Conceptual population model and knowledge review for Western Australian little penguin populations

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Carijoa acknowledges the research included in this review was conducted on Aboriginal land and sea and we recognise the Traditional Custodians of country throughout Australia and their connections to land and sea. We pay our respect to Elders past and present and extend that respect to all Aboriginal and Torres Strait Islander peoples today.

1 Summary

Little penguins, *Eudyptula minor*, are native to Australia, and in Western Australia (WA), colonies of little penguins can be found on Carnac Island, Garden Island and Penguin Island off Perth, and on islands from Augusta to Israelite Bay along the south coast of WA. Despite the national trend of a stable little penguin population overall, the population on Penguin Island has been declining.

The purpose of this review is to identify where knowledge gaps exist for the life stages of little penguins, and the pressures acting upon them, so that management can best direct efforts to improve and sustain the little penguin populations into the future. A conceptual population model was developed in collaboration with subject matter experts to guide the identification of knowledge gaps and was designed to be scalable and transferable across individual colonies and populations in WA.

For Penguin Island, nine high pressures on little penguins were identified and included three 'natural' pressures (ambient temperature, sea surface temperature (SST) influencing the availability of coastal prey species, and storm damage), two 'anthropogenic' pressures (vessel strike and human disturbance) and four 'climate change' pressures (ambient temperature increases, SST increases and marine heatwaves impacting prey species, rainfall impacts on habitat and rainfall impacts on prey). A further 15 medium and low pressures on little penguins were also identified. Human disturbance (anthropogenic) was the high pressure potentially impacting all life stages except eggs, given it encompasses land based disturbances as well as marine based disturbances, such as underwater noise. SST influencing the availability of coastal prey species (natural), rainfall impacts on prey (climate change) and SST increases and marine heatwaves impacting prey species (climate change) are potentially impacting upon nine life stages each.

Following the development of the conceptual population model and identification of pressures on little penguins, a literature review was undertaken to directly inform the extent of knowledge on little penguin life stages included in the model. A total of 18 complete knowledge gaps and four assumed knowledge gaps were identified from the conceptual population model for Penguin Island.

For the juvenile/sub-adult pathway, gaps in knowledge were apparent for the life stages of Year 1 and Year 2-3. For the adult pathway, there was little to no available knowledge on the 3+ years (non-breeding) life stage. Limited or no available knowledge exists for Penguin Island to estimate survivorship or success between Fledge and Year 1, Year 1 and Moult, Year 2-3 and Moult, Courtship and 3+ years (non-breeding), 3+ years (non-breeding) and Moult, and Post-guard and Moult.

No high pressures were considered to have sufficient available knowledge to reliably inform management decisions for the colony on Penguin Island. Human disturbance, such as trampling, development, or underwater noise, was considered a complete knowledge gap for moult and most breeding stages of little penguins. Given the unknowns of where fledglings, Year 1 and Year 2-3 go to forage and what they feed on, it is unknown to what extent climate change driven SST/marine heatwaves and rainfall would impact on these life stages. Similarly, it is unknown to what extent vessel strikes are impacting on Fledglings and Year 1 penguins.

The next step is to prioritise the knowledge gaps arising from the conceptual population model of the Penguin Island colony to help direct targeted management actions.

2 Glossary and acronyms

Glossary	
Ambient	Relating to the immediate surroundings
Anthropogenic	Caused or influenced by human activities
Asynchronous	Not existing or occurring at the same time
Blood-borne	Carried or transmitted by the blood
Breeding success	The survival of an egg through to a fledged juvenile (in the context of little penguins)
Courtship	The behaviour by which different species select their partners for reproduction
Emigration	Leaving a natal colony to join another colony in another location (in the context of little penguins)
Fungal hyphae	A long, branching, filamentous structure
Immigration	Joining a colony different to the natal colony (in the context of little penguins)
Incubation	The process of sitting on eggs in order to keep them warm and bring them to hatching
Natal	Place of birth
Protozoan	A single-celled organism that can be free-living or parasitic
Thermoneutral zone	The range of ambient temperatures where the body can maintain its core temperature solely through regulating dry heat loss
Thermoregulate	Maintaining body temperature with controlled self-regulation independent of external temperatures
Toxoplasmosis	A disease that results from infection from the parasitic *Toxoplasma gondii*
Vector	An organism that carries and transmits an infectious pathogen into another living organism

Acronyms	
DBCA	Department of Biodiversity, Conservation and Attractions
DBT	Dibutyltin
DPIRD	Department of Primary Industries and Regional Development
TBT	Tributyltin
WA	Western Australia

Contents

3 Introduction

3.1 Western Australian little penguin populations

Little penguins, *Eudyptula minor*, are native to Australia and have previously been distributed from Carnac Island off Western Australia, along the southern coastline to South Solitary Island off NSW, and further south to Tasmania. They are Australia's only breeding penguin species. Little penguins, Kororā, are also native to New Zealand and the Chatham Islands in the Pacific Ocean.

In Western Australia, colonies of little penguins can be found on Carnac Island, Garden Island and Penguin Island off Perth (Shoalwater islands group), and on islands off Augusta to Israelite Bay along the south coast of WA, including the Recherche Archipelago (Fig. 1). The population of the Shoalwater islands group is at the northern limit of the species' range. There is also evidence to suggest that there is some historical genetic distinction between the Shoalwater islands and south coast populations around Albany and Esperance up to 2009 (Vardeh et al., 2022).

Globally and nationally, the overall population trend of little penguins is considered stable. They are currently listed as 'Least Concern' by the IUCN and have no conservation listing, aside from 'marine', under the Environment Protection and Biodiversity Conservation Act of Australia. However, the overall stable trend masks localised population fluctuations and is not informed by locations that are considered data deficient. Under Western Australian legislation, little penguins are not listed as Threatened and Priority Fauna.

A national review by Dann et al. (1996) identified Penguin Island as having the colony with the highest conservation significance across Australia. This high conservation significance was based on a number of criteria, and for Penguin Island this included little penguins having a relatively large population size, larger body size than other colonies, a more protracted breeding season, being located at the most northern and western limits of their distribution, being located in an A-Class nature reserve and having a long history of research.

3.2 The issue

Despite the national overall trend of a steady little penguin population, the population on Penguin Island has been declining. The population was estimated at 2400 and 1500 individuals in 2007 and 2008, respectively, and has declined to an estimated 300 in 2019 (Cannell et al., 2011; Cannell, 2018; Cannell, 2020).

Management interventions to date by the Department of Biodiversity, Conservation and Attractions (DBCA) for the Penguin Island colony have included the installation of artificial nest boxes (DBCA, 2019), the building and maintenance of boardwalks to reduce disturbance of sensitive breeding habitat, a reduction in vessel speed limits in local waters, and the annual closure of the island to visitors between mid-June to mid-September, when the first peak of the breeding season occurs. As of August 2022, management interventions have been modified to extend the island closure until mid-October and close the island to visitors during summer days where the ambient temperature is forecast to exceed 35°C. In addition, DBCA facilitates regular monitoring activities through seasonal natural and artificial nest box monitoring and nightly penguin return counts at primary beach return points using remote cameras. DBCA also facilitates a Little Penguin Working Group to help inform management decisions.

Despite management efforts, the Penguin Island colony is still in decline and risks local extinction. There is an urgent need to identify the key pressures acting upon little penguins (natural, anthropogenic and climate change related) and where intervention is likely to be most effective. This requires a sound understanding of current knowledge and an assessment of where research is most required to inform management.

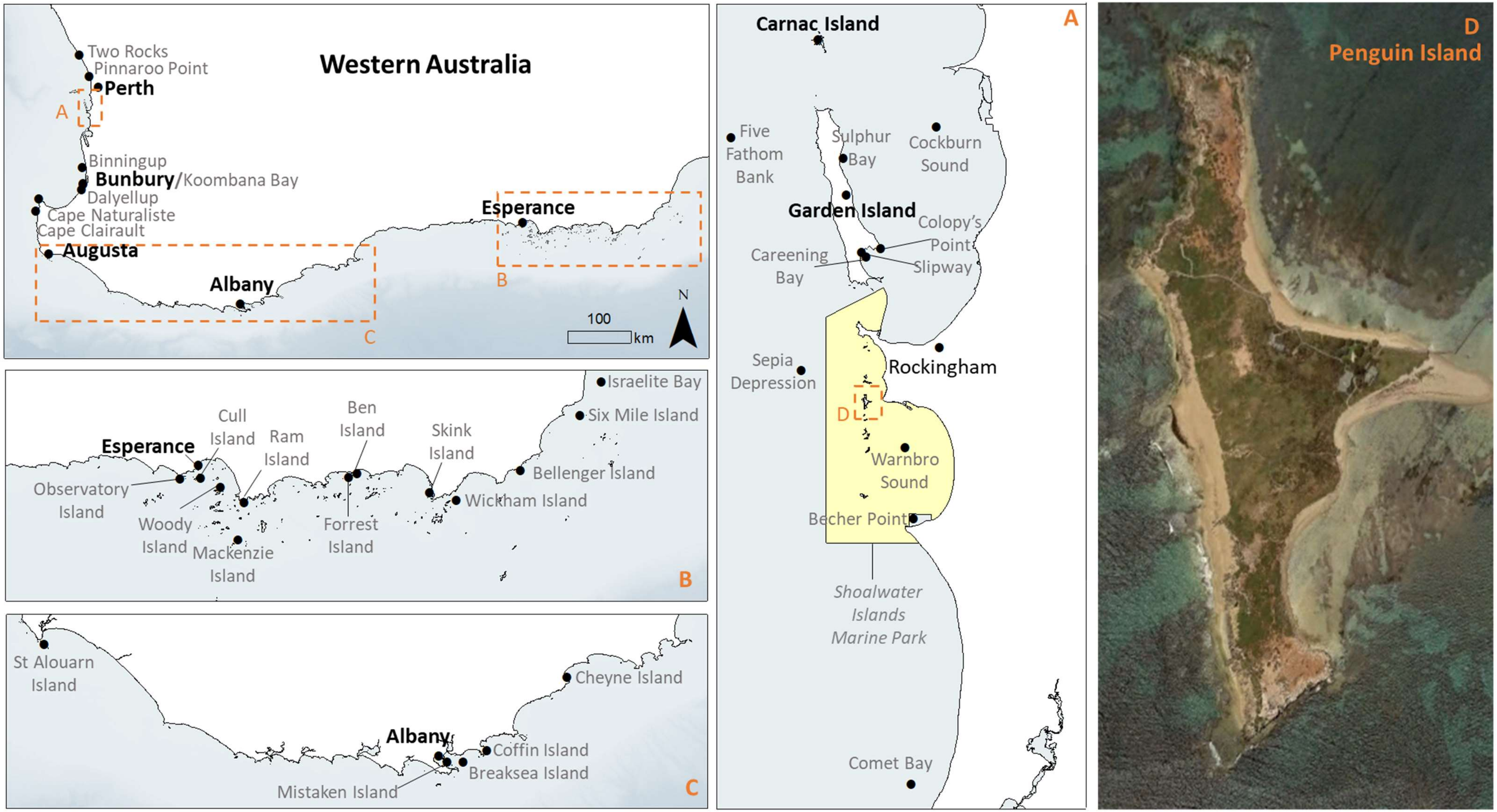

Figure 1. Locations in Western Australia relevant to little penguins and/or mentioned throughout this review, in particular, Penguin Island, Garden Island and Carnac Island.

4 Purpose and Aims

The overall purpose of this review is to identify where management focus and actions should be directed in order to reduce pressures acting on little penguin populations into the future, in particular, for the colony on Penguin Island in the Shoalwater Islands Marine Park. This Penguin Island colony forms the primary focus of this review and conceptual population model, largely because of the management need and the volume of research carried out compared to other locations.

This review focuses on Western Australian little penguins and draws upon knowledge collected from the Shoalwater islands group and south coast populations. The spatial extent includes the northern most colony on Carnac Island (32.1210°S, 115.6621°E) and along the southern coastline to Israelite Bay (33.6482°S, 123.7842°E). Where necessary, knowledge from non-WA colonies has been included for context or guidance.

The scope of this review aims to:

1. Develop a conceptual population model for understanding the key life stages and pressures for little penguin populations in Western Australia
2. Review the current state of knowledge with regards to each of the elements included in the conceptual population model, with a particular focus on Penguin Island
3. Identify key knowledge gaps for Penguin Island arising from the conceptual population model, including documentation of unpublished information that may help to address gaps

Previous knowledge reviews on little penguins in WA include Cannell (2001, 2004). This 2022 assessment builds upon previous reviews with more current published and unpublished literature and identifies unpublished datasets that could be used to inform knowledge gaps. The knowledge gaps presented in this review have resulted from an understanding of the most current and available scientific knowledge, however, it is acknowledged that the little penguin colonies along the WA south coast are relatively understudied compared to the metropolitan colonies.

5 Little penguin conceptual population model

5.1 Conceptual population model development

The development of the little penguin conceptual population model needed to provide a clear avenue for identifying gaps in knowledge, be scalable and transferable across colonies (e.g., Penguin Island) and populations in WA (e.g., Shoalwater islands group vs south coast WA), and provide a template for future mathematical modelling.

To develop the model, a two hour workshop was held on the 29 April 2022. Attendees at the workshop included DBCA staff and little penguin subject matter experts with extensive knowledge of Shoalwater islands group colonies (Table 1).

Following the first draft of the model at the workshop, refinements were made and agreed upon by workshop participants prior to finalisation.

Table 1. Little penguin conceptual population model workshop attendees, April 2022.

Name	Organisation
Belinda Cannell	UWA, Murdoch University
Erin Clitheroe	Murdoch University, DBCA
Thomas Holmes	DBCA
Shaun Wilson	DBCA
Melissa Evans	DBCA
Inês Leal	DBCA
Alicia Sutton	Carijoa Marine Consulting

5.2 Final conceptual population model

The final little penguin conceptual population model incorporates the key life stages of little penguins and includes transition pathways for eggs, juveniles/sub-adults and adults (breeding and non-breeding) (Fig. 2).

The commonality for little penguins older than one year is the moult stage. All penguins moult their feathers and are confined to land during this stage. Little penguins do not reach maturity until they are 2-3 years old, so juvenile penguins cycle between moulting and being at sea. Courtship is the first stage of the breeding phase for mature adult penguins. If successful, parent penguins then cycle through egg laying/incubation, guarding and post-guarding of chicks. If conditions are ideal, a second clutch of eggs can be laid in the same breeding season with the cycle beginning again from the courtship stage. Not all mature adults attempt courtship and may cycle between moulting and being at sea (allocated as 3+ years non-breeding). Penguins who attempt courtship but fail also cycle back around to the moult stage after being at sea for a period of time.

If eggs are laid following a courtship, then the cycle steps through from a hatched chick that is continuously guarded by a parent, to an unguarded chick and finally the fledging stage where the fledgling is ready to leave the nest. Year 1 is defined as a penguin who has successfully fledged and is in its 1st year of life. The inclusion of the Year 1 life stage into the model is to capture a critical time period where many little penguins do not survive to their first moult (e.g., Sidhu et al., 2007). Year 2-3 is defined as a penguin in their 2nd and 3rd year of life who has not yet commenced breeding activities.

Little penguins exhibit high site fidelity and there is little evidence of immigration or emigration for colonies such as Penguin Island (Wienecke, 1993). Accordingly, the conceptual population model presented here is considered a 'closed' population model, although establishment of new colonies at Garden Island demonstrate some movement occurs. As information on immigration and emigration rates of little penguins becomes available, it can be factored into the conceptual population model.

