some sites where only single records of black or brown pups were available (Middle Doubtful, Rat, Morley and Campbell Islands, all in WA), and where only large brown or moulted pups were seen that may have originated from other nearby breeding sites (North Islet, SA; Middle Doubtful Island, SC-WA, and a number of the Abrolhos islands: Square, Lagoon, Keru, Helms, Sandy, West Wallabi and Wooded Island, WC-WA).

The total species-wide pup abundance is 2739, of which 82% (2246) occur in SA and 18% (493) in WA (Table 1). This is based on the most recent and/or best available surveys for each site which extend from 1989 to 2019, but mostly between 2014 and 2019.
Table 1. Summary information on the location, pup abundance and survey history of 80 known Australian sea lion breeding sites. The state (SA: South Australia, WA: Western Australia, NT: Northern Territory), region (KI: Kangaroo Island, SG: Spencer Gulf, SWE: SW-Eyre, CB: Chain of Bays, NA: Nuyts Archipelago, NR: Nuyts Reef) and location (Lat: latitude, Long: longitude) of breeding sites are used to derive the 'pup count', and 'Max count, MR/CPP' (if listed), along with the data source for the listed survey year (DEW: South Australian Department for Environment). The number of breeding surveys with admissible data is listed, along with the year (decimal year) of the earliest and most recent admissible survey, and the duration of the time-series (Interval).

| Breeding site                     | Region | State | Lat (°S) | Long (°E) | Survey Year | Survey Method | Pup Count | Max Count | MR/CPP | Source                                | No. | Earliest Year | Most Recent Year | Interval (yr) |
|-----------------------------------|--------|-------|----------|-----------|-------------|---------------|------------|-----------|--------|---------------------------------------|-----|---------------|------------------|---------------|
| The Pages Islands                 | KI     | SA    | 35.756   | 138.300   | 2014        | G             | 313        | 313      |        | Goldsworthy et al. (2015)              | 15  | 1990.1        | 2014.5           | 24.4          |
| Seal Bay                          | KI     | SA    | 35.995   | 137.317   | 2019        | G, CPP        | 178        | 222      |        | Gol dsworthy unpubl. data             | 12  | 2003.4        | 2019.6           | 15.0          |
| Endang Species Res 44              | SA     |      | 36.068   | 136.703   | 2014        | G             | 11         | 11       |        | Goldsworthy et al. (2015)              | 1   | 2003.5        | 2014.1           | 10.6          |
| Western Isles                      | SG     | SA    | 35.370   | 136.847   | 2020        | A             | 10         | 10       |        | Goldsworthy et al. (2012)              | 1   | 2020.2        | 2020.2           | 2.0           |
| Dangerous Reef                     | SG     | SA    | 34.817   | 136.217   | 2019        | G             | 382        | 382      |        | DEW                                    | 11  | 1999.5        | 2019.0           | 19.4          |
| Albatross Is.                      | SG     | SA    | 35.069   | 136.181   | 2011        | G             | 69         | 69       |        | Goldsworthy et al. (2012)              | 2   | 2009.9        | 2011.4           | 1.5           |
| South Neptune Islands              | SG     | SA    | 35.333   | 136.117   | 2014        | G             | 4          | 4        |        | Goldsworthy et al. (2015)              | 3   | 1970.0        | 2014.5           | 44.5          |
| Lewis Is.                          | SG     | SA    | 34.957   | 136.072   | 2019        | G             | 63         | 63       |        | Goldsworthy et al. (2012)              | 7   | 2003.4        | 2014.5           | 11.1          |
| Williams Is.                       | SG     | SA    | 34.957   | 136.072   | 2019        | G             | 36         | 36       |        | Goldsworthy et al. (2012)              | 11  | 2003.4        | 2014.5           | 11.1          |
| Curia Rocks                        | SG     | SA    | 34.957   | 136.072   | 2019        | G             | 36         | 36       |        | Goldsworthy et al. (2020)              | 3   | 2004.9        | 2014.9           | 10.0          |
| Dangerous Reef                     | CB     | SA    | 33.600   | 134.783   | 2015        | G             | 89         | 89       |        | Goldsworthy et al. (2015)              | 3   | 2003.5        | 2015.3           | 11.8          |
| Point Labatt                       | CB     | SA    | 33.152   | 134.261   | 2013        | G             | 2          | 2        |        | Goldsworthy et al. (2014)              | 0   |               |                  |               |
| Ward Is.                           | CB     | SA    | 33.750   | 134.300   | 2019        | G             | 42         | 42       |        | Goldsworthy et al. (2020)              | 4   | 2006.4        | 2019.7           | 13.3          |
| Lilliput                           | NA     | SA    | 32.449   | 133.669   | 2019        | G             | 63         | 63       |        | Goldsworthy et al. (2020)              | 6   | 2005.2        | 2019.6           | 14.4          |
| Blefuscu                           | NA     | SA    | 32.462   | 133.639   | 2019        | G             | 50         | 50       |        | Goldsworthy et al. (2020)              | 7   | 2005.2        | 2019.6           | 14.4          |
| Breakwater/Gliddon Is.             | NA     | SA    | 32.322   | 133.561   | 2015        | G             | 27         | 27       |        | Goldsworthy et al. (2015)              | 4   | 2005.4        | 2017.8           | 12.4          |
| Fenelon Is.                        | NA     | SA    | 32.583   | 133.283   | 2019        | G             | 31         | 31       |        | Goldsworthy et al. (2020)              | 3   | 2004.9        | 2019.3           | 14.4          |
| West Is.                           | NA     | SA    | 32.517   | 133.250   | 2019        | G             | 36         | 36       |        | Goldsworthy et al. (2020)              | 4   | 2006.4        | 2019.7           | 13.3          |
| Nuyts Reef                         | NR     | SA    | 32.117   | 132.133   | 2019        | G             | 122        | 122      |        | Goldsworthy et al. (2020)              | 2   | 2005.4        | 2019.7           | 4.3           |

