Climate Change Adaptation Strategy for the Little Penguin *Eudyptula minor*

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Disclaimer

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Contents

1. Executive Summary

Penguin Island's Little Penguin colony has undergone a precipitous decline over the past decade. Between 2007 and 2019, the number of penguins in the colony is estimated to have decreased by 80% (Cannell 2020). Factors contributing to the population decrease are numerous and span all life history stages (i.e. chick survival and fledging, juvenile recruitment, adult breeding participation) and settings (i.e. marine and terrestrial) (Cannell *et al.* 2012; Cannell *et al.* 2016; Cannell *et al.* 2020; Campbell *et al.* 2022, B. Cannell, unpub. data).

Climate change is expected to superimpose fluctuations and extremes in rainfall, air temperature, and sea surface temperatures (Indian Ocean Climate Initiative 2012), creating further challenges for Little Penguins in the future, such as delayed nesting, lower chick survival and increased adult mortality. To increase the adaptive capacity of Penguin Island's Little Penguin population, and reduce their sensitivity and exposure to the effects of climate change, directed adaptation strategies are required (Mawdsley 2011; Hobday *et al.* 2015).

This strategy identifies the potential interventions that may be implemented to mitigate the effects of limited prey availability, reduced rainfall, high ambient temperatures, and reduced reproductive performance, i.e. productivity. As such, the interventions are designed to limit any climate impacts on adult survival and maximise the opportunity for successful breeding. Each of the known climate scenarios affecting Little Penguins were tabled along with their potential impact, adaptation option, and vulnerability category, which identified whether the proposed intervention reduces sensitivity, exposure, or increases adaptive capacity. The proposed interventions were then assessed to determine the effectiveness and benefit to Little Penguins using a risk-benefit matrix.

This strategy does not consider the synergistic, direct anthropogenic impacts on Penguin Island's Little Penguin population, such as tourism, development and construction or vessel strike. A comprehensive review of Little Penguin behaviour and ecology, current threatening processes, drivers of population decline, mitigation actions, and directions for future research should be developed via a Little Penguin Management Plan. The removal of non-climate-related stressors will enhance the potential for the recovery of Little Penguins (Mawdsley 2011; Hobday *et al.* 2015).

2. Background

Perth's Little Penguin Population

Penguin Island, located 50 km south of Perth, is a 12.5 ha nearshore island (<700 m from the mainland) located on the northern cusp of the protected embayment of Warnbro Sound. The island is a class 'A' Conservation Park located within the Shoalwater Islands Marine Park and is managed as a conservation park for its flora and fauna and for visitor education and recreation (Department of Biodiversity Conservation and Attractions 2018). The island is also home to a colony of Little Penguins – formerly the largest colony in Western Australia (Cannell 2001).

Penguin Island's Little Penguin colony is the most western colony globally. Together with a colony on nearby Garden Island, and possibly Carnac Island (Dunlop and Storr 1981), they represent the most northern colonies of Little Penguins in Western Australia (Cannell 2001) and are regarded as a metapopulation (Cannell 2012a). The Penguin Island population has been studied comprehensively for more than three decades, including their demography, breeding success, threatening processes and habitat use (e.g. Klomp 1991; Wienecke 1993; Cannell 2001; Cannell *et al.* 2012; Clitheroe 2021).

In Western Australia, Little Penguins have been recognised as having the highest conservation and threat status of all marine fauna, locally (Department of Conservation and Land Management 2003; Cannell 2004). In 1996, the Penguin Island population was assessed as being of national significance, with the highest conservation status of all colonies in Australia, due to its size, unusual morphology, location and isolation from the nearest breeding colony of comparable size, research history, vulnerability, and the administrative status of Penguin Island as a conservation park (Dann *et al.* 1996).

This relatively small and edge-of-range colony is genetically and morphologically distinct from the majority of other colonies in Australia (Wienecke 1993; Cannell *et al.* 2012; Vardeh 2015; Burridge *et al.* 2015). Thus, maintaining genetic diversity of this unique, range-edge population is disproportionally important for survival and evolution in response to changing environmental conditions (Hampe and Petit 2005; Hughes *et al.* 2008). The conservation value of Penguin Island's penguins is further elevated due to the significant economic and social importance this colony upholds.

Since 2010, many fewer penguins have attempted to breed on Penguin Island. Between 2010 and 2021, the number of chicks produced per pair has varied from 0.2–1.7 chicks (B. Cannell, unpub. data; DBCA unpub. data), and with fewer penguins breeding, this has resulted in lower chick production compared with previous years. Thus, recruitment, based on overall chick production, is likely to have reduced since 2010.

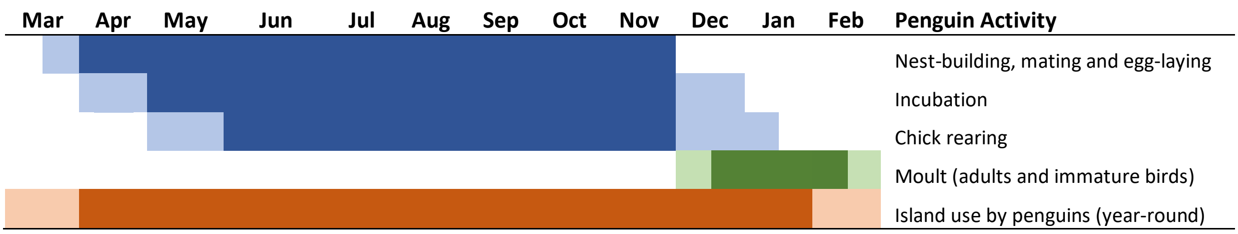
Population estimates in 2019 indicated that the Penguin Island population decreased by ~80% since island-wide estimates using mark-recapture began in 2007 (Cannell *et al.* 2011; Cannell 2020), to around 300 individuals (Cannell 2020, B. Cannell, unpub. data).