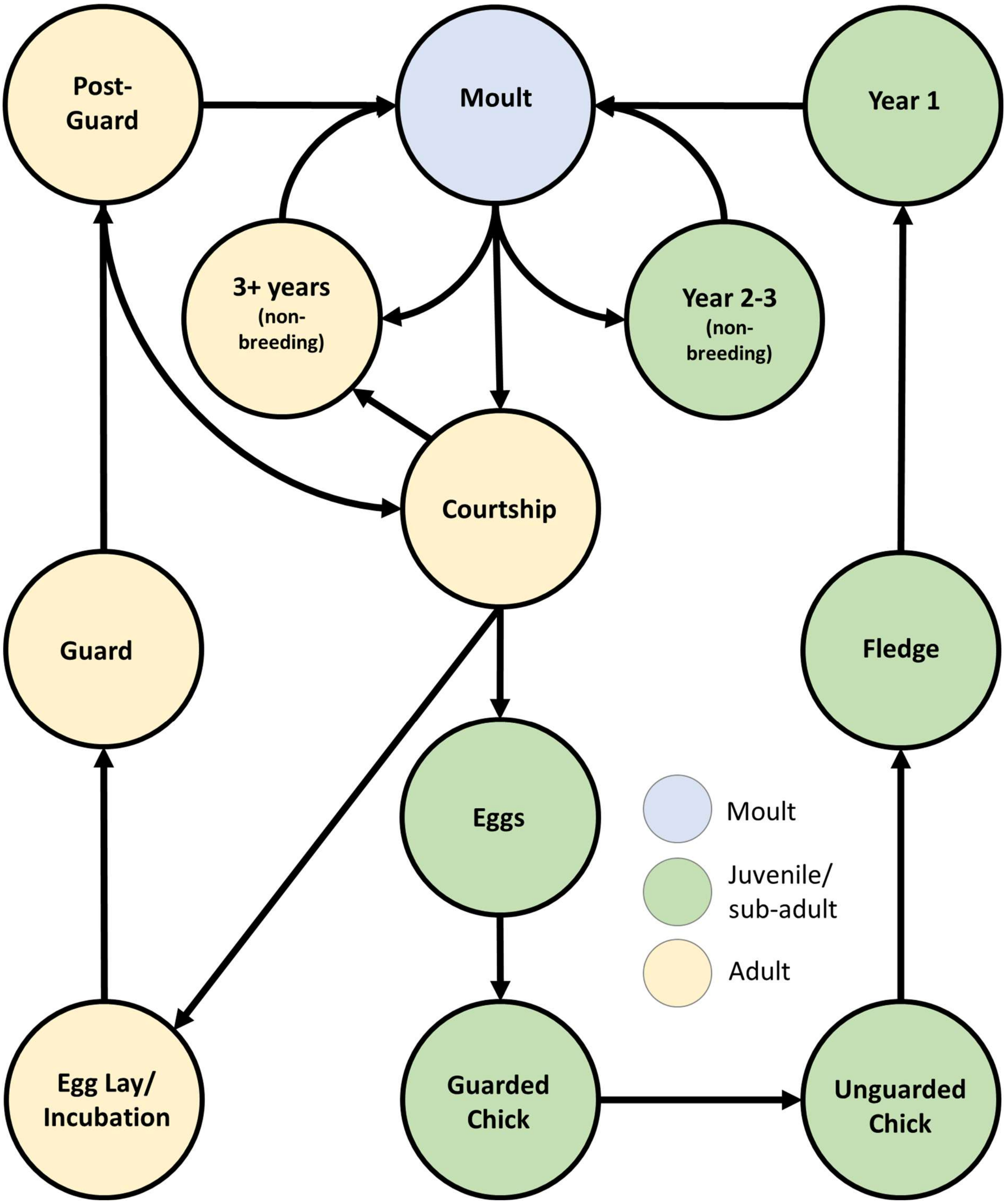

Figure 2. Conceptual population model for little penguins.

6 Assessment of pressures acting on little penguins

The pressures discussed in this review and the following pressure ratings build upon an existing review of pressures on little penguins by Cannell and Friedman (2014, unpublished DCBA draft report).

The types of pressures facing little penguins were categorised under 'natural', 'anthropogenic' or 'climate change'. Pressures were scored for little penguin colonies on Penguin Island, Garden Island and along the south coast of WA (Table 2). The pressures were scored as high (3), medium (2) and low

(1) during a two hour workshop held on the 29 April 2022 (see Table 1). Justifications for the scoring of pressures came from a combination of judgements made by subject matter experts (who attended the workshop) with unpublished and long term knowledge, along with the published knowledge on life stages and pressures presented in section 8.

Twenty four pressures were identified for little penguins in WA. Penguin Island had nine pressures considered to be high and Garden Island had five. There is less published information and expert knowledge known for little penguin colonies along the south coast of WA, and as a result, most pressures could not be scored with confidence. This highlights numerous potential knowledge gaps on how pressures affect little penguins along the south coast of WA, though this does not form the focus of this report. The extent to which little penguins in WA are predated upon by marine predators is unknown, and a pressure score could not be indicated for any location.

The conceptual population model presented in Figure 2 can be combined with the pressures identified in Table 2 and the knowledge presented in section 8 and applied to different little penguin populations in WA. However, given the focus of this review, the conceptual population model (Fig. 2), applied pressures (section 7) and knowledge gaps arising from the model (section 9) is applicable to Penguin Island from hereon in.

Table 2. Pressures facing little penguins from the Shoalwater islands group colonies and along the south coast of WA. Table modified from Cannell and Friedman (2014, unpublished report). The pressures were scored as high (3), medium (2) and low (1) based on consensus views of workshop participants (Table 1). A low confidence or no knowledge of pressures is indicated by '?'. An indication of whether the pressure is occuring in the marine or terrestrial environment is indicated. SST = sea surface temperature.

#	Type of pressure	Penguin Island	Garden Island	South Coast WA	Marine/ Terrestrial
	Natural				
1	Ambient temperature	3	2	?	T
2	SST influencing the availability of coastal prey species	3	3	?	M
3	La Niña/El Niño rainfall cycles	1	1	1	T/M
4	Predators (Land)	1	1	1	T
5	Predators (Marine)	?	?	?	M
6	Disease, parasites and infections	2	2	?	M
7	Storm damage (beaches)	3	1	?	T
	Anthropogenic				
8	Bycatch in commercial fisheries	1	1	?	M
9	Commercial & recreational fishing impacts on prey species	2	1	2?	M
10	Entanglement	1	1	?	M
11	Coastal development impacts on prey species	2	3	2?	M
12	Vessel strike	3	3	?	M
13	Human disturbance	3	1	?	T/M
14	Pollutants	2	2	1?	M
15	Oil spills	1	2	?	M

#	Type of pressure	Penguin Island	Garden Island	South Coast WA	Marine/ Terrestrial
16	Introduced species and pests	2	1	?	T
17	Plastic pollution/ingestion	1	1	1	M
	Climate change				
18	Ambient temperature increases	3	2	2	T
19	Sea level rise	2	1	1	T
20	Oceanographic current shifts	2	2	1?	M
21	Vector-borne disease	1	1	1	M
22	SST increases and marine heatwaves impacting prey species	3	3	?	M
23	Rainfall impacts on habitat	3	1	?	T
24	Rainfall impacts on prey	3	3	?	M

7 Conceptual population model and high pressures for Penguin Island

An assessment was made by the author, DBCA staff and subject matter experts on which high pressures were impacting upon specific life stages of little penguins for Penguin Island (Fig. 3). Only high pressures were included in the conceptual population model for two reasons:

1. Management actions would focus on high pressures, in the first instance, for the greatest chance at improving the little penguin population
2. Clarity of the conceptual population model to focus the attention on the most critical pressures and knowledge gaps

Further still, impacts to the juvenile/sub-adult life stages that occur in nests are often considered secondary or indirect given the pressure initially impacts the parent penguins. Local management actions typically aim to tackle the source of the problem (though not always possible for pressures related to climate change) and these actions would likely result in positive impacts for nest reliant juvenile/sub-adult life stages. For this reason, only high pressures directly impacting nest reliant juvenile/sub-adult life stages are included in the conceptual population model (e.g., human disturbance, ambient temperature and ambient temperature increases).

Nine pressures out of a total of 24 were considered high for little penguins, in general, for the colony at Penguin Island (Table 2). These pressures were either known, assumed or based on findings from other locations. The knowledge review in section 8 helps to identify if there is published information on these pressures acting upon each individual life stage. Section 9 highlights on the conceptual population model where actual gaps in knowledge remain.

The nine high pressures included three ‘natural’ pressures, two ‘anthropogenic pressures’, and four ‘climate change’ pressures. Most little penguin life stages were considered to have some ‘natural’, ‘anthropogenic’ and ‘climate change’ high pressures potentially impacting them (Fig. 3). Eight high pressures were potential impacts on the courtship, egg lay/incubation and guard stages of the adult pathway, followed by seven high pressures potentially impacting the moult phase and post-guard adult life stage. The life stages with the least high pressures potentially impacting them included eggs (n=1) and guarded chick (n=2), recognising that indirect impacts (i.e., via impacts on the parents) were not included for these nest-reliant life stages.

Human disturbance (anthropogenic) was the high pressure potentially impacting all life stages except eggs, given it encompasses land based disturbances as well as marine based disturbances, such as underwater noise. Sea surface temperature (SST) influencing the availability of coastal prey species (natural), rainfall impacts on prey (climate change) and SST increases and marine heatwaves impacting prey species (climate change) are potentially impacting upon nine life stages each. This was followed by vessel strike (anthropogenic) and ambient temperature increases (climate change) potentially impacting eight and seven life stages, respectively.

Time of year was also considered when applying high pressures to each little penguin life stage. For example:

- Ambient temperatures (natural) impacting life stages closer to the summer months, particularly for a late first clutch or second clutch in a season (e.g., unguarded chick) but not on those stages typically occuring during the cooler months (e.g., eggs, guarded chicks, egg lay/incubation and guard)
- Storm damage (natural) not impacting the moult stage given Penguin Island is less likely to have storms and storm damage over the summer months when penguins are moulting

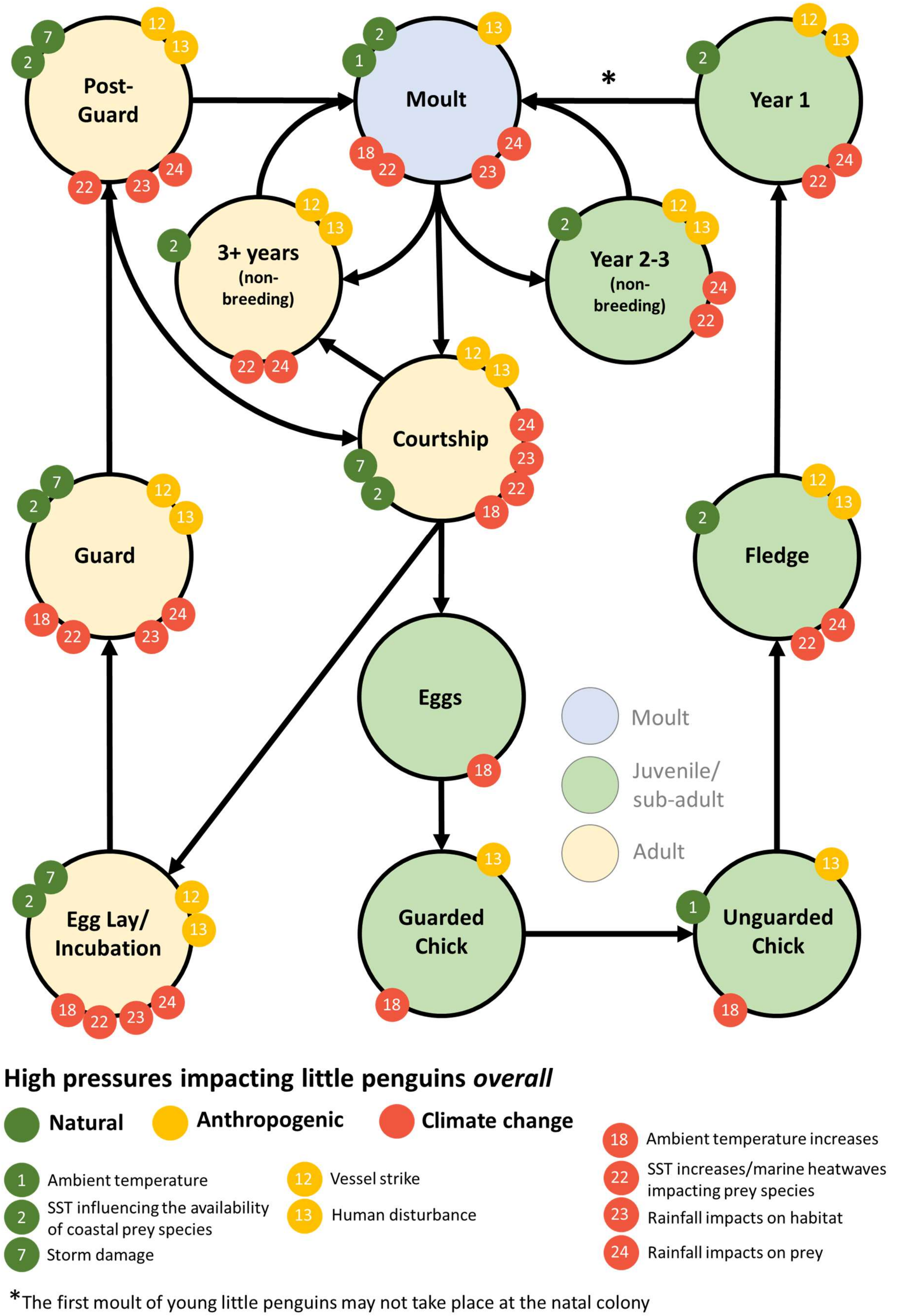

Figure 3. High pressures potentially impacting the different life stages included in the conceptual population model for little penguins from Penguin Island. Indirect impacts on nest reliant juvenile/sub-adult life stages are not included.

8 Updated knowledge review to inform the little penguin conceptual population model

8.1 Overview of the little penguin life cycle

Little penguins from WA have an average life expectancy, following maturity, of ~ 5 years (~ 7-8 years including immature stages) (Wienecke, 1993), with one known record of ~ 20 years old (Cannell 2012 - 'Little Penguin leaves a legacy' -https://www.murdoch.edu.au/news/articles/little-penguin-leaves-a-legacy). The typical life cycle for little penguins every year (based on findings from the Shoalwater islands group) involves a period of moult (~December to March), non-breeding activity (~March), courtship and nest building (spanning across the breeding season), and incubation and chick rearing (~April to December) (Fig. 4, see section 8 for more details). Little penguins from the Shoalwater islands group have a protracted breeding season compared to most other colonies on the south-east coast of Australia and New Zealand (Klomp et al., 1988). Breeding can span from April to January on Penguin Island, Carnac Island and Garden Island (Wooller et al., 1991; Cannell, 2015). For the south coast of WA, historical records identified August to January as the breeding season for locations such as Bald Island and Mistaken Island (Abbott, 1978, 1981; Wienecke, 1993), and more recenently in 2020, from June to December for Mistaken Island (Bayliss, 2022).

Little penguins are asynchronous breeders, which means not all little penguins undertake the different phases of the life cycle at the same time during a breeding season, or between breeding seasons (Wienecke, 1993). The length, timing and success of the breeding season is largely related to the availability of food resources and ideal foraging conditions (Wienecke, 1993; Cannell et al., 2012), which in turn are influenced by oceanographic and environmental conditions. Breeding success is defined as the survival of an egg through to a fledged juvenile.

