Population estimate of the Little Penguin colony on Penguin Island during September to November 2024

A report for City of Rockingham

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1. Executive Summary

The Little Penguins on Penguin Island have been studied over the last three decades. Since 2010, many fewer penguins have been attempting to breed in the nestboxes, which have been monitored for nearly 30 years. A marine heatwave in late 2010/early 2011 and generally warmer sea surface temperatures (SST) in the local coastal waters in most years since is thought to be associated with an overall reduction in prey availability, and years of poorer breeding outcomes for the penguins.

Little Penguins are very faithful to a colony, returning to the colony each year to breed. They also return to the colony where they hatched and are faithful to an arrival beach. Mark-recapture studies conducted on four arrival beaches on Penguin Island, in conjunction with counts of penguins arriving on beaches around the island, have been conducted eight times since 2007. The population has exhibited a declining trend and has decreased 95% since the highest estimate in 2008. An estimated **97 ± 13,** 95% CI: 74-128, **individual** penguins were present on the whole island between September to November 2024, when the mark-recapture study was conducted. This is not statistically significantly different to the estimate in 2023, which was **114 ± 29,** 95% CI: 69-188, **individual** penguins. Both the 2023 and 2024 estimates are significantly different to the estimate in 2019 (309 ± **33** penguins, 95% CI: 251−381). It is possible that the reduced estimate is due to penguins taking a break from breeding and/or a population decline.

The population decline can be driven by the following scenarios: 1) fewer penguins participating in breeding across multiple years, which results in fewer chicks available to recruit back into the population, 2) a reduction in breeding success across multiple years, which results in fewer chicks available to recruit back into the population, 3) a reduction in the survival of fledglings, which results in fewer two to three year old adults returning to the colony and 4) changes in the mortality rate of the adults.

A range of factors are linked to population decline. These include: reduced food availability due to increasing SST and also a lack of nutrients, particularly nitrogen; increasing terrestrial temperatures, which can cause mortality of both chicks and adults from hyperthermia; penguins not being able to access their nest sites, which can be affected by storm damage, overgrowth of plants and anthropogenic changes to arrival sites; recreational watercraft injury; and predation.

Previous tracking studies have identified that the penguins' home range extends from Cockburn Sound to Geographe Bay during the incubation period and is dependent on where they nest on the island. This extensive home range and the various factors contributing to their decline, means that

the conservation needs of the Little Penguins from Penguin Island may differ significantly from the recreational needs of the people. As such, any management strategies developed must be aligned in both the state and local government agencies to ensure that both the penguins' and the peoples' needs are met. Furthermore, to avoid serious impact on the penguin population, it will be necessary to consider the implications of additional structures, such as boat ramps and other infrastructure, within the penguins' home range using robust methods such as decision-support tools.

Abbreviations

SD	Standard Deviation
SE	Standard Error
CI	Confidence Interval

2. Introduction

Little Penguins on Penguin Island have been studied over the last three decades. These seabirds are recognised as key bioindicators for coastal marine environment health as they are relatively easily studied and hence changes in specific parameters can be readily determined. In 2003, it was identified that the penguins from Penguin Island were under threat (Department of Conservation and Land Management, 2003). Moreover, they are key performance indicators for the Shoalwater Islands Marine Park (Department of Environment and Conservation, 2007)

However, a marine heatwave developed in late 2010, and since then many fewer penguins have attempted to breed in the nestboxes, monitored since 1986 (Cannell *et al.* 2024). The breeding success has also varied over this period (Cannell *et al.* 2024). The years of poorer breeding success have been associated with a stronger Leeuwin Current. This current flows southwards and brings warm tropical water that is low in salinity and nutrients (Cresswell & Golding 1980, Cresswell 1990, Feng *et al.* 2003). There is an intra-annual variability of the current, with a maximum flow in autumn-winter. However, it is also stronger during La Niña events, indicated by a positive Southern Oscillation Index (SOI) (Feng *et al.* 2003), which results in more mixing across the continental shelf (Pearce *et al.* 2006). This leads to phytoplankton and zooplankton being removed from the shelf waters, thereby reducing the feeding conditions of fish larvae on the shelf (Gaughan 2007). Thus, in years when the Leeuwin Current is stronger, there is likely to be fewer fish in the nearshore waters, and this is supported by anecdotal evidence of a lower annual abundance of baitfish in the penguins' foraging areas during these years (Moss pers. comm)[1].