3. Little Penguin Life History

Little Penguins depart Penguin Island after fledging or following the completion of the annual moult (December/January). During this time, penguins can remain at sea for up to several weeks but may come ashore at any time (Table 1). Adults are more likely to be at their nest site one, four and seven weeks before laying (Reilly and Cullen 1981). Thus, on Penguin Island, this means they can intermittently return to the colony from February/ March to commence pre-breeding activities, including site prospecting, pair-bonding and nest guarding (Table 1, Wienecke 1993). Little Penguins are philopatric, i.e. they return to the same territory to breed and/or moult each year. The breeding period is relatively protracted, extending from April to December, and the timing of egg-laying is quite variable among pairs (Table 1, Dunlop *et al.* 1988; Wienecke 1993; Nicholson 1994). The peak in egg-laying is variable, often bimodal, with peaks in June and September (Dunlop *et al.* 1988; Wooller *et al.* 1991; Wienecke 1993).

The timing of breeding is also likely related to an upsurge in regional prey abundance (Stahel and Gales 1987, Cullen *et al.* 1992), with breeding overlapping the spawning period of several important penguin prey fishes, including Sandy Sprat *Hyperlophus vittatus* (Klomp and Wooller 1988, Wooller *et al.* 1991, Wienecke 1993, Cannell *et al.* 2016; Greenwell *et al.* 2021).

Table 1. Annual cycle of Little Penguins in Perth metropolitan region and overlapping tourism season (15 September–early June). Little Penguins may use the island year-round (Island-use) with a heavy dependency on land for 10 months of the year (Apr–Jan). Information on penguin activity as per Dunlop et al. 1988; Wienecke 1993).



Clutches typically consist of two eggs and are incubated by both parents for ~35 days (Stahel and Gales 1987). After hatching, chicks are provisioned at the nest site for seven to eight weeks, before fledging (Wienecke 1993). During the breeding season, the distance adult penguins can travel to find food is constrained by the need to return to nesting sites to brood eggs and feed chicks, termed central place foraging (Orians and Pearson 1979). Parental care ceases once chicks fledge, and young birds learn to forage independently.

At the completion of the breeding season, adults undergo a catastrophic moult, whereby all body feathers are replaced simultaneously. Moulting often occurs at the same location of nesting (Reilly and Cullen 1983; Dann *et al.* 1996). However, on Penguin Island, when moulting occurs during the summer months, penguins are observed congregating under structures and limestone rocks close to the water and arrival sites. In preparation for their annual moult, penguins increase their fat reserves, often doubling their weight, to sustain them for the ~three week period they are bound to land and unable to feed (Stahel and Gales 1987; Dann *et al.* 1996). Occasionally, adults may abandon chicks to allow sufficient time to increase their body condition (Cannell 2001). The moulting period is physiologically intense, characterised by increased metabolic rates, energetic expenditure and body temperature, and penguins are often emaciated at the completion of their moult (Stahel and Gales 1987; Cannell 2001).

Juveniles return to their natal territory to moult at around one year of age (Reilly and Cullen 1983) then recruit to the breeding population at two-to-three years of age (Dann and Cullen 1990; Dann 1992). Based on the recapture rates of banded and microchipped birds in the Perth region and elsewhere in Australia, intercolonial movement appears to be very low (Dann 1992b; B. Cannell, unpub. data). Even though Penguin and Garden island penguins are genetically similar (Sinclair, unpubl. data), there seems to be little movement between the colonies. For example, none of the 75 adults and chicks microchipped on Garden Island have been found on Penguin Island during nest surveys or mark-recapture events. Furthermore, of the >2500 penguins that have been marked on Penguin Island since 1986, only one banded adult and no microchipped penguins have been observed on Garden Island (B.Cannell unpubl. data). This does need to be interpreted with caution though, as many of the penguins on Garden Island cannot be identified due to the nature of their nest sites. Further research may enable the estimated number of recruits being exchanged between colonies per generation to be determined. Regardless, the population size of Little Penguins is determined by adult survival, reproductive success, and the number of annual recruits to the colony (Shultz *et al.* 2009; Cannell 2018).

4. Distribution and Conservation Status

Little Penguins are endemic to Australia and New Zealand. In Australia, populations are patchily distributed across southern Australia from Carnac Island, Western Australia (32.1210° S, 115.6621° E) to Broughton Island, New South Wales (32.61580°S 152.31400°E). However, there have been no recent surveys on Carnac Island to confirm whether this small population of 50–80 pairs (Dunlop and Storr 1981) is persisting. In New Zealand, the Little Penguin occurs from the Chatham Islands to mainland New Zealand but is absent from Fiordland and South Westland (BirdLife International 2020).

Globally, the Little Penguin is considered Least Concern by the International Union for the Conservation of Nature (IUCN) Redlist, due to their broad distribution and large population size (BirdLife International 2020). Their global population is cautiously considered stable, with the caveat that 60% of all known breeding sites have unknown population trends (BirdLife International 2020). Where population estimates are available, 29% are deteriorating and 20% are improving (BirdLife International 2020).

In Australia, many Little Penguin populations are threatened, and sites without active conservation measures have experienced severe declines to the extent that some colonies no longer exist (Dann 1994; Stevenson and Woehler 2007; BirdLife International 2020; Cannell 2020). In Western Australia, Little Penguins have the highest conservation and threat status of all marine fauna, locally (Department of Conservation and Land Management 2003). The conservation of the Penguin Island colony was identified as being of national significance, with the highest conservation status of all colonies in Australia (Dann *et al.* 1996).

5. Conservation Rationale

In Western Australia, the conservation of Little Penguins is consistent with legal provisions set out under the *Biodiversity Conservation Act 2016* (*BC Act*). The objects of the *BC Act* are "to conserve and protect biodiversity and biodiversity components in the State; and to promote the ecologically sustainable use of the biodiversity components in the State (s3)." The term biodiversity components include "native species, habitats, ecological communities, genes, ecosystems and ecological processes (s5, *BC Act*)." Thus, the conservation of Little Penguins, their habitat, genes, and ecological function is provided for under the *BC Act*.