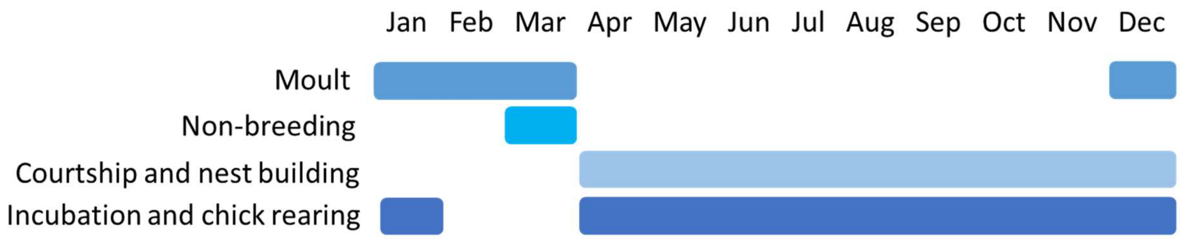

Figure 4. Typical timing for life phases of little penguins from Penguin Island, demonstrating the asynchronous breeding activity that can occur at different times throughout the breeding season (~April-January) for each penguin.

8.2 Little penguin life stages

8.2.1 Moult phase

The moult phase for little penguins (aged 1+ years) lasts for 2-3 weeks and requires penguins to stay on land while they replace all of their feathers (Cannell, 2001). The timing of moult typically occurs between ~ Dec-Mar and ~Nov-Feb each year for Penguin Island and Garden Island, respectively (Cannell, 2015; Clitheroe, 2021). Along the south coast of Australia, historical observations of a moulting individual were made on Ben Island in February 1986, and on Forrest Island, moulted feathers and a moulting individual were found in February and April 1986, respectively (Johnstone and Smith, 1988; Smith and Johnstone, 1988). More recently, little penguins were found moulting in January 2021 on Mistaken Island (Bayliss, 2022).

Following the moult phase, penguins leave the colony, but it is unknown for all WA colonies how long penguins stay at sea or where they go before returning to their natal colonies. Based on a seven year study period (1986-1992), and the banding of 1,678 adult little penguins from Penguin Island, annual survival of adults was estimated to be 75% (Wienecke, 1993).

Little penguins need to build up enough fat and energy reserves to sustain them through the moult phase. If body condition is poor, they may starve to death, which was the case for eight individuals in different stages of moult collected across 2003-2012 in the Perth metropolitan region (Cannell et al., 2016). Additionally, as the annual moult occurs during the summer months where daily temperature maxima are often greater than the thermoneutral zone of little penguins (Horne, 2010), moulting penguins can become heat stressed and even die of hyperthermia (Cannell et al., 2012; Cannell et al., 2016).

No information is currently available for the pre-moult and post-moult behaviour and distribution of little penguins from WA colonies. This is largely due to satellite tags and data loggers being too large to deploy on penguins for months at a time, and affixing tags to penguins in poor body condition (following moult) may hinder their survival (Cannell pers. comm.).

8.2.2 Adult cycle

8.2.2.1 Courtship

The first step in the breeding season is courtship. Little penguins reach sexual maturity at 2-3 years old (Reilly and Cullen, 1981), after which they may or may not engage in courtship every year (Cannell pers. comm.). While the length of courtship has not specifically been studied for penguins from WA colonies, it has been shown to last for 5-6 days and occur one month before egg laying at Phillip Island in Victoria (e.g., Chiaradia and Knowles, 1999). Little penguins return to their natal colonies and exhibit high nest fidelity during the breeding season, such as on Penguin Island (Wienecke, 1993); males exhibited nest fidelity more so than females (77% and 61%, respectively) based on data collected between 1989 and 1992. Further, 29 out of 30 monitored pairs of little penguins that had breeding success returned to the same nest in the next breeding season. Nest fidelity has also been linked with mate fidelity. There is evidence for little penguins returning to the same nest if they also returned to the same mate, and while most little penguins exhibit mate fidelity within years, this is not always the case across years. Wienecke (1993) estimated that 58% of little penguins that changed partners in a breeding season also changed their nest site the following season. More recent estimates are not currently available to assess whether mate fidelity and site fidelity have changed over time for Penguin Island.

The number of breeding attempts of mature adults does not necessarily correlate with breeding success (fledged chicks) in the same year, and factors such as food availability and breeding experience can significantly influence breeding success. For example, in 2016, fewer breeding attempts were observed compared to previous years, though the breeding success of the eggs laid was higher than the long term average, suggesting favourable foraging close to the colony (Cannell, 2017). In other years, higher than average breeding attempts have been made but may have been by inexperienced breeders which resulted in low breeding success (Cannell and Clitheroe pers. comm.).

Based on ten years of data, the breeding success rate appears to be higher for Garden Island than Penguin Island (Cannell unpublished data in Cannell, 2015), though a direct comparison of breeding patterns and breeding success rates, as well as variations over time, is requried for the two islands. The number of breeding penguins on Garden Island was estimated at 140-160 pairs in 2015 (500-600 individuals in total).

8.2.2.2 Egg lay/incubation

Little penguins on Penguin Island make nests in amongst dense vegetation dominated by low lying shrubs, such as *Rhagodia baccata* (berry saltbush), *Nitraria billardieri* (nitre bush) and *Tetragonia decumbens* (sea spinach) (Klomp et al., 1991). Burrows are not common on Penguin Island due to the fragility of the sandy substrate (Klomp et al., 1991). Approximately 120 artificial nest boxes also occur on Penguin Island, with boxes first being installed in 1986 for research purposes, allowing data to be more readily collected from nesting penguins (Klomp et al., 1991; Wienecke et al., 1995). Nest boxes have been opportunistically upgraded across time to incorporate newer and more thermally tolerant designs where possible.

Characteristics of natural and artificial nests, as well as probability of nest use and success was investigated for little penguins on Penguin Island during 2013-2016 (Clitheroe, 2021). Higher little penguin use of natural nests was associated with being close to a landfall site, on flat or gently sloping ground, and immediately surrounded by high vegetation cover. A preference was shown for the shrub *Tetragonia decumbens*, with some occurrences of *Rhagodia baccata*. For artificial nests, which were purposely placed close to landfall sites during installation, the factor most determining nest use was the structure of the box, rather than vegetation (Clitheroe, 2021). Despite artificial nest boxes being abundant on Penguin Island, Clitheroe (2021) reports a relatively low occupation of artificial boxes compared to other locations around Australia. In addition, artificial nest boxes are typically warmer than natural nests (Clitheroe, 2021), and evidence suggests a lower nest fidelity for artificial nest habitat types, compared to natural nest habitat types (Tavecchia et al., 2016).

Nest sites are usually located in proximity to entry and exit points of the water, and little penguin use set routes to exit and enter the colony, such as observed for Garden Island (Cannell, 2015) and Penguin Island (Klomp and Wooller, 1991; Cannell et al., 2011; Bertram, 2013). Little Penguins can congregate together in a behaviour called 'rafting' before making their way onto land at sunset/night (Cannell, 2015). The daily departure times of little penguins from both Penguin and Garden Islands occurs before sunrise (Ropert-Coudert et al., 2006; Cannell, 2015). However, the arrival time back to land occurs around sunset for Garden Island penguins, and approximately 1-2 hours later for Penguin Island penguins (Klomp and Wooller, 1991; Cannell, 2015). The difference in daily arrival times back to the colony may be linked with prey availability and distance travelled to find food, as penguins are visual predators and stop foraging once light levels get too low (Cannell and Cullen, 1998).

If conditions are ideal, little penguins in WA can lay up to two clutches per breeding season (Wienecke, 1993), typically consisting of two eggs per clutch (e.g., Wienecke, 1993; Wienecke et al., 2000; Cannell, 2017; Cannell, 2018). Previous coarse estimates for the Shoalwater islands group finds ~26% of breeding little penguins lay one clutch per year, ~23% lay two clutches, and the remainder do not lay any clutches (Cannell unpublished data in Vardeh, 2015). However, evidence suggests the occurrence rate of two clutches in one season is higher for little penguins from Garden Island than for Penguin Island (Cannell unpublished data in Cannell, 2015). For breeding pairs laying two clutches on Garden Island, the first clutch of eggs is usually laid in June/July and the second clutch in September, but this can vary annually. This is similar for Penguin Island, however fewer first clutches are laid before July.

Both male and females take turns incubating eggs and foraging, and parents incubate eggs for approximately five weeks (Wienecke, 1993). On Penguin Island, the foraging trips taken by each parent during incubation can span days, with an average duration of 7.6 ± 6.5 in 2015 (n = 8 satellite tagged adults) and 5.3 ± 2.5 days in 2016 (n = 7 satellite tagged adults) (Cannell, 2017). Penguins typically forage in one core area during each foraging trip, rather than travelling across multiple areas, with distance travelled generally ranging from 7 – 145 km (Cannell, 2017, 2018). Adult little penguins from Penguin Island have been tracked as far north as Two Rocks (31.4914°S, 115.5956°E) and as far south as Cape Clairault during incubation (33.7167°S, 114.9667°E) (Cannell unpublished data; Cannell, 2016; Cannell, 2017, 2018). Core foraging areas during incubation along the WA coast, identified from the satellite tracking program, include Cockburn Sound, Warnbro Sound, west and north-west of Garden Island, Comet Bay, Lake Clifton-Binningup, Koombana Bay, Dalyellup, and between Cape Naturaliste and Cape Clairault.

For little penguins from Garden Island, foraging occurs in Cockburn Sound during incubation (Cannell, 2015), and penguins can spend up to six days foraging before returning to the eggs (Cannell unpublished data).

8.2.2.3 Guard

During the guard phase, both parents take turns to either guard the chicks intensively or forage (Cannell, 2001). The guard phase typically lasts for 2-3 weeks.

Given the feeding requirements of chicks, parents need to forage closer to the colony, typically staying within 30 km and taking day trips (Cannell unpublished data; Cannell, 2016; Cannell, 2017, 2018). Distances travelled during the guard phase by Penguin Island penguins in 2015 and 2016 ranged from 6.6-25 km (n=12) and 8-21 km (n = 8), respectively (Cannell, 2016, 2017). In 2017, only one adult was tagged due to very low numbers of chicks, and this penguin travelled a maximum of 18 km away from the colony (Cannell, 2018). Significant differences in foraging areas for males and females are yet to be found (Cannell, 2016, 2017).

Core foraging grounds during the guard phase for penguins from Penguin Island include the waters around the Island, Warnbro Sound, Comet Bay, Sepia Depression north-west of Penguin Island, adjacent to Five Fathom Bank, west side of Garden Island and Cockburn Sound (Cannell unpublished data; Cannell, 2016; Cannell, 2017, 2018).

For little penguins from Garden Island, foraging tends to occur in the southern half of Cockburn Sound during the guard phase (Cannell, 2015).

8.2.2.4 Post-guard

The post guard phase lasts 4-5 weeks and both parents may take the opportunity to forage while leaving the chicks unattended (Cannell, 2001).

Given precise daily data is required to identify the transition from the guard to post-guard stage for adult little penguins, no published information has been specifically related just to the post-guard stage. It is likely that references to 'chicks' in published information refer to either guard or post-guard stages.

8.2.2.5 3+ years (non-breeding)

Not all mature adults attempt courtship or they may have a failed courtship (Cannell pers. comm.). It is unknown whether non-breeding individuals remain close to the colony after moult or failed breeding attempts.

8.2.3 Juvenile/sub-adult cycle

8.2.3.1 Eggs

The installation of artificial nest boxes on Penguin Island have greatly facilitated studies on little penguin eggs and other breeding metrics. Trends from a dataset spanning 1986-2011 on Penguin Island have shown that the later the eggs are laid, the lower the hatch rate (Cannell et al., 2012). The timing of egg laying, and any delays, have been related to the availability of food and ideal foraging conditions (Wienecke, 1993; Cannell et al., 2012).

Not all eggs will result in successful hatching of chicks. In 1986 and 1988, 36% (71/198 eggs) and 46% (44/96) of eggs, respectively, did not hatch in monitored artificial and natural nests at Penguin Island (Meathrel and Klomp, 1990). Some eggs were rotten or cracked, and some were abandoned. In years 2007, 2008 and 2010, the percentage of eggs that did not hatch from monitored nests were 33% (56/171), 41% (46/112) and 45% (63/141), respectively (Cannell, 2011). In 2011, only one breeding peak occurred in June, which resulted in a total of 48 eggs being laid in monitored boxes, of which 21 did not hatch (44%) (Cannell, 2012b).

Abandonment of eggs by the parents is a significant risk to breeding success for all little penguin colonies. During a 2016 study on Penguin Island, which deployed tags on adult little penguins who were incubating, eggs were permanently abandoned in three out of 14 nests (20%) (Cannell, 2017). The authors did not attribute the abandonments to the tagging of parents. If food resources are low, parents may need to take longer foraging trips during the incubation period, which can lead to higher rates of egg abandonment (Cannell unpublished data in Cannell et al., 2012). Restricted access to nests can also lead to egg abandonment and is discussed further in section 8.3.1.7.

8.2.3.2 Guarded chick

Newly hatched chicks are unable to thermoregulate for the first few days, or feed themselves, and are closely guarded by parents for approximately three weeks on Penguin Island and Garden Island (Wienecke, 1993; Cannell, 2001).

If two eggs are laid in a clutch, the hatching of each of the eggs is asynchronous (Wienecke et al., 2000), like the entire breeding season. The asynchronous hatching days apart can cause some competition over resources and a higher mortality rate for the chick that hatched second, such as found for little penguins from Penguin Island. Second hatched chicks also tended to have a slower growth rate for all growth variables (Wienecke, 1993).

From a sample size of 44 chicks from Penguin Island and Garden Island between 2016-2018, there were no statistical findings to support gender influencing the order of hatching out of a two egg clutch (Povah, 2021). There was some evidence to suggest the sex ratio of chicks may be female biased for Penguin Island and Garden Island (56.1% and 63.2% of hatchlings were female, respectively), though only marginally significant results were found for the small sample size ($p = 0.092$, $n = 41$ and $p = 0.096$, $n = 19$, respectively). The study also found potential evidence to suggest growth rates are similar for males and female chicks, but males achieve a greater weight, which may suggest a higher energetic cost in raising male offspring. However, consideration should be given to the low sample sizes and that biological or environmental factors affecting growth rate, other than weight and foot length, were not investigated.

8.2.3.3 Unguarded chick

Chicks are unguarded by parents for 4-5 weeks and are able to thermoregulate efficiently (Cannell, 2001). The information provided on growth rates and sex ratios for the previous life stage of guarded chicks would also apply to unguarded chicks, given it is logistically challenging to identify when exactly the transition occurs between the two stages (Cannell pers. comm.).

On rare occasions, there has been evidence for adoption of abandoned chicks on Penguin Island (Wienecke, 1995). Historical observations have been of chicks seeking out a new occupied nest, rather than an adult seeking out an abandoned nest. Those chicks close to fledging were more likely to survive than chicks who were younger and still heavily reliant on food from a parent.

On Six Mile Island along the south coast of WA, two groupings of 6-8 'young' little penguins were observed together under granite slabs in January 1985 (Johnstone and Smith, 1987). More recent accounts of this behaviour have not been publicly documented for other WA colonies, such as on Penguin Island or Garden Island.