Table continued on next page
| Breeding site      | Region | State | Lat  | Long | Year Survey          | Method | Pup count | Max count, MR/CPP | Source                                      | Admissible surveys |
|--------------------|--------|-------|------|------|----------------------|--------|-----------|-------------------|---------------------------------------------|--------------------|
| Bunda 01           | BC     | SA    | 31.481 | 131.061 | 2016, 2018          | CT, D  | -         | 2                 | DEW                                         |                    |
| Bunda 06           | BC     | SA    | 31.414 | 130.562 | 2016, 2019          | CT, D  | 1         | 8                 | DEW                                         |                    |
| Bunda 09           | BC     | SA    | 31.412 | 130.046 | 2016, 2019          | CT, D  | 6         | 15                | DEW                                         |                    |
| Bunda 12           | BC     | SA    | 31.392 | 129.784 | 2016, 2017          | CT, D  | -         | 1                 | DEW                                         |                    |
| Bunda 18           | BC     | SA    | 31.363 | 129.429 | 2016, 2019          | CT, D  | -         | 1                 | DEW                                         |                    |
| Bunda 19           | BC     | SA    | 31.359 | 129.377 | 2016, 2017          | CT, D  | 5         | 14                | DEW                                         |                    |
| Bunda 20           | BC     | SA    | 31.357 | 129.357 | 2016, 2017          | CT, D  | 2         | 1                 | DEW                                         |                    |
| Bunda 22           | BC     | SA    | 31.351 | 129.308 | 2016, 2017          | CT, D  | -         | 1                 | DEW                                         |                    |
| Bunda 152          | BC     | SA    | 31.364 | 129.447 | 2016, 2017          | CT, D  | -         | 11                | DEW                                         |                    |
| Bunda 155          | BC     | SA    | 31.369 | 129.479 | 2016, 2017          | CT, D  | -         | 28                | DEW                                         |                    |
| Twilight Cove      | TC     | WA    | 32.277 | 126.006 | 1996                | G      | 4         | 4                 | Dennis & Shaughnessy (1999)                   | 0                  |
| Spindle Is.        | RA     | WA    | 33.763 | 124.161 | 1990                | G      | 53        | 53                | Gales (1990), Gales et al. (1994)            | 0                  |
| Ford (Halfway) Is.| RA     | WA    | 33.766 | 124.41 | 1990                | G      | 17        | 17                | Gales (1990), Gales et al. (1994)            | 1                  |
| Six Mile Is.       | RA     | WA    | 33.640 | 123.968 | 2017                | G      | 45        | 45                | DBCA, Goldsworthy unpubl. data              | 3                  |
| Round Is.          | RA     | WA    | 34.105 | 123.288 | 2013                | G      | 13        | 13                | DBCA, Goldsworthy unpubl. data              | 3                  |
| Salisbury Is.      | RA     | WA    | 33.360 | 123.352 | 2014                | G      | 10        | 10                | DBCA                                         | 2                  |
| Wickham (Stanley) Is. | RA     | WA    | 34.020 | 123.291 | 2014                | G      | 5         | 5                 | DBCA                                         | 2                  |
| George Is.         | RA     | WA    | 34.050 | 123.259 | 2011                | G      | 13        | 13                | DBCA                                         | 1                  |
| Glennie Is.        | RA     | WA    | 34.096 | 123.105 | 1999                | G      | 21        | 21                | DBCA                                         | 2                  |
| Taylor Is.         | RA     | WA    | 33.920 | 122.873 | 2013                | G      | 4         | 4                 | DBCA, Goldsworthy unpubl. data              | 4                  |
| Kimberley Is.      | RA     | WA    | 33.949 | 122.469 | 2014                | G      | 32        | 32                | DBCA                                         | 3                  |
| Cooper Is.         | RA     | WA    | 34.231 | 123.607 | 2014                | G      | 8         | 8                 | DBCA                                         | 1                  |
| Investigator (Rocky) Is. | RA     | WA    | 34.083 | 123.485 | 1989                | G      | 17        | 17                | Gales et al. (1994)                         | 1                  |
| West Is.           | BB     | WA    | 34.082 | 121.565 | 1989                | G      | 20        | 20                | Gales et al. (1994)                         | 0                  |
| Red Islet           | BB     | WA    | 34.040 | 119.780 | 2017                | G      | 25        | 25                | DBCA                                         | 3                  |
| Middle Doubtful Is.| BB     | WA    | 34.376 | 119.409 | 2012                | G      | 1         | 1                 | DBCA                                         | 1                  |
| Haul Off Rock      | BB     | WA    | 34.702 | 118.661 | 2016                | G      | 24        | 24                | DBCA                                         | 4                  |
| Buller Is.         | JB     | WA    | 30.657 | 115.115 | 2019                | G      | 44        | 44                | DBCA                                         | 12                 |
| Beagle Is.         | JB     | WA    | 29.808 | 114.877 | 2019                | G      | 57        | 57                | DBCA                                         | 12                 |
| North Fisherman Is.| JB     | WA    | 30.130 | 114.944 | 2019                | G      | 40        | 40                | DBCA                                         | 13                 |
| Morley Is.         | AI     | WA    | 28.746 | 113.813 | 2006                | G      | 1         | 1                 | DBCA                                         | 0                  |
| Suomi Is.          | AI     | WA    | 28.719 | 113.837 | 2006                | G      | 4         | 4                 | DBCA                                         | 1                  |
| Rat Is.            | AI     | WA    | 28.715 | 113.784 | 2014                | G      | 1         | 1                 | DBCA                                         | 0                  |
| Campbell Is        | AI     | WA    | 28.694 | 113.836 | 2004                | G      | 1         | 1                 | DBCA                                         | 1                  |
| Leo Is.            | AI     | WA    | 28.688 | 113.860 | 2006                | G      | 2         | 2                 | DBCA                                         | 0                  |
| Gibson Is.         | AI     | WA    | 28.687 | 113.829 | 2006                | G      | 6         | 6                 | DBCA                                         | 1                  |
| S serventys Is.    | AI     | WA    | 28.680 | 113.832 | 2006                | G      | 3         | 3                 | DBCA                                         | 1                  |
| Stokes Is.         | AI     | WA    | 28.673 | 113.852 | 2013                | G      | 2         | 2                 | DBCA                                         | 1                  |
| Alexander Is.      | AI     | WA    | 28.673 | 113.830 | 2006                | G      | 3         | 3                 | DBCA                                         | 1                  |
| Gilbert Is.        | AI     | WA    | 28.667 | 113.827 | 2006                | G      | 9         | 9                 | DBCA                                         | 1                  |
| Long Is.           | AI     | WA    | 28.471 | 113.774 | 2006                | G      | 2         | 2                 | DBCA                                         | 0                  |
| Easter Is.         | AI     | WA    | 28.468 | 113.814 | 2006                | G      | 6         | 6                 | DBCA                                         | 1                  |