Genetic diversity is a fundamental source of biodiversity (Hughes *et al.* 2008), providing the raw material for evolution by natural selection (Fisher 1930). Perth's relatively small and rear-edge Little Penguin population is morphologically and genetically unique (Wienecke 1993; Cannell *et al.* 2012; Vardeh 2015; Burridge *et al.* 2015). Conserving the genetic integrity of this population has important ecological consequences for the species as a whole and is likely to be important for the survival of the Perth metapopulation in response to changing environmental conditions (Hampe and Petit 2005; Hughes *et al.* 2008).

The conservation of Penguin Island's population is also justifiable based on the ecosystem and cultural services they provide (Baker *et al.* 2019). Little Penguins have an important ecological function on Penguin Island, acting as ecosystem engineers, transferring nutrients and energy between terrestrial and marine ecosystems (i.e. *BC Act* "biodiversity component")(Gillham 1961; Smith *et al.* 2011a). Little Penguins in the Perth metropolitan region, and especially in the Rockingham area, are iconic and part of the cultural identity (e.g. penguins are the City of Rockingham's logo). Therefore, they have innate cultural and social value over and above their ecological role or legal status under the *BC Act*.

Efforts to improve the resilience of Little Penguins to climate change through the management of terrestrial and marine ecosystems is necessary. However political will and effective conservation planning is essential (Ropert-Coudert *et al.* 2019).

6. Climate Threats to Penguin Island Little Penguins

Factors contributing to the decrease of Penguin Island's Little Penguin population are numerous and span all life history stages (i.e. chick survival and fledging, juvenile recruitment, adult breeding participation) and settings (i.e. marine and terrestrial) (Cannell *et al.* 2012; Cannell *et al.* 2016; Cannell *et al.* 2020; Campbell *et al.* 2022, B. Cannell, unpub. data). Further research is required to quantify the relative magnitude of both climate and direct anthropogenic impacts, such as potential disturbance from tourism and recreation, on the population. However, this document focusses on impacts associated with a changing climate.

Starvation and Prey Availability

The abundance or availability of the forage fishes, on which these penguins depend, appears to have been negatively impacted by increasing sea-surface temperatures (SSTs), a marine heatwave, strong La Niña periods and by rainfall decline, reducing the flushing of nutrients into coastal waters and productivity (Pearce *et al.* 2011; Cannell *et al.* 2012; Smith *et al.* 2012; Bice *et al.* 2015; Smith *et al.* 2017).

A 20-year study of breeding success on Penguin Island indicated that high SSTs corresponded with reduced success, and egg laying finished later during years with a strong Leeuwin Current (including La Niña periods, Cannell *et al.* 2012). Both increased SST and stronger Leeuwin Currents have the potential to create a seasonal mismatch between spawning and larval growth periods leading to reduced prey availability within foraging distance of the colony, with important flow-on effects for breeding performance and chick mortality (Shultz *et al.* 2009; Cannell *et al.* 2012; Piatt *et al.* 2020).

In 2011, during an unprecedented marine heatwave, there was a four-fold increase in the number of dead penguins found, with many dying from starvation (Cannell *et al.* 2019). This suggests that climate variability in the marine environment is having a strong influence on prey availability and negatively impacting adult survival through starvation. An investigation of the impact of rainfall on prey stocks needs to be included in future modelling.

Hyperthermia and High Air Temperature

The substrates on Penguin Island do not permit Little Penguins to burrow, forcing above-ground nesting under dense vegetation or within nest boxes (Klomp *et al.* 1991). However, surface nests located under bushes and shrubs with insufficient shading or poorly designed nest boxes are unlikely to provide appropriate thermal insulation and/or humidity requirements for eggs and chicks during this period (Klomp *et al.* 1991; Clitheroe 2021).

Air temperatures $\geq$30°C are thermally stressful for Little Penguins and they cannot withstand exposure to temperatures $>$34°C for more than a few hours before body temperatures become dangerously high (Stahel and Gales 1987; Dann and Chambers 2009; Horne 2010). Increased terrestrial temperatures have the potential to significantly challenge the thermoregulatory abilities of this species and reduce survival of both adults and chicks (Stahel and Gales 1987; Klomp *et al.* 1991; Horne 2010; Cannell *et al.* 2012; Cannell *et al.* 2016; Clitheroe 2021). Water loss during the 35-day incubation period may be a function of humidity with potential to influence egg hatching success (Stahel and Gales 1987; Dann and Chambers 2009).

On Phillip Island, Victoria, temperature was identified as an important variable of burrow microclimate with the potential to influence adult survival and breeding success (Dann and Chambers 2009). Burrow type, depth, location, and vegetation type and cover were identified as important factors influencing burrow temperatures (Dann and Chambers 2009). On Penguin Island, both natural and artificial nests are limited in their buffering capacity, particularly when ambient temperatures are high (Clitheroe 2021). The degree of vegetation cover was found to strongly influence the microclimate of both natural nests and nest boxes (Clitheroe 2021).

High air temperatures >34°C are possible in spring and, for example, a 1°C increase in annual temperature more than doubles days >40°C (Breshears *et al.* 2021). A very dangerous combination of climate and ocean conditions delaying breeding occurred in 2021–2022. Late season breeding placed chick-rearing into December and January, a period characterised by high ambient air temperatures. Air temperatures at Swanbourne (weather station 009215) exceeded 34°C on 15 days and 30°C on 28 days, during this period (Bureau of Meteorology 2022). The magnitude of the breeding delay and lower number of chicks that hatched was unprecedented and there is uncertainty about the likelihood of similar events in the future.

Rising temperatures and/or late season breeding on Penguin Island has the potential to (i) increase hyperthermia and adult mortality, and (ii) reduce breeding success through nest desertion, hatching, and fledging success (Dann and Chambers 2009; Cannell *et al.* 2012; Cannell *et al.* 2016). Additionally, there may be sublethal effects. High ambient temperature can lead to increased thermostatic demands reducing fledgling mass, thus, influencing juvenile survival and subsequent recruitment into the colony (Dann and Norman 2006; Catry *et al.* 2011).