8.2.3.4 Fledge

A chick surviving to fledge is the measure of breeding success for little penguins (Wienecke, 1993). Chicks typically fledge after approximately eight weeks (Reilly and Cullen, 1981). The fledging success of first and second hatched chicks on Penguin Island is largely dependent on food availability (Wienecke et al., 2000). Second hatched chicks from a clutch size of two tend to grow at a slower rate and fledge with a lower body mass than first hatched chicks, given first hatched chicks are typically fed first by parents (Wienecke, 1993; Wienecke et al., 2000). If eggs are laid earlier in the season, then fledglings from Penguin Island have been shown to attain a greater weight compared to those fledglings from eggs that were laid later in the season (Cannell et al., 2012).

One of the first estimates of breeding success was based on a dataset spanning 1987-1991 on Penguin Island, which found 21-48% of eggs survived to the fledging stage (Klomp et al., 1991; Wienecke, 1993). Slightly higher estimates of 31-50% for fledging success were calculated from 2007-2010 surveys (Cannell, 2011). However, in 2011, only one breeding peak occurred in June with 48 eggs laid in monitored nests, and breeding success was estimated to be 10% (Cannell, 2012b). A more recent estimate across 2014-2016 found 60% of eggs in artificial boxes survived to the fledging stage (Clitheroe, 2021). The estimate was 66% for natural nests.

8.2.3.5 Year 1

The survival rates of fledglings to 1 year old from any colony in WA is currently unknown, as is where they distribute, forage or moult. The lack of information on the distribution of this life stage is largely due to the ethics of placing loggers or tags that can impact the hydrodynamics of fledglings who are learning to forage for the first time (Cannell pers. comm.).

Based on little penguins from Phillip Island in Victoria and a 36 year dataset (1968-2004), an average of 17% of juvenile little penguins are estimated to survive to one year of age (Sidhu et al., 2007).

8.2.3.6 Year 2-3 (non-breeding)

When chicks fledge and leave the nest, they typically do not return to the colony for 2-3 years (Wienecke, 1993). The return rate of 2-3 year old penguins was 67.5% of the chicks who were banded on Penguin Island between 1986-1992.

Similarly to juvenile little penguins < 1 year old, very little information is currently known for little penguins from WA colonies during the non-breeding stage of their life (1-3 yrs). For penguins aged 2 yrs and over, an estimated annual mortality of 15.11 ± 9.9% was used to inform a population viability model for the Shoalwater islands group and south coast WA colonies (Cannell unpublished data in Vardeh, 2015). This mortality estimate is lower than that for little penguins from Phillip Island in Victoria, which was estimated at 29% for second year and 22% for third year little penguins based on a 36 year dataset (1968-2004) (Sidhu et al., 2007).

8.3 Pressures impacting little penguins

8.3.1 Natural

8.3.1.1 Ambient temperature

Ambient temperatures directly influence the temperature and humidity inside natural and artificial nests. The thermoneutral zone (the range of ambient temperatures where the body can maintain its core temperature solely through regulating dry heat loss) of little penguins from Penguin Island, and likely surrounding metropolitan colonies, is 12-30°C (Horne, 2010). Little penguins can experience thermal stress in temperatures ≥ 30°C and hyperthermia at ≥ 35°C, and this has caused mortalities of little penguins from the Shoalwater islands group, particularly during the moult stage (Cannell et al., 2016).

During twilight and night hours, the temperatures inside natural and artificial nests on Penguin Island are similar to ambient air temperatures (Clitheroe, 2021). During daylight hours, nest temperatures exceed ambient temperatures, causing thermal stress in little penguins on warmer days. For example, ambient temperatures of 25-29.9°C result in thermally stressful conditions inside natural and artificial nest boxes, and ambient temperatures of 35°C or more result in hyperthermic conditions inside nests. On top of this, artificial nest boxes have higher maximum temperatures during the day, exceed upper thermoneutral limits more often and have prolonged extreme temperatures more so than natural nests. During Jan-Feb of 2008, Horne (2010) found temperatures inside artificial nests to be above 30°C for approximately 50% of the time, with a maximum temperature of 39.5°C reached. In an earlier study on Penguin Island, Ropert-Coudert et al. (2004) found artificial nest boxes to be 2.73 ± 1.65°C warmer on average that surrounding bushes, and a maximum temperature of 43.8°C was recorded inside a nest box.

While ambient temperatures can create potentially lethal temperatures inside artificial nest boxes, experimental manipulation of artificial nest boxes on Penguin Island found improvements could be made to boxes to reduce this threat to little penguins (Clitheroe, 2021). Artificial nest boxes placed under shading vegetation had significantly lower maximum nest temperatures compared to unshaded boxes and were comparable or cooler than natural nest sites amongst vegetation. Nests made of buried plastic pipe had cooler daily nest temperatures but slow heat dissipation (Clitheroe, 2021), and subsequent monitoring has found a low use rate of these plastic pipe nest designs compared to wooden boxes (Clitheroe pers. comm.). Allowing for more ventilation and the cooling influence of wind could be achieved through nest orientation and ventilation holes (Clitheroe, 2021).

Little penguins on Garden Island mostly nest in rock walls around the western side of Careening Bay, the Slipway and less so around Colopy's Point and nearby wharves (Cannell, 2015). Rock wall nests are cooler than natural nests in vegetation on Penguin Island (Cannell and Clitheroe pers. comm.). On Carnac Island, little penguins can nest in limestone caves and under vegetation (Dunlop and Storr, 1981), which are also likely cooler than nests on Penguin Island.

Along the south coast of WA, breeding little penguins have historically been observed in burrows under *Sporobolus* grass (e.g., Bellenger Island), *Carpohrotus* covered sand deposits (St Alouarn Island), as well as under granite slabs (e.g., Bellenger, Wickham, Skink, Six Mile Islands) and rock shelves (e.g., Observatory and Cull Islands) (Lane, 1978; Lane, 1982a, 1982b; Johnstone and Smith, 1987; Smith and Johnstone, 1987; Johnstone et al., 1990a, 1990b). No information is currently available on little penguin nest microclimate conditions for these or other islands along the south coast of WA. However, nest boxes were installed on Breaksea Island in 2020 (and soon to be on Cheyne Island), which can be used to investigate nest microclimate in the future (Cannell pers. comm.).

Outside of the nest, elevated temperatures during the day can also delay the onset of breeding for some little penguins, such as pre-laying nest attendance and courtship, as previously observed on Penguin Island (Wienecke 1993).

8.3.1.2 SST influencing the availability of coastal prey species

Little penguins from the Shoalwater islands group primarily forage on coastal baitfish species that rely on a phytoplankton based food web (Dunlop, 2017), such as whitebait/sandy sprat (*Hyperlophus vittatus),* sardines (*Sardinops sagax),* blue sprat (*Spratelloides robustus),* sea garfish (*Hyporhamphus melanochir)* and anchovies (*Engraulis australis*) (Klomp and Wooller, 1988; Wienecke, 1989; Cannell, 2011; Murray et al., 2011; Cannell, 2012a; Cannell, 2012b). While these species may also form part of the diet for little penguins along the south coast of WA, sardines are noted as the dominant prey type in these temperate waters (Dunlop, 2017). Up to 13 different fish species were identified from faecal samples of penguins in 2010 and 2011 (Cannell, 2011; Cannell, 2012b). On occasion, little penguins might also feed on squid and crustaceans (Klomp and Wooller, 1988; Cannell, 2012a). Typically, little penguins forage on these baitfish within 10 km of the coastline (Cannell unpublished data in Cannell et al., 2020).

Baitfish species are consumed by little penguins in varying amounts depending on the different phases of the penguin life cycle. For example, during the breeding period, little penguins typically feed primarily on whitebait/sandy sprat, constituting up to 80% of their diet (Klomp and Wooller, 1988; Cannell unpublished data), whereas prior to breeding, sardines have been known to dominate the diet (Klomp and Wooller, 1988; Cannell unpublished data). Based on faecal samples collected from six chicks during the breeding season in September-October 2012, eight species were identified from DNA, including sardines, scaly mackerel and anchovies (Cannell, 2012a), though the occurrence of scaly mackerel was more prevalent following a marine heatwave in 2011.

When prey abundance is low in foraging grounds surrounding Penguin Island and Garden Island, little penguins need to travel greater distances and expend more energy to find prey, which can be detrimental for raising chicks. For example, the home range of little penguins from Penguin Island during the incubation phase spanned ~2500 km^2 in 2014 and 2015, but only 1337 km^2 in 2016 (Cannell, 2017). During the guard phase, the home range decreased from ~145 km^2 in 2014 and 2015 to 42 km^2

in 2016. The reduced home range in these phases during 2016 suggest that penguins didn't have to travel far to find favourable and high concentrations of prey species.

Little penguins can experience delayed breeding cycles, delayed growth, delayed breeding success, but most importantly, death due to starvation when food resources are low (Cannell et al., 2016). Starvation was found to be the second highest cause of mortality in 163 deceased little penguins collected in the Perth metropolitan coastal areas between 2003-2012; affecting twenty eight adults and one juvenile (Cannell et al., 2016). Most starved individuals were found in spring and summer. The increased rate of deaths of little penguins from starvation following the marine heatwave in 2011 and subsequent La Niña years was attributed to higher sea surface temperatures reducing the abundance of coastal baitfish species in the Perth metropolitan region (Cannell et al., 2019).

The abundance and occurrence of baitfishes can differ year to year due to environmental factors such as SST (e.g., Caputi et al., 1996; Lenanton et al., 2009), which, in turn, can influence the foraging success of little penguins year to year. For example, the decline in juvenile whitebait from key nurseries at Becher Point (Shoalwater Islands Marine Park) and Pinnaroo Point (near Hillarys) was attributed to the strength of the Leeuwin Current and higher sea surface temperatures (Valesini and Tweedley, 2015), whereas commercial catches of whitebait have previously shown a positive relationship with strength of the current (Gaughan, 1996a). For sardines, a stronger Leeuwin Current was negatively impacting the survival of larval stages (Caputi et al., 1996).

8.3.1.3 La Niña/El Niño rainfall cycles

La Niña and El Niño are naturally occurring climatic forces that significantly influence the terrestrial and marine environments of Western Australia. Under La Niña conditions, there is typically higher rainfall and more storm activity across the south-west of WA, while the opposite is true for El Niño conditions (Holbrook et al., 2009). The variability in rainfall across years will influence habitat quality for little penguins. Higher rainfall and storm activity may increase erosion of pathways to nest sites, while less rainfall may reduce native vegetation cover ideal for nesting. The dense *Tetragonia decumbens* shrub is dominant across Penguin Island (Klomp et al., 1991), and it is likely that enough preferable natural nesting habitat is currently available (due to current rainfall cycles) on Penguin Island for little penguin use (Clitheroe pers. comm.). The level of rainfall will also impact the humidity levels inside nests (Clitheroe, 2021). Artificial nests are dryer and less humid than natural nests during spring and summer months on Penguin Island, and more humid than natural nests during autumn and winter months.

Rainfall can also influence the abundance of prey species consumed by little penguins by influencing the salinity of estuarine and coastal embayments. Whitebait/sandy sprat spawn in marine waters, such as Warnbro Sound and Comet Bay, and do so during the winter months when rainfall is higher and salinities are reduced in nearby estuaries (Gaughan et al., 1996). A positive correlation was identified between commercial whitebait catches in Warnbro Sound and rainfall.

8.3.1.4 Predators (Land)

Predation on little penguins is considered low on Penguin Island given it is a mostly isolated island with periodic access via a sand bar. King skinks (*Egernia kingii*) may opportunistically take eggs if they are abandoned (Dunlop et al., 1988; Meathrel and Klomp, 1990). King skinks were also suggested to opportunistically take chicks < two weeks old, based on the disappearance of nine chicks during weekly monitoring of eggs and chicks in 1986 (Meathrel and Klomp, 1990). Australian ravens (*Corvus coronoides*) have been observed on Penguin Island predating on chicks (Cannell pers. comm.).

King skinks, Australian ravens and white bellied sea eagles (*Haliaeetus leucogaster*) have been noted as predators of seabird eggs and chicks for many of the islands along the south coast of WA, including those islands with historic records of breeding little penguins (e.g., Breaksea Island, Coffin, Mackenzie Island, Observatory Island, Ram Island). On Bellenger Island near Israelite Bay, two recently deceased little penguins were found next to a white bellied sea eagle nest during a visit in 1985 (Smith and Johnstone, 1987). On St Alouarn Island off Augusta, a king skink was observed in a little penguin burrow with a half-eaten egg in 1976, and Peregrine falcons (*Falco peregrinus*) were noted as potential predators as well (Lane, 1978). The current threat of such naturally occurring species to little penguins along the south coast of WA is unknown.

8.3.1.5 Predators (Marine)

The level of predation on little penguins by marine species is unknown given the difficulty of directly observing predatory behaviour or obtaining stomach and faecal samples from predators. There has been some instances of deceased little penguins in the Perth metropolitan coastal region with bite marks more consistent with a pinniped than a shark (Melissa Evans pers. comm.). Australian sea lions haul out on islands in close proximity to little penguins colonies along the WA coast, such as on Carnac Island adjacent to Garden Island and Seal Island adjacent to Penguin Island (Osterrieder et al., 2015b). On Kangaroo Island in South Australia, feather and bone remains from at least one little penguin was found in the regurgitate of one individual Australian sea lion (McIntosh et al., 2006), and was not an uncommon prey item for the long-nosed fur seals (*Arctocephalus forsteri*) (Page et al., 2005). Given these occurrences of predation on little penguins have been observed elsewhere in Australia, it is reasonable to assume pinnipeds also predate on little penguins from WA colonies from time to time. However, the frequency may not be high given ten faecal samples of sea lions collected from Shoalwater Bay found no evidence of little penguin remains, or any other seabird remains (Berry et al., 2017).

Seabirds are a commonly consumed prey for tiger sharks (*Galeocerdo cuvier*) off the north-west coast of Australia (e.g., Simpfendorfer et al., 2001), and given tiger sharks and other sharks occur in coastal waters off the Perth metropolitan region, it is, again, reasonable to assume they may opportunistically prey on little penguins.

8.3.1.6 Disease, parasites and infections

Toxoplasma gondii is a protozoan parasite that causes Toxoplasmosis, a disease that affects the liver and spleen, and caused the death of 12 little penguins from Penguin Island during 2011-2012 (Campbell, 2015; Campbell et al., 2022). It has been suggested that prey fish species may have had high parasite loads of *Toxoplasma*, which could have originated from the prevalence of cat faeces in waterways; cats being the definitive host for the parasite.

Four penguins from the cluster of 12 penguins that died of toxoplasmosis were also infected with another parasite, *Haemoproteus* spp., which were the first known recordings for little penguins in WA (Cannell et al., 2013). It was postulated that biting midges on Penguin Island were the most likely vector of the blood-borne *Haemoproteus* spp., and that the strong La Niña period across 2010/2011 caused heavy rainfall during austral spring and summer and a record number of hot days, subsequently leading to ideal conditions for midges or other vectors of the parasite.

Disease from blood-borne parasites does not appear to be prevalent for little penguins in WA. An analysis of 30 blood smear samples from Penguin Island collected in 1992 showed no evidence of blood-borne parasites (Jones and Shellam, 1999), and post mortems of 134 little penguins from the Perth metropolitan coastal region between 2004-2012 recorded low incidences (~7%). However, with changing climatic conditions, it is uncertain how disease prevalence amongst little penguins may change, and this is discussed further in section 8.3.3.4.