| Total SA           |        |       | 2111  | 2246  |                     |        |           |                  |                                             |
| Total WA           |        |       | 493   | 493   |                     |        |           |                  |                                             |
| Overall total      |        |       | 2604  | 2739  |                     |        |           |                  |                                             |
There is a general cline in regional pup abundances, increasing from west to east across the species’ range, largely reflecting the greater pup abundance in SA, but also larger breeding sites (Fig. 2). Only 4 sites produce more than 100 pups in a breeding season, and all are in SA (The Pages Islands, Seal Bay, Dangerous Reef, Nuyts Reef). These sites make up 38% of total pup abundance but just 5% of breeding sites. Most (81%) breeding sites produce fewer than 50 pups in a breeding season, and 56% produce fewer than 20 (Table 1). The species-wide median pup abundance per breeding site is just 14 (27.0 in SA, 8.5 in WA).

Baseline data, defined as having admissible data from at least 1 survey, were available for 70 (88%) of the 80 breeding sites across the species’ range (96% of SA and 75% of WA sites) (Table 2). Contemporary estimates, with at least 1 admissible survey obtained in the last decade, were available for 60 (75%) of the 80 breeding sites (96% of SA and 44% of WA sites) (Table 2).

### 3.2. Trends in abundance

Of the 1776 individual site-surveys evaluated, just 228 (13%) from 60 breeding sites were judged to provide admissible data. Of these, 189 surveys from 30 breeding sites (38% of total breeding sites) had 3 or more comparable breeding season surveys suitable for trend analysis (Table 2, Fig. 3). Of these 30 breeding sites, 77% were in SA and 23% were in WA; furthermore, they accounted for 74% of the species-wide pup abundance (79% of SA, and 54% of WA pup abundance). The duration between the earliest and most recent survey ranged between 1.5 and 44.5 yr (mean = 16.4 yr) for all breeding sites (Table 1), and between 2.9 and 44.5 yr (mean = 18.5 yr) for breeding sites with 3 or more comparable surveys (Table 3).