A study into nest site use on Penguin Island showed that Little Penguins preferentially selected nest sites with taller vegetation with a south-westerly facing entrance and in areas close to known landfall sites (Clitheroe 2021). When nest boxes were selected, use was predominantly driven by structure of the box with longer boxes used preferentially (Clitheroe 2021). Importantly, selection of nest boxes was not associated with vegetation cover, with penguins equally likely to select exposed boxes for nesting and as such, exposing penguin occupants to potentially dangerous thermal conditions (Clitheroe 2021).

Late season breeding also has the potential to overlap the adult moulting period, meaning that nesting attempts may be foregone and/or chicks abandoned prematurely. Mortality from hyperthermia is particularly prevalent in adults during their annual moult period (D'Amore and Jessop 1995; Cannell *et al.* 2016), which, on Penguin Island, takes place over the Austral summer. On Penguin Island, moulting penguins (which cannot go to sea as they are not waterproof) are often observed retreating to the water to drink sea water and cool down by paddling their feet (the only place on their body from which they can lose heat). However, this is usually only observed when there is no perceived threat such as the presence of humans. Thus, during the summer months when tourist visitation is high, the risk of mortality from hyperthermia is exacerbated on hot days.

Extreme temperature conditions during the 2008/09 summer resulted in the death of dozens of Little Penguins. In response, ad hoc cooling strategies have since been implemented to reduce heat-related mortality. These strategies, which include manual watering of vegetation and moulting sites and the provision of water baths (in which penguins are observed standing in) may reduce heat stress among penguins but are labour intensive and limited to the current plumbing system available on the island.

7. Climate Projections for Western Australia and Implications for Little Penguins

Surface Air Temperature Projections

South-western Australia's climate is highly variable and, at times, extreme. In the future, climate change is expected to superimpose fluctuations and extremes, creating challenges for Little Penguins (Indian Ocean Climate Initiative 2012). In south-western Australia, mean annual temperature is projected to increase by 0.5–1.2°C under intermediate- and high-emissions scenarios, compared with average conditions (i.e. those recorded between 1986–2005, Indian Ocean Climate Initiative 2012). By 2090, mean annual temperatures are projected to increase by 1.1–2.1°C and 2.6–4.2°C under intermediate- and high-emission scenarios, respectively (Indian Ocean Climate Initiative 2012). Average minimum, maximum and temperature extremes (i.e. heatwaves) are projected to be in line with the projected mean temperatures (Indian Ocean Climate Initiative 2012). The number of days with maxima exceeding 35°C is projected to increase from 28 days in the recent past (1971–2000) to 36 days in 2030 and 40 days under an intermediate-emission scenario (Indian Ocean Climate Initiative 2012).

Rising air temperature on Penguin Island has the potential to (i) increase hyperthermia and adult mortality (Cannell et al. 2016), and (ii) reduce breeding success through nest desertion, and reduced hatching and fledging success (Dann and Chambers 2009; Cannell *et al.* 2012). When Little Penguins are exposed to high air temperatures, they become thermally stressed, initially hyperventilating, which may cause oxygen depletion in burrows or nesting boxes that are poorly ventilated (Dann and Chambers 2009). Increased water loss during incubation also has the potential to influence egg hatching success (Stahel and Gales 1987; Dann and Chambers 2009). With the number of days >35°C expected to increase (Indian Ocean Climate Initiative 2012), heat exposure is likely to become increasingly problematic for Little Penguins on Penguin Island during their incubation, chick-rearing and moulting periods.

Modelling with a 2.0°C temperature increase scenario predicted that the number of days nests exceed thermally stressful conditions (≥30°C) on Penguin Island will increase by 37% and 56% in natural nests and nest boxes, respectively (Clitheroe 2021). The number of days predicted to exceed hyperthermic conditions (≥35°C) will increase by 41% and 49%, in natural nests and nest boxes, respectively (Clitheroe 2021).

Rainfall Projections and Evaporative Demand

South-western Australia's drying trend is projected to continue with reductions potentially exceeding 20 mm in some months (Indian Ocean Climate Initiative 2012). By 2030, mean rainfall is projected to decrease by 5–6% compared with current conditions under intermediate and high-emissions scenarios (Indian Ocean Climate Initiative 2012). By 2090, mean rainfall is projected to decrease by 12% (range 1–15%) or 18% (range 5–35%) under intermediate- and high-emissions scenarios, respectively (Indian Ocean Climate Initiative 2012). However, the intensity and variability of rainfall is projected to increase as the atmosphere warms. The mean maximum 1-day rainfall is projected to increase by 6% or 9% by 2090 under intermediate- and high-emissions scenarios, compared with current conditions (Indian Ocean Climate Initiative 2012).

Rainfall will have important implications for the future of river flow in the region and the marine fauna species that have life history strategies that rely on river flow and productivity, particularly for recruitment (CSIRO 2021). This has the potential to influence the abundance of coastal fishes, like Australian Anchovy *Engraulis australis* and Sandy Sprat *Hyperlophus vittatus,* whose recruitment is positively correlated with high rainfall (Gillson 2011; Bice *et al.* 2015; CSIRO 2021). These species are important prey of Little Penguins in Western Australia (Klomp and Wooller 1988; Murray *et al.* 2011).

Evaporation in south-western Australia is projected to increase by 2.5% by 2030, as a result of drier and warmer conditions. By 2090, evaporative demand may increase by 5.4% or 10.3% under intermediate- and high-emissions scenarios (Indian Ocean Climate Initiative 2012).

Changes in temperature, rainfall and evaporative demand have the potential to decrease habitat availability for Little Penguins by reducing vegetation cover and altering nest microclimate (Dann and Chambers 2009; Clitheroe 2021). This has important implications for breeding success and adult survival during their annual moult. Managing habitat quantity and quality for Little Penguins may be used to buffer against environmental change (Clitheroe 2021).

Background Sea Surface Temperature and Marine Heatwaves

Sea surface temperatures in the Australian region have warmed by 1°C since 1910 and eight of the ten warmest years have occurred since 2010 (CSIRO 2021). Warming is projected to increase by 1–2°C by 2030 and 2–3°C by 2070 and is also projected to extend to depths of up to 500 m by 0.5–1°C (Poloczanska *et al.* 2007).