Parasites can infest the gastrointestinal tract of little penguins and in some cases, cause mortality (Cannell et al., 2016). Between 2003-2012, a high parasite load was deemed to be the cause of mortality for 5% penguins (including three juveniles) found in the Perth metropolitan coastal area, the most common parasite being nematodes (*Contracaecum* spp).

Form the same Cannell et al. (2016) investigation on causes of little penguin mortality, fungal hyphae caused infections and subsequent mortality in four individuals, including one juvenile, which affected the lungs and air sacs. Infections from bacteria were identified for a further two adults.

8.3.1.7 Storm damage (beaches)

Storms can cause erosion of sand banks and dune slopes and impact the ability of little penguins to reach their nests (Cannell, 2001). Monitoring of chicks during 1989 on Penguin Island revealed a decline in growth rate after parents were prevented from accessing nests to feed chicks following a significant storm event (Wienecke, 1995).

Erosion caused by storm driven waves, particularly during winter, would impact the western side of Garden Island, while the eastern side facing Cockburn Sound is more protected (DoT, 2009). Given the majority of little penguins are nesting on the south-eastern side of Garden Island (Cannell, 2015), storm damage to nests and entry points could be considered low. While nesting occurs predominantly on the eastern side of Penguin Island, some nesting does occur on the western side (see Cannell, 2020), which would likely be exposed to strong waves and erosion during storm events.

8.3.2 Anthropogenic

8.3.2.1 Bycatch in commercial fisheries

Trawl, haul, seine and pot fisheries occur in coastal waters where little penguins may be foraging for food. However, little penguin bycatch was estimated to be low (Cannell, 2004), and a review of the 'Status reports of the fisheries and aquatic resources of Western Australia' for the past 10 years found no reported bycatch of little penguins in any of the operating fisheries off Perth or the south coast of WA (e.g., Newman et al., 2021).

8.3.2.2 Commercial and recreational fishing impacts on prey species

Stocks of whitebait and southern garfish have been negatively impacted by overfishing and environmental variables off the Perth metropolitan coast, which limits the resources available to little penguins.

Whitebait are in the top five of the highest caught finfish in the West Coast Estuarine and Nearshore Scalefish Resource, with between 10.9-40.2 tonnes being caught between 2016-2020 (Duffy et al., 2021). Since the 1990s, the catch of whitebait has had cyclical peaks but generally shows a declining trend, and the low catch in 2020 of 10.1 tonnes was from one fishery, the South West Beach Seine Fishery, and mostly from the Bunbury area. The whitebait stock is currently considered 'unsustainable-recovering' by the Department of Primary Industries and Regional Development (DPIRD), following a risk rating of 'severe' in a 2018 stock assessment. When whitebait abundance in WA is low, DPIRD recognises that commercial fishing of whitebait poses a 'moderate risk' to little penguins. Recent management interventions introduced in 2019 aim to reduce the commercial catch of whitebait by 50% of the average historical catch (Duffy et al., 2021).

Southern garfish is commercially fished in the West Coast and South Coast Bioregions. The stock is currently considered 'unsustainable-recovering' by DPIRD and commercial and recreational fishing of this species has been closed for the Perth metropolitan area since 2017 (between Lancelin and Lake Preston/Myalup) (Duffy et al., 2021). The species is dependent on seagrass, has a small breeding stock, low dispersal rate and low fecundity, all of which contribute to the species being vulnerable to overfishing (Smith et al., 2017). The decline appears to be reflected in the diet of little penguins from Penguin Island, with the composition of garfish in faecal samples decreasing over time from an estimated 17% in 1986 to 0% in 2010-2012 (Klomp and Wooller, 1988; Cannell, 2011; Cannell, 2012b; Cannell, 2012a).

Australian sardines are a dominant catch species, as well as an indicator species, for the West Coast Small Pelagic Scalefish Resource (Norriss and Blazeski, 2021b). Following two herpesvirus outbreaks that caused mass mortalities of sardines in the 90s, the reported catch has remained relatively low given a switch in effort to target scaly mackerel. The West Coast Bioregion Stock was considered to have recovered by mid-2000s (Gaughan et al., 2008), and is currently considered by DPIRD as 'sustainable-adequate' with a 'low risk' from commercial fishing to the ecosystem (Norriss and Blazeski, 2021b). Australian sardines are also targeted by the South Coast Small Pelagic Scalefish Resource. Catches have remained low since the herpesvirus outbreaks, but the species is considered to be 'sustainable-adequate' along the south coast, and fishing of this species is considered to be a 'low risk' to the ecosystem (Blazeski et al., 2021; Norriss and Blazeski, 2021a).

Australian anchovies are commercially caught under the West Coast and South Coast Small Pelagic Scalefish Resources, and blue sprat infrequently, however more detailed information on their stocks or sustainability are not provided in the *Status reports of the fisheries and aquatic resources of Western Australia.*

The size range of fishes that are consumed by little penguins and taken by recreational fishers are often different (i.e., little penguins consuming a smaller size range) (Cannell, 2001; Smallwood et al., 2018). However, it should be recognised that overfishing of mature/breeding age fishes can have negative flow on effects for the population (Cannell, 2004), such as observed for southern garfish, which has been closed to all fishing in the Perth metropolitan area since 2017 to allow for the stock to recover (Duffy et al., 2021). Despite this, small catches of southern garfish by shore fishers has occurred off Perth since the closure, but are reported as released (e.g., Tate and Smallwood, 2021). Not all southern garfish catch was reported as released from boat fishers in the West Coast Bioregion during a 2017/2018 survey (Ryan et al., 2019). Southern garfish are mainly caught by recreational boat fishers in autumn and winter months, a time when little penguins are foraging to feed growing chicks. For other small pelagic fishes, such as sardines and anchovies, the catches by recreational fishers are reported as low (e.g., Ryan et al., 2019; Norriss and Blazeski, 2021b).

8.3.2.3 Entanglement

Entanglement in rubbish such as fishing line has been recorded on occasion for little penguins (Cannell, 2001; Clitheroe pers. comm.). However, it is unknown to what extent entanglement is a threat given many penguins would die at sea.

8.3.2.4 Coastal development impacts on prey species

Coastal development can cause a number of impacts on coastal fishes, including but not limited to irritation of gills from suspended dredged sediments, possible sinking of eggs by adhering sediments, consumption of dredge sediments by larvae, underwater noise from construction or operational processes, direct removal of habitat, poor water quality, discharges into water bodies and toxic contaminants that make their way through the food chain and accumulate in tissues. Limited knowledge exists on these specific impacts on baitfishes consumed by little penguins of the Shoalwater islands group or along the south coast of WA.

Cockburn Sound is the most intensively used marine embayment in WA, and further coastal developments in the sound are proposed, such as a new port and desalination plant on the eastern margin of the Sound, just north of James Point (Water Corportation, 2019; Westport, 2020). Cockburn Sound provides sheltered waters for spawning fishes, such as whitebait, and provides ideal habitat (seagrass) for others such as southern garfish (Gaughan, 1996b; Smith et al., 2017). Significant declines in seagrass habitat occurred between the 1960-80s during a time when wastewater and industrial outflow from coastal developments were released directly into the Sound. Seagrass declines continued into the early 2000s, but considerable improvements made by industry and government have helped to greatly improve the water quality and reduce the loss of seagrass (BMT, 2018). A Marine Science Program in Cockburn Sound is currently underway by the Western Australian Marine Science Institution (https://wamsi.org.au/research/programs/wamsi-westport-marine-science-program/), which will investigate the impacts of coastal developments and cumulative pressures on the marine environment, including the fish species that inhabit the area and are consumed by little penguins.

A significant whitebait nursery used to occur at Becher Point, Shoalwater, and the whitebait that the penguins consumed originated from this nursery site (Lenanton et al., 2003; Cannell, 2011; Cannell, 2012b). A boat ramp was constructed at Becher Point in 2010, however was not definitively found to be the cause of a decline in whitebait abundance or other fish fauna, such as blue sprat (Valesini and Tweedley, 2015). Whitebait abundance was found to be decreasing for at least four years prior to the boat ramp construction, and the declining trend in abundance was also noted for Pinnaroo Point north of Perth, which lead to the suggestion that environmental factors are the likely primary cause.

8.3.2.5 Vessel strike

Little penguins forage and rest in coastal areas, typically within 10 km of the coastline (Cannell unpublished data in Cannell et al., 2020), that overlap with recreational water-based activities, such as recreational boat use. Little penguins from Penguin Island and Garden Island use the coastal waters around Rockingham, where the human population will continue to increase and recreational boat ownership is high (DPI, 2009; CoR, 2021).

Little penguins can forage in shallow waters and need to surface to breath, making them susceptible to interactions with vessels (Cannell et al., 2020). When diving and foraging in shallow waters (< 5 m), depth loggers attached to four penguins from Penguin Island in 2001 revealed they spent the majority of their total sea time at the surface (approximately 70%) and performed dives that lasted 30-40 seconds each (Ropert-Coudert et al., 2003; Kato et al., 2006; Cannell et al., 2020). Evidence of trauma was identified for ~26% of deceased little penguins found around the Perth metropolitan coastal area between 2003-2012 (n = 168 in total), two of which were juveniles and the rest adults (Cannell et al., 2016). Almost 70% of trauma cases included lacerations to the body, and in some cases, fractures, loss of limbs and partial beheadings. Trauma was the most prevalent cause of mortality in the little penguins examined, and many of the injuries were consistent with propeller strikes from motorised vessels. Given not all deceased little penguins are found, the true extent of the impact of vessel strikes is unknown. The potential for interactions with vessels in the local bays surrounding Penguin Island and Garden Island would seasonally differ, given penguins typically forage further afield during summer.

In addition to vessel strike, disturbance to resting penguins by approaching vessels or vessel noise may also impact upon their energy and oxygen reserves and, in turn, affect foraging success and chick survival (Cannell et al., 2020).

There are no known investigations into the prevalence of vessel strike on little penguins along the south coast of Australia, however as human populations increase, so would motorised recreational boat use. Off Albany, recreational boating facilities are improving and the Albany Waterfront Marina was built in 2011 (City of Albany, 2016). Based on a 2% pa growth rate of the population in Albany, the number of boat launches per day is estimated to increase from 290 (2016) to 400 per day by 2036 in urban areas. The Esperance Bay Marina is also proposed for redevelopment given it is currently at capacity, along with the nearby Bandy Creek Boat Harbour (EBYC, 2022).

8.3.2.6 Human disturbance

Human disturbance to little penguins could be a physical disturbance to the penguin or habitat, such as direct trampling of nests or vegetation, infrastructure that clears habitat, underwater noise impacting upon hearing, or a non-physical disturbance, such as blockages to nests from crowds of people, or continual noise and movement by people around nests.

Penguin Island is open to the public every day between mid-October (mid-September prior to August 2022) and early June and attracts up to 130,000 visitors a year (DBCA, unpublished data). Moulting of little penguins primarily occurs during December-January on Penguin Island. During this time, they are restricted to land for up to three weeks, and this time period coincides with the peak visitation rates of visitors to the island (Cannell, 2001). In an attempt to manage the disturbance caused by visitors, pathways and boardwalks were installed, recreational activities are restricted at some locations and DBCA rangers and volunteers are present to educate the public and reduce disturbance (Cannell, 2001; Hughes, 2012). Prior to the management interventions above, in 1986-88, the number of eggs hatching in nest boxes in disturbed areas compared to less disturbed areas was 44% and ~80%, respectively (Klomp et al., 1991). The percentage of successful fledglings was also higher for less disturbed sites. No recent studies on current disturbance impacts has been undertaken, however little penguins trying to reduce heat stress by retreating to the water have only been observed doing so when people are not immediately present (Clitheroe pers. comm. in Clitheroe, 2021).

Little penguins from Garden Island forage for baitfishes over the Kwinana Shelf and along the eastern margin of Cockburn Sound where coastal developments, such as a new port and desalination plant, are proposed (Water Corportation, 2019; Westport, 2020). Foraging is more wide-ranging throughout

Cockburn Sound during incubation and more restricted to the southern half of the Sound during chick guarding, however both foraging areas overlap with proposed development locations (Cannell, 2009; BMT, 2018). Future disturbance to little penguins from these developments could include construction and operational underwater noises, and increased vessel traffic.

Naval operations on Garden Island can potentially disturb little penguins, particularly given nests occur in rock walls along Careening Bay and in between wharves (Cannell, 2015). Foraging also occurs in Sulphur Bay where there is marine based naval activity. However, given little penguins arrival and departure times are known for Garden Island (Cannell, 2015), activities can be adapted to reduce disturbance.

8.3.2.7 Pollutants

Heavy metals (mercury, cadmium, lead, selenium) and chemical contaminants (TBT, DBT) have been found in little penguins from the Shoalwater islands group, including in fledglings (Cannell et al., 2016). However, it is currently unknown to what extent contaminants contribute to mortality.

Moulted feathers from little penguins (n=16) held at the Penguin Island Discovery Centre during 2011-2012 had concentrations of cadmium and selenium comparable to the fish species they were fed (<0.25 mg/kg and ~1.25 mg/kg, respectively), suggesting little bioaccumulation of these metals (Dunlop, 2017). However, concentrations of lead were almost eight times higher and mercury 78 times higher in feathers than fish samples, indicating the bioaccumulation and biomagnification potential, respectively. It should be noted that metals accumulate differently in different body tissues. For example, cadmium is known to accumulate in organs such as kidneys, while lead can be most concentrated in bone tissues.

Cadmium and lead concentrations were overall low in moult feathers collected from adult penguins on Penguin, Garden, Mistaken and Woody Islands between 2009-2012, with no significant differences found between colonies (Dunlop, 2017). Mercury concentrations were lowest for Woody Island and highest for Garden Island penguins (where penguins are foraging in the most intensively used marine embayment in WA). Selenium concentrations were highest at Mistaken Island (5.9 mg/kg 1.41) and generally similar for Penguin, Garden and Woody Islands (2.73-3.41 mg/kg).

There has been a history of contamination in Cockburn Sound given the intense use of the embayment by industry (DEP, 1996; CSMC, 2006). TBT has also been found in sediments in Warnbro Sound and Comet Bay.

8.3.2.8 Oil spills

Oil spills can have a significant impact on little penguins given they use surface waters and shorelines. No known documented oil spill impacts on little penguins from the Shoalwater islands group or south coast WA colonies were identified for this review.

A recent risk assessment of oil spills was conducted for zones along the WA coast. The overall risk rating (a combination of shoreline exposure and protection priorities) for the Fremantle and Cockburn Sound area was 'very high' and decreased in risk further south from Fremantle Port (e.g., 'moderate' risk for Binningup-Cape Bouvard) (Navigatus Consulting, 2018c). Further vessel and port operations in Cockburn Sound could be expected to increase the risk of oil spills and will pose more of a risk for little penguins from Garden Island than from Penguin Island (noting however that some penguins from Penguin Island forage in Cockburn Sound).

The coastline around the south-west corner to Albany has a combination of 'high' risk to 'very low' risk locations for oil spills, whereas the coastline from Albany to the WA/SA border is mostly 'very low' risk (Navigatus Consulting, 2018b), except for the allocation of a 'high risk' at Esperance (Navigatus Consulting, 2018a).

Naval activities on Garden Island were not included in the oil spill assessment as a risk due to vessels having limited movements, carrying limited fuel/oil and being structurally sound (Navigatus Consulting, 2018c). Cannell (2004) has previously found that whilst the potential occurrence of a large oil spill is low but significant, the Department of Defence has well defined procedures in place for clean-up operations.