Since the marine heatwave, the sea surface temperatures (SST) in the local coastal waters have often been warmer than average, with notable exceptions in 2015 (winter) 2016 (all year) and 2018 (majority of the year) (Cannell *et al.* 2024, Mitchell *et al.* 2024). There was evidence of greater abundance of baitfish from commercial fishermen in 2015 and 2016 (Moss pers. comm, Mendolia pers. comm), and the penguins produced more than the average numbers of successful chicks per pair (CPP) in these years, with 2016 having the most CPP ever recorded (Cannell *et al.* 2024). Despite this high productivity, fewer penguins attempted to breed in 2015 and 2016, compared to the long-term average, and there has been a declining trend since (Cannell *et al.* 2024). Recent modelling suggests that penguins are less likely to lay eggs when baitfish availability in the southwest region is reduced (Cannell *et al.* 2024), highlighting the importance of this region for pre-breeding penguins.

On Penguin Island, eggs are laid any time from April – November (Cannell *et al.* 2024 [Supplement]), and the penguins are asynchronous, meaning they do not all breed at the same time. Breeding includes an incubation period, where both parents take turns incubating the two eggs that are laid, a guard-phase once the chicks hatch, and a post-guard phase. Incubation typically takes approximately five weeks and multiple tracking studies during this period by Cannell (eg. Cannell 2014, 2015, 2016, 2017, 2018, 2019 and Cannell unpubl. data) have shown the Penguin Island penguins can remain at sea for much longer than the average three to five days observed for the Phillip Island penguins in Victoria (Chiaradia and Kerry 1999). They can also forage more than 150 km south in Geographe Bay and beyond (Cannell 2014, 2015, 2016, 2017, 2018, 2019, Cannell unpubl. data). The guard phase typically lasts two to three weeks and is characterised by the adults taking turns to forage at sea, usually within 30 km of the colony, and generally only for one to two days (Collins *et al.* 1999, Saraux *et al.* 2011, Cannell 2014, 2015, 2016, 2017, 2018, 2019, Cannell unpubl. data). During the post-guard phase, the parents alternate between long trips that last for several days, and short trips, lasting for one day (Saraux *et al.* 2011). Once the chicks have fledged, when they are approximately eight weeks old, they leave the colony. They are not shown where or how to forage. Many do not survive their first year at sea (Sidhu *et al.* 2007), but the survival rate has been shown to vary

[1]It is noted that it would be preferable to have measures of abundance, as derived from commercial fishing data. However, DPIRD are unable to supply data for a fishing block*species if there are less than three commercial fishers, as is the case in most of the blocks where the penguins are known to forage. Thus Moss, who is a commercial baitfisher within penguin foraging habitat, has supplied the "anecdotal" evidence, which was based on his commercial catches.

between colonies, e.g. 17% at Phillip Island, Victoria (Sidhu *et al.* 2007) and 42% at Oamaru, New Zealand (Agnew *et al.* 2016). Breeding attempts can fail at any stage, and penguins can lay a second clutch. They can also successfully raise two clutches in a season, but this is dependent on timing of the first attempt (it has to be earlier in the year), and adequate availability of prey. So, in any given year, a penguin pair can raise zero, one or two clutches, and a maximum of four chicks.