Results of regression analyses undertaken on the 30 breeding sites with 3 or more comparable pup abundance surveys are detailed in Table 3 and Fig. 3. The average growth rate among the 30 breeding sites was \(-2.0\%\) yr\(^{-1}\) (range \(-9.9\) to \(1.7\%\) yr\(^{-1}\), SD = 3.0%) and varied considerably among breeding sites (Fig. 4). For SA, the average growth rate was \(-2.6\%\) yr\(^{-1}\) (SD = 3.2%; n = 23 sites) and for WA, it was \(-0.3\%\) yr\(^{-1}\) (SD = 0.6%; n = 7 sites) (Table 3). Overall, the median growth rate was \(-1.2\%\) yr\(^{-1}\).

There was no clear geographic pattern in the growth rates of breeding sites among or within regions (Tables 3 & 4). The greatest rates of decline were in the SW Eyre (\(-8.7\%\) yr\(^{-1}\)) and Bunda Cliffs (\(-5.9\%\) yr\(^{-1}\)) regions, followed by the Nuyts Archipelago (\(-1.9\%\) yr\(^{-1}\)), Chain of Bays (\(-1.6\%\) yr\(^{-1}\)) and Spencer Gulf (\(-1.5\%\) yr\(^{-1}\)) (Table 4). The lowest declines were in the Recherche Archipelago and Bremer Bay regions (both \(-0.6\%\) yr\(^{-1}\)), and Kangaroo Island (\(-0.1\%\) yr\(^{-1}\)) (Table 4). The only region recording stable/positive growth was the Jurien Bay region (Table 4). Changes in population growth rates could not be determined for Nuyts Reef, Twilight Cove or the Abrolhos Islands regions.

### 3.3. Population reduction

Regression analyses undertaken on the 30 breeding sites with 3 or more comparable surveys were used to estimate the reduction between past and
Fig. 3. Trends in pup abundance for 30 Australian sea lion subpopulations with 3 or more comparable surveys. The plots show changes in pup abundance over time for each breeding site, to which an exponential regression model with ±95% confidence limits (shaded) has been applied.
present pup abundances over a period of 3 generations (42.3 yr) between 1977.2 (1977) and 2019.5 (2019) (Table 3). Overall, pup abundance estimates were 5477 in 1977 and 2019, giving an estimated decline over 3 generations of 64.0% (Table 3).

The probability distribution of the reduction in the ASL population over 3 generations based on Monte Carlo simulations indicates that the probability that the pup abundances have declined by at least 30% over a 3-generation period was 100% (1000 of 1000 simulations), and the probability that they have declined by at least 50% over a 3-generation period was >98% (>980 of 1000 simulations) (Fig. 5). The median decline in pup abundance over 3 generations was 61%.

4. DISCUSSION

4.1. Species-wide assessment

This study provides the first quantitative estimate of the trends in abundance of ASL populations across their range, although trends could not be determined for some subregions. We found that the ASL population is much smaller than previously estimated, and is declining. This reduction in population size (based on pup abundance) exceeds 50% over a period of 3 generations (42.3 yr), and clearly meets the ‘Endangered’ criteria (decline ≥50% and ≤80%) under IUCN Criterion A2b (namely, A2: ‘Population reduction observed, estimated, inferred, or suspected in the