Accidental fuels spills from recreational and commercial vessel do occur but are usually unreported publicly.

8.3.2.9 Introduced species and pests

The threat of introduced predators, such as foxes, cats and dogs, to little penguins on Penguin Island is currently low given the limited connections with the mainland (Cannell, 2004). Any future changes to shoreline movement and sediment cell patterns may increase or decrease the exposure of the sandbar and access to the island. Rats have been observed on Penguin Island and have also been observed to predate on healthy chicks and adults (pers. comms. in Cannell and Friedman 2014, unpublished DCBA draft report).

In June 1996, one fox made it across the causeway to Garden Island and caused the death of 25 tammar wallabies in 11 days (Short et al., 2002). Feral cats have also previously occurred on Garden Island (Brooker et al., 1992).

Along the south coast of WA, Wienecke (1993) noted that some specimens included in a morphometric study were obtained from an island near Albany after a cat was released onto the island and killed 19 individuals.

8.3.2.10 Plastic pollution/ingestion

While there has been limited observations of plastic ingestion by little penguins, ingestion of plastics by prey species should also be considered. Fibres and other anthropogenic particles were found in the stomachs of Australian sardines (n=27) caught in the Frenchman Bay fishing zone near Albany in 2019 (Crutchett et al., 2020). Ingestion of plastics was considered low in comparison to those reported for sardine populations from other locations around the world.

8.3.3 Climate change

8.3.3.1 Ambient temperature increases

For climate change projections in Australia, the locations of Penguin Island, Garden Island, and the south coast along to Israelite Bay, fall within the Southern and South-Western Flatlands West sub-cluster where average air temperatures are predicted to increase in all seasons with very high confidence (CSIRO and Bureau of Meteorology, 2022). Projections for 2030 include an averaged increase of 0.5-1.1°C (for all emission scenarios) above 1986-2005 temperatures, and by 2090, an increase of 2.6-4°C for a high emission scenario. Further, extreme temperatures are also set to increase, with projections showing very high confidence for the frequency of hot days and the duration of warm spells.

On Penguin Island, the temperature and humidity was measured in 51 natural and 46 artificial little penguin nests across 2013-2017 (Clitheroe, 2021). These measurements informed models that simulated a 2°C increase in the ambient air temperature in order to investigate the potential impact on little penguins. Compared to current day conditions, the number of days where nest temperatures exceeded thermally stressful conditions (≥ 30°C) were predicted to increase by 37% and 56% for natural and artificial nests, respectively. This increase was 41% and 49%, respectively, for the number of days exceeding hyperthermic conditions inside the nest (≥ 35°C).

Increasing ambient temperatures would impact stages of the little penguin cycle differently. For example, measurements taken at 13 artificial boxes across 2007-2008 on Penguin Island were used to show that an increase in 4°C in ambient temperature would be needed before thermally stressed conditions would be observed for breeding adults, given many of the breeding stages are occuring during cooler months (Horne, 2010). Whereas moulting adults and chicks would be more susceptible to thermal stress from increasing ambient temperatures given these stages coincide with warming summer conditions.

While there is some evidence to show temperatures inside a limited number of nests in rock walls and nest boxes on Garden Island were cooler than ambient temperatures (Cannell, unpublished data), no future projections have been made for nest microclimates for Garden Island, or along the south coast of WA. However, the ambient temperature is still projected to increase for these locations.

8.3.3.2 Sea level rise

Sea level has risen at a rate of 1.4 mm/year across Australia's coastlines between 1966-2009 (CSIRO and Bureau of Meteorology, 2022). For Penguin Island, Garden Island, and the south coast of WA, sea level is expected to rise between 0.07 to 0.18 m above the 1986–2005 level by 2030, with very high confidence. Sea level rise can threaten little penguin burrowing and nesting sites through inundation or erosion of pathways to nests.

8.3.3.3 Oceanographic current shifts

The Leeuwin Current influences the distribution and abundance of little penguin prey species (e.g., Lenanton et al., 1991; Caputi et al., 1996). In turn, climate change and natural climatic variability influence the strength of the Leeuwin Current (Feng et al., 2009). The Leeuwin Current has had a slow weakening trend since the mid-1970s due to weakening winds reducing the pressure gradients in the tropical Pacific Ocean and shallowing the thermocline. By 2030, model projections do not show a significant change in the volume of water transported by the Leeuwin Current but do predict more weakening of the current by 2100. This is due to a predicted changes in the west – east gradient of the thermocline and sea level in the tropical Pacific Ocean (Holbrook et al., 2009). These changes, however, will be coupled with increasing SST. Confidence around model projections for the Leeuwin Current are not high, and other large scale influencing climatic drivers, such as the Indian Ocean Dipole and Southern Annular Mode, need further investigation.

Changes to the strength of the Leeuwin Current will influence the alongshore connectivity of fishes (Feng et al., 2010), the advection of eggs and larvae (e.g., Fletcher et al., 1994; Caputi et al., 1996), and distribution depending on the volume and persistence of warmer waters along the WA coast. These changes will have flow on effects to the breeding success of little penguins (Cannell et al., 2012). La Niña years, which are associated with a stronger Leeuwin Current, lower southerly winds, weaker Capes Current and higher sea surface temperatures along the coast (e.g., Feng et al., 2009, Feng et al., 2013), have had lasting impacts on little penguins, whereby reproductive output has been reduced by 20% in years following a La Niña event (Cannell et al. 2012).

8.3.3.4 Vector-borne disease

With a changing climate comes changes to air temperatures, precipitation, humidity, winds and rainfall, all of which can influence both the cycles of vector-borne diseases and the vector species (Gage et al., 2008; Zhang et al., 2008). Cannell et al. (2013) describes the first cases of *Haemoproteus* spp. infection in little penguins from Penguin Island and suggests the incidence of this vector borne disease was facilitated by an increase in biting midges (or other vectors) due to a strong La Niña event causing high ambient temperatures and above average rainfall in austral spring and summer. The increase or decrease of vector-borne diseases under climate change for the Perth metropolitan and south coast WA regions is unknown, as is the expected impact on little penguins from these regions.

8.3.3.5 SST increases and marine heatwaves impacting prey species

SST has been increasing at a greater rate along the lower west coast of WA, which is one of three 'hot spots' in the Indian Ocean with faster rising SST than the Indian Ocean average (Feng et al., 2009). The surface waters off Rottnest Island, close to the Shoalwater islands group of little penguins, has risen at least 0.6°C since the 1950s. Rising temperatures off the west coast of WA have largely been recorded during the austral autumn and winter months (Caputi et al., 2009).

SST is a strong driver of baitfish occurrence and abundance along the south west coast of WA (e.g., Caputi et al., 1996; Lenanton et al., 2009). A decline in whitebait and other species was noted at Becher Point (Lenanton et al., 2003; Valesini and Tweedley, 2015), within the Shoalwater Islands Marine Park, as well as off Pinnaroo Point near Hillarys, based on data spanning back to 1996 (Valesini and Tweedley, 2015). These declines in abundance were linked to the strength of the Leeuwin Current and higher SST. Australian sardines are also at risk of a southward contraction under climate change and rising SST (Norriss and Blazeski, 2021b; Norriss and Blazeski, 2021a).

High SST in April and May in the inshore and offshore waters have been linked to the breeding performance of the little penguins on Penguin Island (Cannell et al., 2012). These influences of SST on the timing of breeding and breeding success have been linked to the influence of SST on prey species in the coastal waters. Some evidence suggests that elevated SST has influenced the breeding success of little penguins from Penguin Island more so than penguins from Garden Island (Cannell et al., 2014).

In 2011, temperature anomalies of 2-4°C above average persisted for months along the WA coastline. For Cockburn Sound (and Warnbro Sound), these high temperatures persisted for 8-12 weeks (Jan-Apr) (Pearce et al., 2011; Rose et al., 2012). Numerous marine heatwaves of different intensities and durations have occurred along the WA coast over time, such as in 1989, 1999 and 2015 (Hobday et al. 2018; Kajtar et al., 2021). The number of marine heatwave days has been shown to increase following the strongest La Niña events on record (e.g., 1988/1989, 1998/1999, 2007/2008, 2010/2011) (Kajtar et al., 2021). Marine heatwaves are projected to become more frequent, intense, and persistent in Australia under climate change (Commonwealth of Australia, 2020).

Following the marine heatwave of 2011, the spawning and migration patterns of many fish species were impacted for subsequent years (Caputi et al., 2014). Lower catches of whitebait and southern garfish occurred across 2012-2014 and was likely a result of the marine heatwave causing delayed or failed spawning (Fletcher et al., 2017). A significant drop in abundance of whitebait and other fishes was also noted following the marine heatwave across the summer of 2010/2011 at Becher Point (Valesini and Tweedley, 2015). Changes in the diet of little penguins from Penguin Island were noted following the marine heatwave. Scaly mackerel was considered a rare occurrence in the diet, however, in 2011 and 2012, this species comprised the largest proportion (40% and 47%, respectively) (Cannell, 2012a; Cannell, 2012b). Conversely, whitebait was not as prevalent in the diet of little penguins following the marine heatwave.

For the colony on Penguin Island, elevated SST prior to a breeding season has been linked to reduced courtship, delayed egg laying, and a higher occurrence of egg abandonment (Cannell et al., 2012). Evidence of this occurred following the marine heatwave in 2011, where elevated temperatures persisted above average for several years, and overall chick production was low (Cannell, 2017, 2018).

8.3.3.6 Rainfall impacts on habitat

Rainfall is projected to decline, with high confidence, across the Perth metropolitan region and south coast of WA during winter and spring (Andrys et al., 2017; CSIRO and Bureau of Meteorology, 2022). Reduced rainfall would be expected to impact the native vegetation growing on island colonies, and the microclimate of nests which, in turn, may reduce ideal nesting habitat for little penguins, as suggested for Penguin Island (Clitheroe, 2021).

8.3.3.7 Rainfall impacts on prey

The impacts of reduced rainfall on fishes has been studied for estuarine ecosystems more so than coastal marine waters. For example, low rainfall is believed to be partly responsible for ongoing low stock abundance of Perth herring in the estuaries of the West Coast Bioregion (Duffy et al., 2021).

Reduced rainfall can mean reduced run-off from land or reduced groundwater inputs into the marine environment. In Cockburn Sound, nitrogen loads enter the system primarily via groundwater discharge due to reduced rainfall and runoff (Greenwood et al., 2016; BMT, 2018). Reduced flows and nutrient outputs from the Swan River are also likely under a drying climate (BMT, 2018). A reduction in nutrients in the water column can lead to a reduction of plankton growth in Cockburn Sound (BMT, 2018), which is the base of the food chain for many of the fish species consumed by little penguins (Dunlop, 2017). Conversely, unseasonal rainfall, high nutrient loads and high SST can stimulate phytoplankton blooms in Cockburn Sound (BMT, 2018), which may result in fish kills. Phytoplankton blooms may be more of a risk to Cockburn Sound given it is an embayment with less water circulation compared to other areas of the coastline where little penguins feed on coastal fishes.

The direct influence of reduced rainfall on prey species may be difficult to separate out from other climate change or environmental factors.

9 Conceptual population model highlighting knowledge gaps specific to Penguin Island

The level of knowledge was assessed for each life stage, survivorship/success pathway and pressure within the context of informing adequate management decisions. Table 3 provides the four knowledge categories used when assessing the pressures impacting life stages of little penguins. Available knowledge refers to reports, books or journal articles. Levels of knowledge do not take into account data that has been collected but not analysed or written up.

Table 3. The levels of knowledge applied to pressures impacting life stages of little penguins.

Level of knowledge	Definition
Full knowledge ● ● ● (green, yellow, red)	Enough available knowledge about the pressure to inform management decisions for this colony. Information has been peer reviewed.
Partial Knowledge ● (light grey)	Some available knowledge has been collected relating directly to this colony, but with some gaps. May or may not be peer reviewed.
Assumed Knowledge ● (dark grey)	Assumed based on general biological and ecological knowledge, or examples elsewhere, but no direct evidence relating to the colony in question.
Knowledge Gap ● (black)	No information collected or knowledge available.

Following the review of knowledge in section 8, 18 complete knowledge gaps and four knowledge gaps to address assumed knowledge could be identified from the conceptual population model for Penguin Island (Fig. 5) (Table 4).

For the juvenile/sub-adult pathway, gaps in knowledge were apparent for the life stages of Year 1 and Year 2-3 (Fig. 5). For the adult pathway, there was little to no available knowledge on the 3+ years (non-breeding) life stage. For all other juvenile/sub-adult and adult life stages, the biology and ecology was considered to be relatively understood for the purposes of this project scope. It is important to acknowledge that there would still be specific gaps that would help improve our understanding of these relatively understood life stages.

The arrows between life stages in the conceptual population model are used to give an indication of survivorship or success rate (Fig. 5). Limited or no available knowledge exists to estimate survivorship or success between Fledge and Year 1, Year 1 and Moult, Year 2-3 and Moult, Courtship and 3+ years (non-breeding), 3+ years (non-breeding) and Moult, and Post-guard and Moult.

No high pressures were considered to have enough available knowledge to inform management decisions for the colony on Penguin Island (Fig. 5). Knowledge on human disturbances on life stages was generally lacking and considered a knowledge gap for all life stages. Given the unknowns of where fledglings, Year 1 and Year 2-3 go to forage and what they feed on, it is also unknown to what extent climate change driven SST/marine heatwaves and rainfall would impact on dietary resources for these life stages. Similarly, it is unknown to what extent vessel strikes are impacting on Fledglings and Year

1 penguins. Eight out of 12 life stages had at least one high pressure that was considered to have assumed knowledge.

The following assumption and caveats should be considered for the knowledge gaps arising from the conceptual population model:

- Only high pressures are included in the conceptual population model. High pressures may change to medium or low across seasons or years.
- Indirect impacts on nest reliant juvenile/sub-adult life stages are not included in the conceptual population model.
- If there was evidence in the literature of a pressure on ‘adults’ or ‘juveniles/sub-adults’ in general (e.g., specific life stage not mentioned), then this pressure was applied to all life stages of an adult or juvenile/sub-adult.
- If a pressure acted on nesting habitat, e.g., rainfall impact on habitat, then this pressure was applied to all life stages that involved a nest.
- Fledglings were considered to be leaving the nest, so pressures impacting nests were not applied to the fledge stage.
- Mentions of ‘prey’ refers to prey occuring in coastal waters, not offshore waters. The distribution of some life stages is unknown.
- Assessments of the levels of knowledge is based on the best available information at the time of assessment.