Changes in SST have the potential to impact the abundance and distribution of penguin prey (Smith *et al.* 2011b; CSIRO 2021), influence the body condition of the penguins (Wienecke *et al.* 1995, Cannell *et al.* 2019), the timing and duration of breeding and/or create seasonal mismatches between penguins and their prey (Monaghan *et al.* 1989; Shultz *et al.* 2009; Cannell *et al.* 2012). Such changes have the potential to reduce breeding performance, increase chick mortality (Shultz *et al.* 2009; Cannell *et al.* 2012; Piatt *et al.* 2020) and reduce post-moult recovery (Dann and Chambers 2009). Stratification of the water column is expected to increase with increased SST (Poloczanska *et al.* 2007), which may negatively impact productivity and food availability for penguins (Dann and Chambers 2009).

Sea Level and Shoreline Changes

Mean sea level is projected to increase by 0.9 m by 2100 (City of Rockingham 2019). Sea-level modelling has not been completed for Penguin Island, however, modelling along the Rockingham coastline and nearby Garden Island shows considerable inundation of coastal areas by the end of the century (Coastal Risk Australia 2022). A 1 cm rise in mean sea level will result in the shoreline moving 1 m further inland with erosion and inundation likely to be exacerbated during storm events (City of Rockingham 2019). These assessments suggest that arrival and departure beaches and low-lying breeding areas used by Little Penguins on Penguin Island will be impacted by increased sea levels in the future. This will be problematic as Little Penguins are very faithful to not only nesting areas, but also arrival and departure beaches (Cannell *et al.* 2011).

Coastal erosion, and the frequency and intensity of storm events is likely to increase with climate change, which may drive changes in habitat use and landing points of Little Penguins (Cannell 2001; Dann and Chambers 2009). Modelling is required to understand how sea level rise will impact breeding habitat through inundation and erosion and penguin access to breeding sites (see Dann and Chambers 2009).

8. Potential Climate Adaptation Strategies

Climate change and variability in the marine environment is already impacting Penguin Island's Little Penguin population, and climate projections indicate the situation is likely to worsen in the future (Indian Ocean Climate Initiative 2012; CSIRO 2021). Consequently, directed adaptation strategies are required to increase adaptive capacity, and reduce the sensitivity and exposure of Little Penguins to the effects of climate change (Mawdsley 2011;

Hobday *et al.* 2015). Strategies to address the issues of starvation and prey availability, reduced rainfall, high ambient temperatures, and reduced productivity are outlined below.

It is possible that, over time, forage fishes will adjust to the changing marine climate and recover - perhaps with a different set of relationships to oceanic variables. Spatial and temporal variability in distribution and abundance is characteristic of small forage fishes, with declines in the abundance of one species partially offset by another (Fields 1965; Dalzell and Lewis 1989; Ayvazian and Hyndes 1995; Fauchald *et al.* 2000). Furthermore, tropicalisation of the marine environment on the WA coast has led to shifts in fish distribution (Hutchins and Pearce 1994; Wernberg *et al.* 2016). For example, during the marine heatwave in 2011, Sandy Sprat were replaced in the diet of Little Penguins by Scaly Mackeral *Sardinella lemuru* and an increase in Australian Sardine (pilchards) *Sardinops neopilchardus,* but poor breeding participation and success that year indicated that the fish were not locally abundant (Cannell 2012b). For Little Penguins then, one component of the adaptation strategy should focus on bridging lengthy periods of low prey abundance whilst buying time for a new regime to establish.

The abundance of coastal forage fishes, such as Sandy Sprat and Australian Anchovy, appears to be dependent on the estuarine nutrient plumes that generate productive patches of phytoplankton in the coastal marine environment (Gillson 2011; Bice *et al.* 2015; CSIRO 2021). 2021 was the wettest year since 1995 (Bureau of Meteorology 2022) and there appears to have been a major rebound in the abundance of these important forage fish as a result. A study on the diet of Australian Fairy Tern *Sternula nereis nereis* over the 2021–22 summer showed a significant increase in the composition of Sandy Sprat and Australian Anchovy (C. Greenwell, unpub. data) compared with previous years (Greenwell *et al.* 2021). These fishes were also found to be in high abundance in the diet of Crested Terns *Thalasseus bergii* on Penguin Island between November 2021–January 2022 (J.N Dunlop, unpub. data).

The increased abundance of forage fish may provide a possible short-term reprieve for the Penguin Island colony in 2022. The long-running monitoring program on Penguin Island will inform changes in the timing of breeding and productivity.

Starvation and Prey Availability

During the breeding season, the distance Little Penguins travel to find prey is constrained by the need to return to nesting sites to feed chicks (Cannell 2018; Cannell *et al.* 2020). However, their prey - small pelagic, schooling or forage fishes, can be dynamic and heterogeneously distributed in the marine environment (Ayvazian and Hyndes 1995; Fauchald *et al.* 2000). The issue of forage fish availability might benefit from concentrating the available biomass in space and time at key locations within foraging range of the Penguin Island colony. This could be done using engineered structures similar to Fish Aggregating Devices (FADs) or a floating reef targeting pelagic clupeoid fishes, i.e. sprats and anchovies (Dalzell and Lewis 1989).

To enhance productivity and habitat to attract forage fish schools, a floating reef (similar to an artisanal payao) with swing mooring and vertically integrated rope curtain system, and potentially seeded with mussels and/or bivalves, is proposed (Fig. 1). This simple structure would be relatively low cost and easily removable if the structure was not successful in attracting clupeoid fishes. One potential location for the pilot floating reef is in Warnbro Sound. The area is characterised by shallow subtidal sandflats (10–15 m deep), in sheltered waters inshore from a limestone reef and within foraging range of Penguin Island (Cannell 2018; Cannell et al. 2020).