| Breeding site                      | Region | Earliest survey | Most recent survey | Time series duration (yr) | Number of surveys | r       | Pups 1977 | Pups 2019 | Estimated 3-gen change (%) |
|------------------------------------|--------|----------------|--------------------|---------------------------|-------------------|---------|-----------|-----------|-----------------------------|
| The Pages                          | SA     | 1990.1         | 2014.5             | 24.4                      | 15                | −0.005  | 514       | 418       | −18.6                        |
| Seal Slide                         | SA     | 2003.4         | 2018.4             | 15.0                      | 11                | 0.011   | 7         | 12        | 58.9                         |
| Seal Bay                           | SA     | 2003.4         | 2019.6             | 16.2                      | 12                | −0.010  | 253       | 167       | −33.9                        |
| South Neptune Islands              | SA     | 1970.0         | 2014.5             | 44.5                      | 3                 | −0.018  | 9         | 4         | −53.5                        |
| Dangerous Reef                     | SA     | 1999.5         | 2019.0             | 19.4                      | 11                | −0.014  | 639       | 359       | −43.8                        |
| Lewis Is.                          | SA     | 2005.9         | 2014.7             | 8.8                       | 3                 | 0.005   | 67        | 84        | 25.5                         |
| Liguanea Is.                       | SA     | 2004.9         | 2019.8             | 14.9                      | 3                 | 0.032   | 95        | 25        | 73.6                         |
| Rocky (South) Is.                  | SA     | 2011.9         | 2019.2             | 7.3                       | 3                 | −0.099  | 396       | 6         | −98.6                        |
| Four Hummocks Islands              | SA     | 2011.9         | 2019.2             | 7.3                       | 3                 | −0.088  | 366       | 9         | −97.6                        |
| Rocky (North) Is.                  | SA     | 2011.9         | 2014.7             | 2.9                       | 3                 | −0.074  | 615       | 26        | −95.7                        |
| Jones Is.                          | SA     | 2005.0         | 2014.8             | 9.8                       | 6                 | 0.017   | 8         | 17        | 109.3                        |
| West Waldegrave Is.                | SA     | 2003.5         | 2015.3             | 11.8                      | 3                 | −0.050  | 584       | 70        | −88.0                        |
| Pearson Is.                        | SA     | 2003.7         | 2019.7             | 16.0                      | 5                 | −0.001  | 32        | 30        | −6.1                         |
| Ward Is.                           | SA     | 2006.4         | 2019.7             | 13.3                      | 4                 | −0.005  | 53        | 43        | −18.7                        |
| Nicolas Baudin Is.                 | SA     | 2006.4         | 2019.2             | 12.8                      | 4                 | −0.031  | 234       | 63        | −73.1                        |
| Olive Is.                          | SA     | 2003.5         | 2019.3             | 15.8                      | 11                | −0.027  | 286       | 90        | −68.4                        |
| Lilliput Is.                       | SA     | 2005.2         | 2019.6             | 14.4                      | 6                 | 0.005   | 62        | 63        | −2.1                         |
| Blefuscu Is.                       | SA     | 2005.2         | 2019.6             | 14.4                      | 7                 | −0.035  | 225       | 51        | −77.5                        |
| Breakwater/Gliddon Is.             | SA     | 2005.4         | 2018.2             | 12.7                      | 4                 | 0.014   | 15        | 28        | 79.8                         |
| Lounds Is.                         | SA     | 2008.3         | 2019.6             | 11.3                      | 4                 | −0.015  | 49        | 26        | −47.7                        |
| West Is.                           | SA     | 1992.0         | 2019.6             | 27.6                      | 4                 | −0.041  | 149       | 26        | −82.4                        |
| Purdie Is.                         | SA     | 2005.4         | 2019.6             | 14.2                      | 4                 | −0.041  | 375       | 66        | −82.5                        |
| Bunda Cliffs                       | SA     | 1991.6         | 2016.1             | 24.6                      | 10                | −0.059  | 150       | 12        | −91.9                        |
| Six Mile Is.                       | SC-WA  | 1991.3         | 2017.9             | 26.5                      | 3                 | 0.002   | 40        | 44        | 10.7                         |
| Kimberley Is.                      | SC-WA  | 1992.1         | 2014.2             | 22.1                      | 3                 | −0.013  | 51        | 29        | −41.9                        |
| Red Ilet                           | SC-WA  | 1989.7         | 2017.0             | 27.4                      | 3                 | −0.002  | 28        | 25        | −9.5                         |
| Haul Off Rock                      | SC-WA  | 1989.7         | 2016.9             | 27.3                      | 4                 | −0.009  | 32        | 22        | −32.6                        |
| Buller Is.                         | WC-WA  | 1989.8         | 2019.5             | 29.7                      | 12                | 0.001   | 43        | 45        | 6.1                          |
| Beagle Is.                         | WC-WA  | 1988.4         | 2019.4             | 31.0                      | 12                | 0.004   | 59        | 69        | 16.3                         |
| North Fisherman Is.                | WC-WA  | 1988.4         | 2019.4             | 31.0                      | 13                | −0.004  | 51        | 43        | −15.1                        |
| South Australia                    | SA     | 1999.5         | 2019.0             | 19.4                      | 11                | −0.014  | 639       | 359       | −43.8                        |
| Western Australia                  | SA     | 1999.5         | 2019.0             | 19.4                      | 11                | −0.014  | 639       | 359       | −43.8                        |
| Overall                            | SA     | 1999.5         | 2019.0             | 19.4                      | 11                | −0.014  | 639       | 359       | −43.8                        |

The probability distribution of the reduction in the ASL population over 3 generations based on Monte Carlo simulations indicates that the probability that the pup abundances have declined by at least 30% over a 3-generation period was 100% (1000 of 1000 simulations), and the probability that they have declined by at least 50% over a 3-generation period was >98% (>980 of 1000 simulations) (Fig. 5). The median decline in pup abundance over 3 generations was 61%.