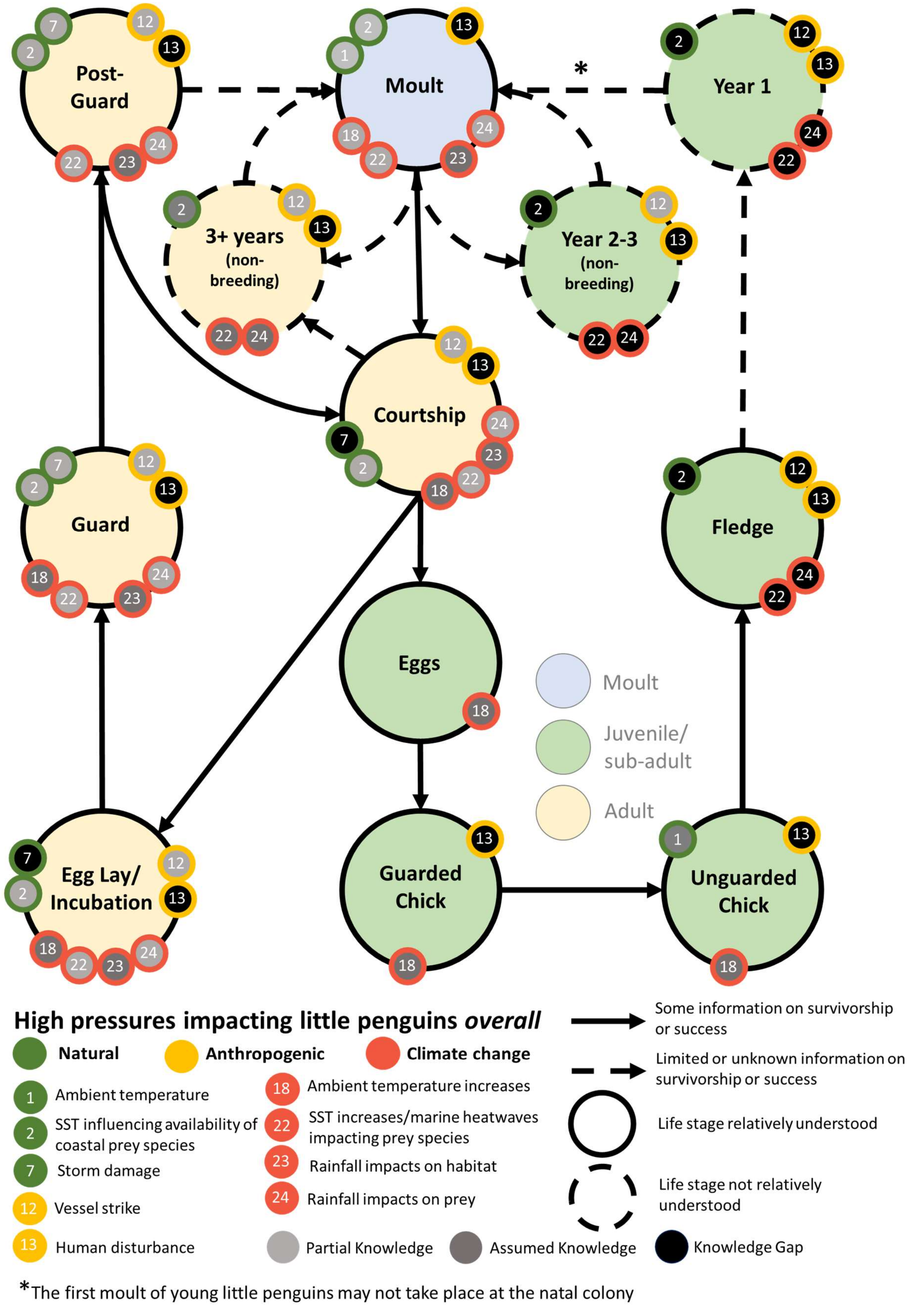

Figure 5. Conceptual population model for little penguins from Penguin Island showing where knowledge gaps exist for life stages, survival between life stages and pressures potentially impacting life stages. Indirect impacts on nest reliant juvenile/sub-adult life stages are not included.

Table 4. Knowledge gaps resulting from the conceptual population model for little penguins from Penguin Island. Knowledge gaps for low and medium pressures, and for indirect pressures on nest reliant juvenile/sub-adult life stages, are not included.

Life stage	Specific knowledge gap
Courtship	Has the rate of nest fidelity changed since previous estimates (e.g., 30 years ago) and is nest fidelity significantly linked to breeding success?
Eggs	Is the proportion of unhatched eggs changing? If so, why?
Year 1, Year 2-3	Where do fledglings and sub-adults (1-3 years) travel and forage, and what is their diet?
Year 1	Where do Year 1 little penguins undertake their first moult and what additional pressures may they face?
Year 2-3	Where do Year 2-3 little penguins undertake their moult?
3+ years (non-breeding)	What key factors are preventing or deterring a mature little penguin from engaging in courtship, and can these be remedied?
3+ years (non-breeding)	Where do mature non-breeders travel and forage between moults?
Fledge, Year 1	What percentage of fledglings survive to 1 year old?
3+ years (non-breeding), Courtship	What percentage of young, inexperienced breeders are engaging in courtship and what is the courtship failure rate for these penguins?
Year 1, Year 2-3, 3+ years (non-breeding), Post-guard	What are the survival rates of little penguins between the key life history stages of fledglings to 1, 2, 3 years, as well as non-breeding and post breeding adult little penguins.
Moult, Courtship, Egg lay/incubation, Guard, Post-guard, Year 1, Year 2-3, 3+ years (non-breeding)	What is the current age distribution of little penguins and, more particularly, breeding penguins?
Courtship, Egg lay/incubation	What proportion of the little penguin population is breeding?

High pressure	Life stage	Specific knowledge gap
Human disturbance	Moult, Courtship, Guarded chick, Unguarded chick, Fledge, Egg lay/Incubation, Guard, Post-guard, 3+ years	How much does human presence on the island disturb (physically and physiologically) little penguin breeding and moulting, and are there threshold levels of human presence that trigger disturbance to little penguins?
Human disturbance	Courtship, Fledge, Year 1, Year 2-3, Egg lay/Incubation, Guard, Post-guard, 3+ years	What types of underwater noise can cause significant disturbance to little penguins?
Storm Damage	Courtship, Egg lay/Incubation, Guard, Post-guard	How frequently do storm events cause damage or erosion to key entry/exit points to the extent that little penguins are prevented from accessing nests?
SST influencing coastal prey availability, SST increase/marine heatwaves impacting prey species, Rainfall impacts on prey	Fledge, Year 1, Year 2-3	How does SST and rainfall influence the prey species specifically targeted by fledglings and Year 1-3 penguins, and how is this expected to change under climate change?

SST influencing coastal prey availability, SST increase/marine heatwaves impacting prey species, Rainfall impacts on prey	Moult, Courtship, Egg lay/Incubation, Guard, Post-guard, 3+ years, Fledge, Year 1, Year 2-3	How would shifts in diet influence the supply of essential nutrients needed to maintain little penguin health?
Vessel strike	Fledge, Year 1	Is vessel strike a significant cause of mortality and injury rates in fledglings and Year 1 little penguins?
Vessel strike	Courtship, Egg lay/Incubation, Guard, Post-guard, 3+ years, Fledge, Year 1, Year 2-3	What locations are vessel strikes most common?
Vessel strike	Courtship, Egg lay/Incubation, Guard, Post-guard, 3+ years, Fledge, Year 1, Year 2-3	What types of vessels are responsible for vessel strikes on little penguins?
Predation (marine)	Courtship, Egg lay/Incubation, Guard, Post-guard, 3+ years, Fledge, Year 1, Year 2-3	Is the level of predation on little penguins by marine predators high? NB: This pressure has not been included on the conceptual population model given the level of pressure is unknown
High pressure	**Life stage**	**Specific knowledge gap (to address 'Assumed Knowledge')**
Ambient temperature increases, SST increase/marine heatwaves impacting prey species, Rainfall impacts on prey	Courtship, Eggs, Guarded chick, Unguarded chick, Egg lay/incubation, Guard, Post-guard	How will a changing climate influence when breeding occurs for little penguins, and the survival of eggs through to sub-adults? Are there areas on Penguin Island more prone to excess temperature that may alter breeding/moulting success and mortality?
Rainfall impacts on habitat	Moult, Courtship, Egg lay/Incubation, Guard, Post-guard	How much suitable natural nesting habitat is available and needed on Penguin Island, and is this a limiting resource for the population? What is the projected change of suitable nesting vegetation with changing rainfall patterns?
Ambient temperature increases	Guarded chick, Unguarded chick	What are the thermal stress limits of chicks?
Ambient temperature, SST increase/marine heatwaves impacting prey species, Rainfall impacts on prey,	3+ years	Where do 3+ year (non-breeding) adults forage, and how does SST and rainfall influence the prey species they target?

10 Recommendations for next steps

The assignment of pressures to the conceptual population model for little penguins from Penguin Island focused on high pressures only. While the knowledge review included information on all low, medium and high pressures identified in section 6, low and medium pressures were not considered further in relation to the conceptual population model. This means that the identified knowledge gaps represent the most important gaps to address for management, but also the minimum number of gaps that could be addressed. This is particularly important in the context of cumulative pressures, where many low pressures acting on little penguins at once may combine to have a significant impact on the health and survival of little penguins. The number of pressures overlapping is also dependant on the time of year as is the severity of a pressure. It is recommended that consideration be given to low and medium pressures where feasible, and that a combination of consistent management actions and adaptable management actions (depending on the time of year or occurrence of a new pressure) would be most effective for the little penguin from Penguin Island.

Twenty two knowledge gaps were identified from the conceptual population model for little penguins from Penguin Island based on available information. Penguin Island has a long history of research effort, largely due to the installation of ~125 artificial nest boxes on the island that allow for easier data collection and capture of little penguins. There is a wealth of data that has been collected from colonies of the Shoalwater islands group that remains unpublished. It is recommended that this unpublished data be used to address some of the knowledge gaps identified in section 9 where possible. This may allow managers and researchers to progress knowledge gaps more quickly, particularly given the urgency around better understanding the decline in little penguins from Penguin Island. A table of collected published and unpublished data from Penguin Island and other colonies is provided in Appendix 1.

Efforts were made throughout this review to focus the attention of management on the most pressing knowledge gaps for little penguins from Penguin Island e.g., high pressures and life stages with little to no published information. It is recognised that not all knowledge gaps can be addressed equally given the temporal and spatial scales of gaps or the difficulty in obtaining data. The prioritisation of knowledge gaps can help in this instance and often involves scoring gaps according to a set of criteria that is 'fit for purpose' for the organisation or institution attempting to address the knowledge gaps. Given the overall purpose of this review was to identify where management focus and actions should be directed in order to improve and sustain the little penguin population on Penguin Island, possible scoring criteria that could assist in the prioritisation process might include:

- management applicability
- feasibility; and
- urgency

This review focuses on Penguin Island given the declining population of little penguins. Many of the pressures and knowledge gaps identified for Penguin Island would apply to other little penguin colonies along the WA coast. However, the attention these other colonies have received is significantly less than Penguin Island and thus the number of knowledge gaps is expected to be greater. The conceptual population model presented in this report can be applied to other colonies and meta-populations and provides a basis to identify knowledge gaps for these colonies.

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Conceptual population model and knowledge review for Western Australian little penguin populations

Appendix 1

A collation of data collected on little penguins and their habitats in Western Australia, current to July 2022

Alicia Sutton

Carijoa Marine Consulting

October 2022

Prepared for the Department of Biodiversity, Conservation and Attractions, Western Australia

Appendix 1 - A collation of data collected on little penguins and their habitats in Western Australia, current to July 2022.

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
Adult body condition	Artificial nest boxes, Mark-recapture	Specific project	Penguin Island	1986-2019	Fortnightly, except for mark-recapture	Physical measurements	Murdoch University, Belinda Cannell	- 1986-1993 data - Wienecke et al 1995 - 1986-2018 data - Cannell et al 2019	
Adult metrics - sex	Only in artificial nest boxes	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe		
Adult metrics - weight	Only in artificial nest boxes	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe		
Adult metrics bill morphometrics	Only in artificial nest boxes	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe		
Arrival patterns		Specific project	Penguin Island	1986, 2007/8, 2010, 2011, 2017, 2019	Aug-Dec	Beach counts, Night vision monoculars	Murdoch University, Belinda Cannell, N. Klomp	- 1986 data - Klomp and Wooller 1991 - 2007 data - LeFurge 2007 - 2008 data - Parish 2009 and Cannell et al 2011	Paper in prep. Klomp collected data in 80s
Arrival patterns		Specific project	Penguin Island	2012?			UWA, A Bertram	- Bertram 2013	
Banding	n = 74 adults and 5 young	Specific project	Carnac Island	1979-1980		Banding	Murdoch University, R. D. Wooller and J. N. Dunlop	- Dunlop and Storr 1981	
Blood samples	Chicks @4 weeks or more. 61 chicks samples in total from artificial boxes only. 17 blood samples from adults from artificial boxes	Specific project	Penguin Island and Garden Island	April-Dec 2016-2018		25-gauge needle for blood, DNA extraction and PCR	Murdoch University, Belinda Cannell	- Povah 2021	

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
Breeding - # clutches	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe		
Breeding - # clutches	Artificial nest boxes, but in 2007-2009, natural nest sites were also monitored	Specific project	Penguin Island	1986-2019 (gaps in 2003 - 2004, 1992 or 93)	Fortnightly	Physical measurements	Murdoch University, Belinda Cannell	- 1986-2011 data - Cannell et al 2012	Paper in prep.
Breeding - # clutches	Mostly natural nests, some artificial. Different metric to PI given can't always tell if there are two eggs or chicks in the rock wall nests. The metric is the # nests that have at least one chick that fledges	Specific project	Garden Island	2001-current	Initially weekly for 2 years, then monthly, then since 2021 has been fortnightly	Physical measurements	UWA, Belinda Cannell and Dep of Defence	- Some information included in Cannell 2015	Reports not released at this stage. Paper in prep.
Breeding - # eggs	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Breeding - # eggs	Artificial nest boxes, but in 2007-2009, natural nest sites were also monitored	Specific project	Penguin Island	1986-2019 (gaps in 2003 - 2004, 1992 or 93)	Fortnightly	Physical measurements	Murdoch University, Belinda Cannell	- 1986-2011 data - Cannell et al 2012	Paper in prep.
Breeding - # eggs	Mostly natural nests, some artificial. Different metric to PI given can't always tell if there are two eggs or chicks in the rock wall nests. The metric is the # nests that have at least one chick that fledges	Specific project	Garden Island	2001-current	Initially weekly for 2 years, then monthly, then since 2021 has been fortnightly	Physical measurements	UWA, Belinda Cannell and Dep of Defence	- Some information included in Cannell 2015	Reports not released at this stage. Paper in prep.
Breeding - # fledglings	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe	- Clitheroe 2021	

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
Breeding - # fledglings	Artificial nest boxes, but in 2007-2009, natural nest sites were also monitored	Specific project	Penguin Island	1986-2019 (gaps in 2003 - 2004, 1992 or 93)	Fortnightly	Physical measurements	Murdoch University, Belinda Cannell	- 1986-2011 data - Cannell et al 2012	Paper in prep.
Breeding - # fledglings	Mostly natural nests, some artificial. Different metric to PI given can't always tell if there are two eggs or chicks in the rock wall nests. The metric is the # nests that have at least one chick that fledges	Specific project	Garden Island	2001-current	Initially weekly for 2 years, then monthly, then since 2021 has been fortnightly	Physical measurements	UWA, Belinda Cannell and Dep of Defence	- Some information included in Cannell 2015	Reports not released at this stage. Paper in prep.
Breeding - # hatchlings	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Breeding - # hatchlings	Artificial nest boxes, but in 2007-2009, natural nest sites were also monitored	Specific project	Penguin Island	1986-2019 (gaps in 2003 - 2004, 1992/93)	Fortnightly	Physical measurements	Murdoch University, Belinda Cannell	- 1986-2011 data - Cannell et al 2012	Paper in prep.
Breeding - # hatchlings	Mostly natural nests, some artificial. Different metric to PI given can't always tell if there are two eggs or chicks in the rock wall nests. The metric is the # nests that have at least one chick that fledges	Specific project	Garden Island	2001-current	Initially weekly for 2 years, then monthly, then since 2021 has been fortnightly	Physical measurements	UWA, Belinda Cannell and Dep of Defence	- Some information included in Cannell 2015	Reports not released at this stage. Paper in prep.
Breeding occupancy	Percentage of all nests with breeding activity was recorded, Artificial and natural nest	Specific project	Penguin Island	2013-2016		Physical measurements	Murdoch University, Erin Clitheroe	- Clitheroe 2021	