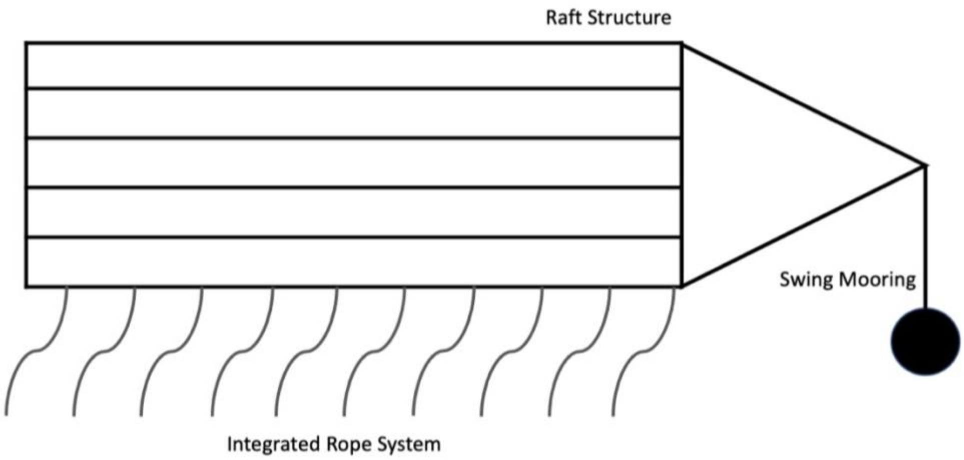


Figure 1. The adaptation floating reef structure with swing mooring and integrated vertical rope system that may be used to aggregate clupeoid fishes for foraging Little Penguins *Eudyptula minor* in Warnbro Sound.

<u>*Monitoring/ Research*</u>

- Baitfish monitoring at floating reef compared to adjacent bare sandy areas.
- Monitor changes in Little Penguin predator abundance.

Reduced Rainfall and High Ambient Temperature Solutions

1. Enhancement and targeted irrigation of vegetation to improve the microclimate of natural nests. Efforts should focus on increasing the percentage cover of the preferred vegetation species of Little Penguins, as identified by (Clitheroe 2021), to increase shade over nest sites and reduce evaporation of soil moisture.

   Little penguins preferentially nest in relatively well-established succulent shrub (Clitheroe 2021). Thus, it would likely take a number of years for vegetation to reach a condition that would be considered optimal for nesting. Given the low population of Little Penguins on the island, nesting habitat is not currently a limiting factor. However, thoughtful habitat enhancement will have long-term benefits for penguins, particularly as their population recovers, and the island as a whole.

Monitoring/ Research

- Temperature, humidity, and vegetation cover in irrigated vs unirrigated areas.
- Nest use/density in irrigated vs unirrigated areas.
- Change in vegetation composition/structure.

To help guide planning and vegetation enhancement efforts, detailed surveys of vegetation, penguin nests and access points are required, as a priority. This project would also benefit from a thermographic survey and creation of a humidity and thermal (heat) map to understand how surface temperatures and humidity vary across the island, how this may be influencing Little Penguin nest habitat selection and hatching success, and to identify key habitat/restoration areas.

Monitoring/ Research

- Broad scale habitat characteristics associated with nest density/use.
- Broad scale topographical and habitat characteristics associated with ground temperature.

2. Investigate insulated or double-walled nest boxes that provide a stable microclimate for Little Penguins, including during high temperatures (i.e. >34°C). Nest boxes should be suitably ventilated and provide ease of access for monitoring, with consideration given to placement and heat reflectance. In South Australia, the direction of ventilation holes in relation to nest entrance was found to be important in reducing temperature (D. Colombelli-Negrel, pers. comm.).

   A multi-year study investigated the efficacy of different nest box designs to reduce their internal temperature on Penguin Island (Clitheroe 2021). The designs were effective at reducing both the maximum temperature and number of hours exposed to stressful conditions (>30°C, Clitheroe 2021). Partially buried tunnels, and artificial shading of boxes reduced maximum nest temperatures by 2°C, while the addition of shading vegetation was most effective, reducing maximum temperature by 4°C. The newer timber box designs with shading vegetation had a thermal profile 2˚C cooler than natural nests (Clitheroe 2021).

   It may be possible to further reduce internal temperatures of nest boxes and alternative materials (e.g. clay, which is being trialled in South Australian and Tasmania) methods of insulating or shading artificial nests should be investigated. On the east coast of Australia, UV-stabilised, insulated nest boxes have been developed to support wildlife species that utilise hollows (Habitat Innovation & Management 2022). Using a similar concept, next boxes may be customised to suit Little Penguins (M. Callan, Habitat Innovation & Management, pers. comm.). In South Australia and Tasmania, artificial nests have a structure that encourages vegetation growth on the nest are also being trialled (D.

Colombelli-Negrel, pers. comm.). A design that allows for vegetation growth without inhibiting access for monitoring would be ideal.

Monitoring/ Research

- Test 2–3 designs for efficacy in buffering against heat in exposed areas.
- Monitoring of breeding success in insulated nest boxes.

3. Increasing temperatures and heatwaves are predicted in the future. Little Penguins may benefit from a mist-spray humidifier network to reduce ambient temperatures in high-density nesting areas and moulting hotspots, to improve microclimate, and reduce heat stress of vegetation.

   An aerial cooling system was recently trialed in Bendigo to reduce temperatures in a Grey-headed Flying-Fox camp and reduce vegetation heat stress (World Wildlife Fund 2021). Data loggers showed a reduction of 2°C in the test area, and the vegetation heat stress index was also reduced (World Wildlife Fund 2021). A similar system is due to be trialled in a Grey-headed Flying-fox camp in Paramatta, Sydney by Taronga Conservation Society Australia (Taouk 2021) and for flying-foxes in Clarence Valley, Maclean (Silver and Williams 2010).

Monitoring/ Research

- Temperatures and humidity in cooled vs uncooled areas.
- Body temperature of penguins in cooled vs uncooled areas (using thermographic camera).
- Investigate the the effects of additional moisture on flora and other island fauna.

4. Development and installation of refilling watering points in penguin moulting hotspots, to reduce thermal stress and hyperthermia of moulting adults. The Town of Victoria Park has recently developed and installed innovative bird waters around the city, and water is automatically refilled twice per day via a battery-operated irrigation control value, to ensure birds have access to fresh water on hot summer days (Town of Victoria Park 2022). A similar concept could be explored and adapted to suit Little Penguins.