4. DISCUSSION

4.1. Species-wide assessment

This study provides the first quantitative estimate of the trends in abundance of ASL populations across their range, although trends could not be determined for some subregions. We found that the ASL population is much smaller than previously estimated, and is declining. This reduction in population size (based on pup abundance) exceeds 50% over a period of 3 generations (42.3 yr), and clearly meets the ‘Endangered’ criteria (decline ≥50% and ≤80%) under IUCN Criterion A2b (namely, A2: ‘Population reduction observed, estimated, inferred, or suspected in the
past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible’ and b: ‘an index of abundance appropriate to the taxon’) (IUCN Standards and Petitions Committee 2019, p. 16). Results from our study are consistent with the current IUCN Red List assessment for the species (Goldsworthy 2015). Three important considerations provide confidence that the species-wide assessment in trends in abundance is both representative and robust: the 30 sites where trends in abundance could be estimated account for over 75% of the species-wide pup abundance; they span most of the geographic range of the species; and our assessment of population reduction is relatively insensitive to the error distributions around past and present breeding site pup abundances (over 98% of Monte Carlo simulations produced a decline of >50% over a 3-generation period).

The average rates of declines in pup abundances were greater for SA (−2.6% yr⁻¹) compared to WA (−0.3% yr⁻¹) breeding sites. However, this apparent difference may be an artefact of the low survey effort across large parts of the WA ASL distribution. Most (~75%) of the WA time-series data come from just 3 sites within a state marine reserve in the Jurien Bay region (which accounts for 29% of the WA ASL pup abundance) that have been frequently surveyed over the last 30 yr. It is unclear how representative the Jurien Bay breeding sites are of ASL trends elsewhere in WA. Time-series data for the remaining WA regions (Abrolhos, Bremer Bay, Recherche Archipelago, Twilight Cove) that account for 71% of the WA ASL pup abundance are very limited, with just 13 admissible surveys across 4 of the remaining 29 breeding sites.
Our results suggest that total pup abundance for the species (integrated across 80 known breeding sites) is at least 25% lower than that derived from an assessment based mostly on surveys conducted some 11 to 15 yr earlier (between 2004 and 2008) of 3622 pups (Shaughnessy et al. 2011). However, our study also included pup numbers from 6 recently discovered breeding sites (SA: Western Isles, Williams Island, Curta Rocks, Rocky [South] and Cap Islands; WA: George Island; their combined pup abundance was 67), and from 3 sites where earlier surveys appear to have been conducted either too early or outside the breeding season (Nuyts Reef, North Casuarina and Rocky [North] Islands, which underestimated pup abundance by at least 138 pups). These 2 factors suggest that earlier surveys may have underestimated pup number by at least 205. Accounting for these factors suggests an even greater decline of around 30% over the last 15 yr.

Shaughnessy et al. (2011) estimated the total size of the ASL population to be 14 780, based on multiplying pup numbers by 4.08 to estimate total population size. That multiplier was developed by Goldsworthy & Page (2007) and was based on a generic otariid life-table developed by Goldsworthy et al. (2003), adjusted for a 1.5 yr breeding interval and female longevity of 25 yr. A more recent ASL life-table that utilised survival estimates from the Seal Bay population, adjusted to achieve a stable population growth, derived a multiplier of pup numbers to total population size of 3.83 (Goldsworthy et al. 2010). With this multiplier, the size of the ASL population based on surveys from 2004 to 2008 becomes 13 872; and for the present study (surveys up to 2019) it is 10 402. These are likely to be over-estimates because the appropriate multiplier depends on the growth rates of the populations (Harwood & Prime 1978), which are known to differ among breeding sites. In both instances, the ASL population was assumed to be stable, but the reduction in pup abundance between the 2 surveys indicates that a lower multiplier may be more appropriate, and that the total population may number <10 000 individuals. However, how estimates of pup abundance relate to actual pup production and population size is poorly understood for the ASL.