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
Causes of mortality		Specific project	Perth metro region	2001-ongoing		Gross post mortem, histopathology, electron microscopy, PCR, immunohistochemistry	Belinda Cannell	- Some 2003-2012 data - Cannell et al 2016 and Campbell et al 2022	Data since ~2013 not yet published; Murdoch no longer performing necropsies. Now done by DPIRD.
Chick foot length	46 individuals	Specific project	Penguin Island and Garden Island	April-Dec 2016-2018		Physical measurements	Murdoch University, Belinda Cannell	- Povah 2021	
Chick weights	46 individuals	Specific project	Penguin Island and Garden Island	April-Dec 2016-2018		Physical measurements	Murdoch University, Belinda Cannell	- Povah 2021	
Deceased penguins - beach walks	Volunteers walk the beach and keep an eye out for dead penguins.	Specific project	Cockburn Sound to Mandurah (only CS for 2022-23)	2007-09, 2022-2023	Weekly	Walking 'transects'	Murdoch Uni and UWA, Belinda Cannell		
Diet	Regurgitant and Faecal samples	Opportunistic/specific project	Penguin Island	1986-1989, 1995-7, 2004-current	Opportunistic	Field regurgitant and faecal samples	Klomp (80s), Wienecke (1989) Nicholson (year: 1994), Connard (year: 1995), Cannell (year: 1996/7-ongoing)	- 1986 data - Klomp and Wooller 1988 and Wienecke 1989 - 2008-2010 data - Murray et al 2011 - 1995 data - Connard 1995	Some historical data been analysed, report imminent, but will be due for publication next year. Also paper

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
								- 2012 data - Cannell, Murray and Bunce 2013- - 2011 data - Cannell 2011	in prep with 2011 and 2012 data
Diet	Faecal samples	Specific project	Garden Island	~2014 onwards		Field samples	UWA, Belinda Cannell		Not all samples have been analysed
Distribution	Distribution of little penguins on the island	Specific project	Mistaken Island	2019-2020		Transects	Student project (UWA), Belinda Cannell		New projects
Diving behaviour	Includes adult movements during chick guard phase	Specific project	Penguin Island	1995, 2001-02, 2016-19		Data loggers - GPS and 3D accelerometer tags	Connard (year: 1995), Cannell (year: 2001-02, 2015 - ongoing); Yan Ropert-Coudert (year: 2001-2002)	- 2001 data - Cannell et al 2020 - 2016 data - Cannell 2017 - 2017 data - Cannell 2018 - 2001 data - Ropert-Coudert et al 2003 - 2002 data - Ropert-Coudert et al 2006 - 1995 data - Connard 1995	Still analysing recent diving behaviour data. Future paper expected.
Diving behaviour	During incubation and chick rearing phases (2007-2009), during chick rearing phase (2013-2018), foraging	Specific project	Garden Island	2013-2018, 2021		Data loggers - GPS and 3D accelerometer tags	Belinda Cannell		Publication intended

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
	during incubation in 2021								
Effect of ravens on LP	Was not successful as solar panel cameras were not fit for purpose.	Specific project	Penguin Island			Cameras	Belinda Cannell		
Egg loss	n = 80 natural and 55 artificial nests	Specific project	Penguin Island	1986, 1988	Weekly	Egg counts	Murdoch University. C. Meathrel, N Klomp	- Meathrel and Klomp 1990	
Faecal samples	Adults and chicks samples from artificial nest boxes or direct interception. N = 99	Specific project	Penguin Island	2008-2010	Opportuni stic	Faecal collections, DNA extraction and sequencing	Murdoch University, Daithi Murray, Belinda Cannell	- Murray et al 2011	
Fledgling weights	Only in artificial nest boxes	Specific project	Penguin Island	2013-2016	Fortnightly	Physical measurements	Murdoch University, Erin Clitheroe		
Fledgling weights	Artificial nest boxes, but in 2007-2009, natural nest sites were also monitored	Specific project	Penguin Island	1986-2019 (gaps in 2003 - 2004, 1992 or 93)	Fortnightly	Physical measurements	Murdoch University, Belinda Cannell	- 1986-2011 data - Cannell et al 2012	Paper in prep.
Fledgling weights	Mostly natural nests, some artificial. Different metric to PI given can't always tell if there are two eggs or chicks in the rock wall nests. The metric is the # nests that have at least one chick that fledges	Specific project	Garden Island	2001-current	Initially weekly for 2 years, then monthly, then since 2021 has been fortnightly	Physical measurements	UWA, Belinda Cannell and Dep of Defence	- Some information included in Cannell 2015	Reports not released at this stage. Paper in prep.
Food chain/diet using stable isotopes	Feather samples from adults and chicks	Specific project	Penguin Island	2014-onwards	Opportuni stic	Stable isotope analysis	UWA, Belinda Cannell (Nic Dunlop for SIA in his 2017 paper)	- Some included in Dunlop 2017 and Dunlop et al 2013	Not all samples have been analysed
Food chain/diet using stable isotopes	Feather samples from adults and chicks	Specific project	Garden Island	2013-onwards	Opportuni stic	Stable isotope analysis	UWA, Belinda Cannell		Not all samples

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
									have been analysed
Foraging habitat		Specific project	Breaksea Island	TBA, depends on when penguin starts using nest boxes, and when funding for a student project becomes available		Satellite tags, data loggers	Student project (UWA), Belinda Cannell		New projects
Foraging habitat and home range	Planned for near future	Specific project	Cheyne Island	Upcoming		Satellite tags, data loggers	Student project (UWA), Belinda Cannell		New projects
Frequency and distribution of little penguins	Using cameras to find entry and exit points, frequency of occurrence	Specific project	Mistaken Island, Breaksea Island			Cameras	Belinda Cannell and student project (UWA)		
Genetics		Specific project	Penguin Island, Garden Island, Cheyne Island, Mutton Bird Island, Mistaken Island, Woody Island, Wickham Island	2002, 2004, 2007-2009, 2016-2018		blood samples	Bill Sherwin leading genetics work	- 1999-2009 data - Vardeh 2015 - some pre 2009 data - Peucker et al. 2009	Unpublished data but used in Vardeh 2015 thesis. Paper in prep. Belinda Cannell also gave some of the PI genetics

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
									data to Peucker et al 2009 to include in study
Genetics		Specific project	Garden Island	2007-2009, 2016-2018		blood samples	Murdoch Uni, UWA, Belinda Cannell		Student project
Ground cover habitat	Can use to get % cover or more detailed data of vegetation types	Specific project	Penguin Island	2014-2016	Yearly in March	Photo quadrats ~5-7m2	DBCA		
Growth rates of chicks	50 artificial nest boxes. Body mass and body measurements	Specific project	Penguin Island	1989-1991	Weekly	Physical measurements, digital scale and calico bags	Murdoch University, Barbara Wienecke	- Wienecke 2000	
Hormone levels	During breeding and moult phases. For wild and captive penguins	Specific project	Penguin Island	1999-2000		Blood samples, hormone assays?	UWA, Belinda Cannell	- Cannell 2000 and Cannell and Martin 2001	Still to be published
Metal and selenium concentrations in moulted feathers		Specific project	Penguin Island, Garden Island, Woody Island, Mistaken Island	2009-2012		Feather samples	Nic Dunlop	- Dunlop 2017 and Dunlop et al 2013	
Metal concentrations and stable isotope analysis of moulted chick feathers	n = 104 chick feather samples	Specific project	Penguin Island		Opportunistic	Stable isotope analysis	Nic Dunlop	- Dunlop 2017	
Metal concentrations in fish and captive	n = 16 feather samples from captive moulting	Specific project	Penguin Island	2011-2012	Monthly	Tissue and feather samples, metal concentration analysis	Nic Dunlop	- Dunlop 2017	

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
little penguin feathers	penguins at the discovery centre								
Modelling breeding success	Considering environmental variables	Specific project	Penguin Island and Garden Island	All annual data available			UWA, Belinda Cannell		Paper in prep.
Nest accessibility	During monitoring would note whether nests were inaccessible. Where possible, nests would be made accessible.	Opportu nistic	Penguin Island	2013-ongoing	Opportuni stic	Physical measurements			
Nest attributes - landscape position	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Once off	Physical measurements; Composite Surfaces - Multibeam LIDAR Laser	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Nest attributes - nest/box measurements	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Once off for artificial, annually for natural nests	Physical measurements	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Nest attributes - vegetation (fine scale)	Artificial and natural nest	Specific project	Penguin Island	2013-2016	Quarterly	Photographs	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Nest box humidity	Recorded from ~50 artificial nest boxes and ~47 natural nests	Specific project	Penguin Island	2013-2016	30 min recordings for 12 months each nest	75 temperature loggers were rotated through artificial and natural nests	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Nest box installations	With the aim to start a monitoring program if nest boxes are used by little penguins	Specific project	Breaksea Island	2020			Student project (UWA), Belinda Cannell		New projects
Nest box installations	Planned for near future	Specific project	Cheyne Island	Upcoming			Student project (UWA), Belinda Cannell		New projects

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
Nest box temperature	Recorded from ~50 artificial nest boxes and ~47 natural nests	Specific project	Penguin Island	2013-2016	30 min recordings for 12 months each nest	75 temperature loggers were rotated through artificial and natural nests	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Nest box temperatures		Specific project	Penguin Island	2002, 2006-07, 2009-2011, 2013-2017		Temperature loggers	Murdoch University/National Institute of Polar Research, Belinda Cannell, Yan Ropert-Coudert, Erin Clitheroe	- 2002 data - Ropert-Coudert et al. 2004 - 2013-2016 data - Clitheroe 2021	Some temperature data from PI was used by Horne 2010 from SA, for thesis on temperature thresholds
Nest box temperatures	Natural nests and nest boxes	Specific project	Garden Island	2013-onwards		Temperature loggers	UWA, Belinda Cannell		Unpublished
Nest occupancy	Percentage of all nests where nesting activity was recorded), Artificial and natural nest	Specific project	Penguin Island	2013-2016		Physical measurements	Murdoch University, Erin Clitheroe	- Clitheroe 2021	
Penguin ID		Specific project	Penguin Island	NA	NA	Automatic RFID readers	DBCA		Not yet implemented
Penguin rehabilitation data	Rehab data is available from Discovery Centre but not very clean data. Includes records of incidents, interactions with people (e.g., someone reporting a penguin), injuries and outcomes for the	Opportunistic	Penguin Island	2014-ongoing, some data recorded pre 2014 but less consistent	Opportunistic	Health/monitoring logs	DBCA		

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
	penguins. Could help inform a mortality and injury study.								
Physiology		Specific project	Penguin Island	2007			Lyndal Horne, Belinda Cannell	- Horne 2010	
Pollutants/contaminants	n = 20 birds, small number of organs	Specific project	Perth metro region	2004 - onwards	Opportunistic	Tissue samples	Student project (Murdoch), Belinda Cannell		Will be getting more samples analysed based on funding availability. Student project will be published
Population estimates	To estimate population abundance. Weights were also taken	Specific project	Penguin Island	2007-08, 2010-11, 2017, 2019	Aug-Dec	Beach counts, mark recapture, Night vision monoculars, Low fences to create a corral, physical measurements, portal microchip reader	Murdoch University, Belinda Cannell	- 2007-2011; 2017 data - Cannell 2018 and Tavecchia et al 2016 - 2019 data - Cannell 2020 - 2018 data - Cannell 2019	Paper in prep.
Population estimates	For the main colony on GI	Specific project	Garden Island	2001-onwards	Monthly or fortnightly nest checks	burrow counts	UWA, Belinda Cannell	- Some information included in Cannell 2015	Paper in prep.
Population estimates		Specific project	Mistaken Island	2019-2020		Transects	Student project (UWA), Belinda Cannell		New projects
Population estimates	Planned for near future	Specific project	Cheyne Island	Upcoming		Transects	Student project (UWA), Belinda Cannell		New projects

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
qPCR assays of prey baitfish	Engraulis australis (Australian Anchovy), Spratelloides robustus (Blue Sprat), Sardinops sagax (Australian Pilchard) and Hyperlophus vittatus (Sandy Sprat)	Specific project			Once-off	qPCR assays of tissue samples	Murdoch University, Daithi Murray, Belinda Cannell	- Murray et al 2011	
Radiotracking	Pre-breeding, Breeding, Pre moult, small sample size	Specific project	Penguin Island	1996-97	during pre-breeding, breeding and pre-moult stage	Radio trackers	Belinda Cannell	- Mentioned in Cannell 2001	In a report to Bowman Bishaw and Gorham
Routine post mortems	Routine post mortems including internal and external examinations and notes on body condition. N > 160	Opportunistic	Perth metro region	2001 - ongoing	Opportunistic	Gross post mortem, histopathology, electron microscopy, PCR, immunohistochemistry	Murdoch University Veterinary Hospital; Kym Campbell (kym.campbell@dpird.wa.gov.au); Belinda Cannell	- Some 2003-2012 - Cannell et al 2016 - 2012-2013 - Campbell et al 2022	
Satellite tagging	To examine foraging habitat during incubation and chick rearing	Specific project	Penguin Island	2007-09, 2013-2019		Satellite and GPS tags	Murdoch University, Belinda Cannell	- 2007, 2008,2009,2013-2019 data (satellite tags deployed on Penguin Island in all years, and on Garden Island in 2007-2008) - Cannell 2014; Cannell 2015; Cannell 2016; Cannell 2017; Cannell	Paper in prep for 2007-2009 data

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
								2018; Cannell 2019	
Satellite tagging	To examine foraging habitat during incubation and chick rearing	Specific project	Garden Island	2007-2008, 2013-2018, 2021		Satellite and GPS tags	UWA, Belinda Cannell	- Cannell 2015	Paper in prep for 2007-2008 data
Sex and growth parameters	Re-analysis of data used by Povah 2021	Specific project	Penguin Island and Garden Island	April-Dec 2016-2019			Murdoch University, Belinda Cannell		
Sexing of chicks for determining sex ratios	Using blood samples from chicks @4 weeks or more. 61 chicks samples in total from artificial boxes only.	Specific project	Penguin Island and Garden Island	April-Dec 2016-2019		25-gauge needle for blood, DNA extraction and PCR	Murdoch University, Belinda Cannell	- Povah 2021	
Site and mate fidelity		Specific project	Penguin Island	1990-92, 1994			Wienecke, Nicholson	- 1989-1992 data - Wienecke 1993 - 1994 data - Nicholson 1994	
Survival estimates	Influence of different environmental variables on survival	Specific project	Penguin Island				Murdoch University, Belinda Cannell		Paper in prep. Presented at World Seabird Conference 2021
Timing of breeding		Specific project	Mistaken Island	2019-2020		Burrow checks	Student project (UWA), Belinda Cannell		New projects
Vegetation mapping		Specific project	Breaksea Island	2020		Transects	Student project (UWA), Belinda Cannell		New projects
Vegetation mapping		Specific project	Mistaken Island	2019-2020		Transects	Student project (UWA), Belinda Cannell		New projects

Data type	Description	Purpose	Location	Time period of data collection	Frequency of data collection	Methods for data collection	Custodian of data	Has the data been published?	Comments
Vegetation mapping	Planned for near future	Specific project	Cheyne Island	Upcoming		Transects	Student project (UWA), Belinda Cannell		New projects