5. Establish new sub-colonies in cooler refuges to mitigate the impact of high ambient temperatures and disturbance from tourist visitation. Habitat and thermal maps would be required to inform the most appropriate locations for translocation. This intervention would require a combination of vegetation enhancement, installation of insulated nest boxes, social facilitation, i.e. conspecific call-playbacks, and chick translocation methods.

Reduced Productivity and Viability

Hand-rearing abandoned and/or failing chicks for release back into the wild may be a way of maintaining colony size, particularly among chicks that are produced and abandoned by adults late in the breeding season. In South Africa, abandoned and weak African Penguin *Spheniscus demersus* chicks are rescued and rehabilitated for release, as part of the African Penguin Biodiversity Management Plan (Department of Environmental Affairs 2013; SANCCOB 2022). The program has been identified as an essential and successful component of bolstering the wild population and more than 7,000 chicks have been released since 2006 (Department of Environmental Affairs 2013; SANCCOB 2022).

A replicated study in South Africa between 1994–1999 found that the survival of hand-reared orphaned African Penguin chicks (11%, n=47) was similar to that of naturally-fledged chicks (9%, n=36, Whittington 2003). The proportion of birds surviving to breeding age was almost identical, suggesting that hand-rearing was successful in producing chicks with an equal chance of survival compared with naturally fledged conspecifics.

A study between 2007/08–2016/17 on Yellow-eyed Penguin *Megadyptes antipodes,* indicated that rehabilitated chicks had a lower post-fledging survival probability (0.23 ± 0.10—0.47 95% CI) than both healthy (>5 kg, 0.38 ± 0.26—0.51 95% CI) and underweight (<5 kg, 0.28 ± 0.11—0.53 95% CI) naturally fledged conspecifics (Alden *et al.* 2021). However, chicks admitted for rehabilitation were likely to die due to starvation, if left in the wild, due to the injury or death of one or both of their parents (Alden *et al.* 2021). Of those rescued, 91% survived rehabilitation and were successfully released, “indicating that intervention does play an important role in increasing the numbers of chicks fledged during years of poor food supply” (Alden *et al.* 2021). The time spent in rehabilitation was inversely proportional to admission weight, but early intervention could reduce the time orphaned chicks spend in captivity and the resources required for a successful release (Alden *et al.* 2021).

An agreed set of decision rules, based on chick growth models, would need to be developed to guide orphaned Little Penguin chick selection. That is, to determine which chicks under the seasonal conditions, would be suitable for rehabilitation with early intervention and before emaciation. Translocation, husbandry, and release protocols would also need to be developed.

Post-fledging survival is not well known for the Penguin Island Little Penguin population. However, understanding survival rates would be important for modelling population growth and assessing the value of chick rescue and rehabilitation - particularly given the high costs and time investment required. Further research should be undertaken to understand survival among naturally fledged chicks. This may also include a pilot study to investigate survival of hand-reared chicks, which may then be used to inform rescue and/or translocation plans.

Monitoring/ Research

- Determine survival of naturally fledged chicks on Penguin Island.
- Post release survival of translocated chicks, wild bred vs captive bred (naturally bred chicks as control).
- Return rate of translocated chicks to release area.
- Determine the breeding success of any future translocated chicks.

9. Adaptation Options

Each of the known climate scenarios affecting Little Penguins were tabled along with their potential impact, adaptation option, and vulnerability category, which identified whether the proposed intervention reduces sensitivity, exposure, or increases adaptive capacity (Table 2, following Hobday *et al.* 2015).

Table 2. Climate scenario with resulting impact, adaption options and vulnerability category (i.e. does the intervention reduce sensitivity, exposure or increase adaptive capacity).

Scenario	Impact	Adaptation Option	Vulnerability Category
Declining productivity	Increased adult mortality	Artificial fish aggregating structure (floating reef)	Adaptive capacity
Declining productivity	Reduced breeding productivity	Artificial fish aggregating structure (floating reef)	Adaptive capacity
Declining productivity	Reduced breeding productivity	Colony supplementation by chick rescue and translocation	Adaptive capacity
Declining productivity	Reduced breeding productivity	Colony supplementation by release of captive bred chicks	Adaptive capacity
Increased air temperature	Decreased chick survival	Modification of nest boxes	Exposure
Increased air temperature	Increased adult mortality during moult	Shading of artificial nests by increasing vegetation or shade structures	Exposure
Increased air temperature	Increased adult mortality during moult	Installation of cooling system	Sensitivity
Increased air temperature	Increased chick and adult mortality	Targeted irrigation	Exposure
Increased air temperature	Increased adult mortality during moult	Installation of watering points	Exposure
Increased air temperature	Increased adult mortality during moult	Temporary closure of island during heatwaves	Adaptive capacity
Increased air temperature	Increased chick and adult mortality	Climate ready restoration using heat/drought tolerant species	Exposure
Increased storm activity	Storm damage to arrival points, reducing accessibility leading to reduced breeding success	Stabilise arrival dunes (sandbag/ structures)	Exposure
Increased storm activity	Storm damage to arrival points, reducing accessibility leading to reduced breeding success	Knock down escarpments caused by storm surge and high tides	Exposure

10. Intervention Prioritisation

Each of the proposed interventions have been assessed to determine the effectiveness and benefit to Little Penguins using a risk-benefit matrix (Tables 3, 4). The matrix considers the likelihood of a scenario being effective in the long-term and the benefit of the proposed initiative, if effective. The matrix uses a qualitative assessment, drawing on peer reviewed literature and expert opinion. Where the consequences of activities are unknown, the precautionary principle has been applied.

The levels of benefit for the proposed intervention are defined as low, moderate, high, and very high. Categories for the likelihood of long-term effectiveness are defined as almost certain, likely, possible, unlikely, or unknown.

Table 3. Intervention risk-benefit matrix.