Although our study identified a general increase in the size of regional ASL populations from west to east across the species’ range, one of the more perplexing observations is the marked within-region variability in the size and trends in abundance of individual ASL breeding sites. Although the largest breeding sites (including the 4 that produce more than 100 pups) are in SA, breeding sites of varying size and trends (de-
ment of Sustainability Environment Water Popula-
tion and Communities 2013). These include deaths
caused by bycatch in fisheries, interactions with
aquaculture operations and entanglement in marine
debris; habitat degradation and prey depletion;
human disturbance to breeding sites (including
tourism); deliberate killings; disease; pollution and
oil spills; and climate change with potential inund-
ation of breeding sites and changes to food webs
and prey availability (Goldsworthy et al. 2009a). Data on
the relative and cumulative importance of these fac-
tors is limited. Known impacts include fisheries by-
catch (especially in demersal gillnets), entanglement
in marine debris and disease (hookworm) (Page et al.
2004, Goldsworthy & Page 2007, Goldsworthy et al.
2010, Hamer et al. 2013, Marcus et al. 2014, 2015).
The relative impacts of these on the population sus-
tainability has only been assessed for bycatch in the
demersal gillnet fishery off SA. Between 2006 and
2009, bycatch mortality was estimated to be unsus-
tainable over much of the species’ range, and was
likely to have resulted in declines observed at some
breeding sites (Goldsworthy et al. 2010). Between
2010 and 2012, the Australian Fisheries Manage-
ment Authority introduced a range of management
measures into the gillnet, hook and trap fishery off
SA to mitigate bycatch of ASL, including spatial clo-
sures around all ASL breeding sites, electronic mon-
itoring of fishing activity, bycatch trigger limits and
the ability to use alternate fishing methods (hooks)
(Australian Fisheries Management Authority 2015).
Logbook data on ASL interactions reported since
2012 suggest that these measures have reduced ASL
bycatch mortality in that fishery, but the extent to
which they have reduced population declines is
unknown. A separately managed demersal gillnet
fishery occurs off WA and is also known to have
interactions with ASL. Spatial closures have been
recently introduced into that fishery (2018), but with
no independent monitoring of fishing activity (and
bycatch rates), the success of these closures in reduc-
ing ASL mortality is uncertain. The bycatch of ASL
pups and juveniles in rock lobster pots has been
largely mitigated through the introduction of pot-
spikes in rock lobster fisheries off WA and SA
(Campbell et al. 2008a, Goldsworthy et al. 2010,
Mackay & Goldsworthy 2017).

4.3. Survey gaps and methodology

This study has identified some key data gaps and
deficiencies in knowledge of the status and trends in
ASL populations. As detailed above, key regions that
are poorly represented include the Abrolhos Islands,
Bremer Bay, Recherche Archipelago and Twilight Cove, all in WA. These regions have had low survey
effort over recent decades based in part on their re-
moteness and lack of accessibility. As a consequence,
when surveys are undertaken, there is a high likeli-
hood they will occur outside the breeding season and
not provide admissible data. Less than half of these
sites (45%) have had an admissible, contemporary
survey within this last decade, and only 14% of them
have 3 or more comparable surveys from which a
trend in abundance can be estimated. The situation
for SA populations is much better, but there are still a
number of breeding sites with no baseline surveys, or
for which an acceptable survey has only been
achieved recently. More than half of the breeding
sites still lack enough comparable surveys from
which to assess trends. Committing to a more syste-
matic survey approach is the only way to address
these key gaps and improve confidence in the status
and trends in abundance of ASL across their range.

Given the asynchronous breeding pattern of the
species, a critical aspect of survey success (irrespec-
tive of the methodology used) is timing the surveys
of individual sites appropriately with respect to their
breeding season and their pup production. As noted
in Section 2, the duration of an ASL breeding season
in a particular breeding site varies with its pup pro-
duction, and this affects how surveys are designed/
planned, particularly the number of surveys and
their timing relative to the beginning and end of the
pupping season. For most breeding sites (<150 pups),
a single appropriately timed survey at the end of the
breeding season is sufficient. As pup production and
the duration of the breeding season increase, so does
the likelihood that early-born pups will have moulted
before the end of the breeding season, be more
aquatic and less available to survey. For such sites,
multiple surveys increase the likelihood of obtaining
a count at ‘peak’ pup numbers and providing admis-
sible data that can be used in trend analysis.

An added complication is that the interbreeding
interval is not consistent within and between breed-
ing sites. Although available data suggest that the
breeding interval is generally between 17 and 18 mo,
it can vary between breeding seasons and sites. At
Seal Bay, the interbreeding interval ranges from 16
to 19.9 mo (Shaughnessy et al. 2006), but it has not
been estimated so precisely for any other breeding
site. This feature of the breeding biology has meant
that planning the most appropriate time to survey a
breeding site can be extremely challenging, espe-
cially for sites that have not been surveyed for some years. As such, maintaining knowledge on the timing of breeding seasons for sites is critical to ensure the successful timing of future surveys. Beyond the timing of surveys, consistency in the survey approach is essential. In particular, accurate recognition of pup pelage categories during surveys is critical to determining survey timing relative to the stage of the breeding season, and in evaluating if the survey provides admissible data for trend analysis.

4.4. Recommendations on future monitoring strategies for the species

Population genetic studies on ASLs have indicated little or no interchange of females between breeding sites, even for those separated by short distances (Campbell et al. 2008b, Lowther et al. 2012). The important conservation implication from such extreme philopatry is that each breeding site is effectively a closed population. In light of this, conservation and management measures need to focus at the level of the breeding site (subpopulation). That half of the known ASL breeding sites produce fewer than 14 pups every 18 mo with the likelihood that most sites are effectively closed subpopulations, heightens the conservation imperative to improve monitoring efforts. At the most basic level, identifying and managing threats to facilitate recovery of the species will be underpinned by an ability to detect changes in the status and trends of individual breeding sites/subpopulations.

A future monitoring strategy is essential to meet the objectives of the Australian Sea Lion Recovery Plan (Department of Sustainability Environment Water Population and Communities 2013), and ensure that any recovery following management and threat mitigation (such as bycatch mortality in demersal gillnet fisheries) can be adequately assessed. Most historic monitoring has been ad hoc and opportunistic, resulting in many surveys being undertaken at the wrong time and providing inadmissible data. As a consequence, significant gaps in baseline data remain over much of the species’ range, and limited time-series data are available to assess trends in abundance. Developing and committing to a more systematic monitoring strategy is essential to address these key gaps and enhance current monitoring of the species.

Recent survey efforts in SA using helicopters have improved access to breeding sites on islands compared to boat transport, thereby facilitating a marked increase in survey efficiency and capacity. The use of helicopters has enabled multiple sites to be surveyed within a day, quickly and efficiently, and has increased the capacity to monitor ASL regional breeding phenology (without necessarily having to land at each island). Given that many breeding sites are just tens of kilometres apart, it is feasible to survey all breeding sites within a region by helicopter over the course of 1–2 d. In past decades, ASL breeding sites were largely accessed by boat, limiting the number of sites that could be feasibly surveyed, with access often curtailed by unfavourable weather conditions. Such logistic constraints dictated a monitoring strategy focussed on a small number of ‘key’ (accessible) sites, which were hoped to be indicative of regional trends and abundance (Goldsworthy et al. 2009a,b, Pitcher 2018). Over the last decade, the monitoring strategy for ASLs in SA has changed to undertaking regionally comprehensive surveys, because helicopters make this feasible, efficient and cost-effective (Goldsworthy et al. 2015, 2020). This change has markedly improved the information on the status of ASLs at many breeding sites, resulted in the discovery of a number of new breeding sites, enabled regional trends in abundance to be assessed and facilitated a more comprehensive assessment of the conservation status of the species across its range.

ASLs typify many of the current issues facing global sea lion populations. Their dependence on shallow coastal seas exposes populations to increased interactions with human activities, which are the prevailing cause of the decline in most species (Kovacs et al. 2012). As high trophic-level marine megafauna, the status of sea lion populations reflects the health and integrity of their marine ecosystems, and they are harbingers of biodiversity loss and human impacts in our coastal seas (Boyd et al. 2006, Hazen et al. 2019). Improved monitoring of the species will increase the understanding of population dynamics and the targeting and assessment of critical conservation measures.

Acknowledgements. We thank the Australian Marine Mammal Centre (AMMC), the Department for Environment and Water (DEW) (SA) and the Department of Biodiversity, Conservation and Attractions (DBCA) (WA) for supporting the surveys of Australian sea lion breeding sites. Surveying of some breeding sites in SA was supported by in-kind funding received from the Great Australian Bight Research Program, a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), The University of Adelaide and Flinders University. The work was conducted under an animal ethics permit from the SA Department of Primary Industry and Regions (PIRSA) Animal
Ethics Committee (Approval No. 32-12) and the DEW, Scientific Research Permit (A24684). We thank Janice Goodwins, Sandy Carruthers and Lisen Loan (DEW) for facilitating recent surveys in SA, and Dr. Rebecca McIntosh (Phillip Island Nature Park). Clarence Kennedy, Melanie Stonnell, Tanya Rosewarne, Alana Bins, Martine Kinloch (DEW) and other DEW staff involved in Australian sea lion monitoring at Seal Bay and the Seal Slide on Kangaroo Island. For logistic assistance with island surveys, we thank Erin Gibson, Sam Henschke and Will Miles (Helifarm), Tony Jones (Protec Marine, Aqualinc Marine), Darren Guidera and Kangaroo Island Helicopters. For assistance with field work, we thank Jarrod Hodgson, Sol Kraitzer, Paul Rogers, Leonardo Mantilla, Alex Dobrovolskis and Ian Moody (SARDI), Kristian Peters, Andrew Sleep, Robbie Sleep, Yasmin Wolfe and Dyson Taverner (DEW), Emma Rowe, Lisa West, Matt Davey, Vaughn Chapple, Melissa Evans, Miecha Bradshaw, Stephen Goodlich, Anthony Desmond, Jon Pridham, Sarah Comer and Stephen Butler (DBCA), Richard Campbell, David Holley, Kevin Crane, Paul Jennings and Peter Collins (formerly DBCA), Sylvia Osterrieder and Chandra Salgado-Kent (formerly of Curtin University), Mathew Hourston (Department of Primary Industries and Regional Development) and Rory McAuley. We thank Professor Helene Marsh (Chair of Threatened Species Scientific Committee), Professor David Keith (University of New South Wales) and Dr. Ivan Lawler (Department of Agriculture, Water and the Environment) for analytical advice.

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Editorial responsibility: B. Louise Chilvers, Palmerston North, New Zealand
Reviewed by: 2 anonymous referees

Submitted: November 18, 2020
Accepted: February 8, 2021
Proofs received from author(s): April 19, 2021