Likelihood of Long-term Effectiveness	Intervention Benefit			
	Not Significant	**Minor**	**Moderate**	**Major**
Almost Certain	Low	Moderate	Very High	Very High
Likely	Low	Moderate	High	Very High
Possible	Low	Moderate	High	Very High
Unlikely	Low	Low	Moderate	High
Unknown	Low	Low	Moderate	High

Table 4. Intervention risk-benefit matrix for Little Penguins.

Likelihood of Long-term Effectiveness	Intervention Benefit			
	Not Significant	**Minor**	**Moderate**	**Major**
Almost Certain			Vegetation enhancement	Nest box insulation Nest box shading
Likely			Targeted irrigation	Cooling system Watering points Island closures
Possible			Dune stabilisation Modify escarpments	
Unlikely				
Unknown	Chick hand-rearing and translocation* Captive breeding* Floating reef*			

* The long-term effectiveness and benefit of the intervention is unknown. Research trials are necessary to accurately assess this information.

11. Intervention Assessment Rationale

Vegetation cover, nest box shading and insulated nest boxes

The proposed initiatives of increased vegetation cover, nest box shading and insulating of nest boxes to reduce the internal temperature of nests was assessed by Clitheroe (2021) is Almost Certain to have Moderate–Major benefits for Little Penguins at all stages of their lifecycle (i.e. eggs, chicks and adults, Table 4).

Cooling system, watering points, targeted irrigation and island closures

The initiative of a cooling system has not previously been tested for penguins. However, an aerial cooling system trialled in a Grey-headed Flying-Fox camp in Bendigo reduced temperatures by 2°C whilst simultaneously reducing vegetation heat stress (World Wildlife Fund 2021). The number of days exceeding 35°C is projected to increase under intermediate-emission scenario (Indian Ocean Climate Initiative 2012 - for detail, see Hyperthermia and High Air Temperature)***,*** rendering moulting penguins vulnerable to hyperthermia. Assuming the results can be replicated for Little Penguins, the intervention is Likely to be of Major benefit to Little Penguins (Table 4).

The effect of water baths on reducing heat stress among moulting Little Penguins has not been quantified. However, Little Penguins are known to cool down by paddling their feet (the only place on their body from which they can lose heat) and are commonly observed standing in water baths when moulting on hot summer days. The proposed intervention of installing watering points is expected to have a similar effect to natural paddling and is Likely to be of Major benefit to Little Penguins (Table 4).

Little Penguins moult during some of the warmest months of the year (i.e. December and January) – a period that coincides with high tourist visitation. Natural predator avoidance behaviour (see Stahel and Gales 1987) during periods of tourist visitation may prevent moulting penguins from moving to cooler refuge areas. Closing Penguin Island on hot days (e.g. when the expected maximum is projected to exceed 35°C) may reduce the potential for hyperthermia. Thus, this management intervention has been assessed as being Likely to be of Major benefit to Little Penguins.

Vegetation enhancement

Enhancing vegetation to improving the microclimate and reduce temperatures within natural nests and nest boxes was assessed as being Almost Certain to a Moderate benefit to penguins. This intervention is likely to be important for all stages of the lifecycle (i.e. egg, chick, adult brooding and moulting stages, Table 4).

Targeted irrigation
Targeted irrigation is likely to be most effective on hot days to prevent vegetation senescence. This intervention is Likely to be of Moderate long-term benefit to moulting penguins.

Dune stabilisation and modify escarpments
Storm damage, storm surges and high tides have the potential to impact arrival points and reduce accessibility, leading to increased stress or reduced breeding success in the short term. This intervention may have a Possible, Moderate benefit to adult breeding penguins.

Chick hand-rearing, translocation, captive breeding, and floating reef
These interventions were not able to be assessed and require research trials to determine the possible long-term benefit to Little Penguins. Chick hand-rearing and translocation and have been effective tools in the recovery of other penguin and seabird populations around the world but has not been assessed for Little Penguins. Similarly, while floating reefs have been shown to aggregate clupeoid fishes (see *Starvation and Prey Availability*), their efficacy at providing a reliable food source for Little Penguins is unknown.

12. Recommendations

Non-Climate-Related Stressors

The removal of non-climate-related stressors will enhance the potential for species recovery in response to climate change (Mawdsley 2011; Hobday *et al.* 2015). On Penguin Island, human activity is concentrated in areas where most penguins can obtain suitable nest sites (Klomp *et al.* 1991), potentially creating conflict between recreation and conservation. Furthermore, the impact of development and construction on the penguin population has not been formally assessed in the past.

Given the rapidly decreasing trajectory of the population, a precautionary approach should be invoked to improve conservation outcomes for Little Penguins and reduce cumulative pressures. Consideration should be given to island tourism and future projects with the potential to increase disturbance.

Develop a Little Penguin Management Plan

Despite the rapidly decreasing population trend, there is currently no specific plan for the management of Little Penguins in Western Australia. To help inform future conservation actions and the recovery of the population, a Penguin Management Plan should be developed in accordance with s69 of *BC Act*. The management plan should include a review of Little Penguin behaviour and ecology, all current threatening processes, drivers of population decline, mitigation actions to minimise threats and a threat prioritisation matrix, and directions for future research. The removal of non-climate-related stressors will enhance the potential for a recovery of the Little Penguin population in response to climate change (Mawdsley 2011).

A technical advisory group should be developed to coordinate the implementation of measures set out under the management plan. A collaborative partnership approach between state government agencies, non-government organisations, scientists, industry, and the broader community is the best approach for effective implementation and species recovery (Department of Agriculture Water and the Environment 2021). Informed, empowered and responsive governance is critical to the decision-making process and reducing further decline (Martin *et al.* 2012)

Undertake Habitat and Nest Mapping

At present, the spatial distribution and density of Little Penguin nests, moulting habitats and travel pathways on Penguin Island has not been quantified. This is a critical knowledge gap and a comprehensive nest density and habitat use survey should be carried out as a priority. This includes mapping the distribution of all natural and artificial nests, and identifying important moulting habitat, access points and pathways. This information can be used to help inform future management decisions on the island and should be revised every three years.

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