Little Penguins are very faithful to a colony, returning to the colony each year to breed. So annual adult survival is important for population growth of Little Penguins. However, Little Penguins return to their natal colony, i.e. the colony at which they hatched, and do so when they are approximately two to three years old to start breeding (Dann & Cullen, 1990; Dann, 1992). Occasionally they can return to the colony as one year old but have not been observed breeding at this age. So, both chick production and survival of the juveniles over that one-to-three-year period are also important for population growth, perhaps more so than adult survival (Sandvik *et al.* 2012, Cannell *et al.* 2024). Since 2007, when population estimates began, there has been a declining trend of Little Penguins using the island from September-November (during the typical latter half of the breeding season). In fact, the population has declined by > 90% and was estimated at **114 ± 29 (SE),** 95% CI: 69-188 individual penguins in 2023 (Cannell 2024). This was despite both the highest breeding success ever recorded in 2016 (Cannell *et al.* 2024) coinciding with healthy stocks of baitfish seen by local commercial fishers in late 2018-early 2019 (Moss pers. comm), and cooler than average SST in the first half of 2019 (Cannell *et al.* 2024).

In 2019, the population was estimated at 309**± 33 (SE),** 95% CI: 251-381 individual penguins. Since the 2019 estimate, the annual breeding success has been both below and above average (LPWG meeting minutes). Despite this, breeding participation has remained low, and the number of breeding attempts in 2023 was the lowest ever recorded (LPWG meeting notes). Aside from prey availability, there is concern that infrastructure changes on the island, and in Cockburn Sound where some of the penguins on Penguin Island forage, could potentially impact the penguins if not managed appropriately.

3. Purpose and Aims

The overall purpose of this project is to understand the size of the current population to help refine the management required both on the island and in the marine environment.

The aims of this study were to determine:

1) the population of Little Penguins during September to November 2024, and

2) if the population is in decline.

4. Methodology

4.1 Study Area

Penguin Island (32°18’S, 115°41’E) is a 12.5 ha limestone island that lies 600 m offshore, approximately 50 km south of Perth, Western Australia (Fig. 1). Both the northern and southern ends of the island are limestone plateaux that reach 10-12 m above sea level (Chape 1984). Sand beaches surround the eastern and central western sections of the island.

Fig. 1. Location of Penguin Island, Western Australia, indicated by the red dot, is approximately 50 km south of Perth (green dot) and 600 m offshore.

4.2 Field Methods

Definition of Population Sampled

Although the penguins are asynchronous breeders, peak numbers of eggs generally are laid in June and September (Dunlop *et al.* 1988, Cannell *et al.* 2024). However, the timing and number of peaks does vary between years (Cannell *et al.* 2024 [Supplement]). The asynchronous breeding means that on any given night in the breeding season, the birds coming ashore could be prebreeding adults involved in courtship or prelaying attendance, partners of penguins incubating eggs or guarding chicks, or have post-guard phase chicks. Courtship generally occurs about one month before egg lay and lasts for five to six days (Chiaradia & Kerry 1999) and prelaying attendance at the nest site occurs one to two weeks before egg lay. During incubation, the penguins take turns to forage at sea, and on Penguin Island, the observed maximum duration of a single incubation foraging trip determined from satellite tracking data has been 20 days (Cannell unpub.data). During the guard phase, the penguins alternate between guarding the chicks and foraging for one to two days. After this guard phase, both parents forage every day, but the duration of their trip can vary. After each foraging trip, the penguins return in the evening to their nest site and use an arrival beach which they have a high site fidelity to i.e. a penguin caught at one arrival beach will not be caught at another arrival beach (Cannell *et al.* 2011, Cannell *et al.* 2024). As the beach captures coincided with breeding, and encompassed a seven-week block, we were likely to catch penguins that were involved in two to three of these breeding stages. In addition to breeding birds, both juveniles and non-breeding adults could be caught (Dann & Cullen 1990; Sutherland & Dann 2012). However, as only a few chicks are marked at fledging and juveniles are similar in appearance to adults, it is not possible to identify any unmarked bird as either a juvenile (one-to-two years old), or an adult (≥3 years old). Thus, the population sampled during the mark-recapture is composed of breeding adults and potential breeders.

Beach Counts

Counts of arriving penguins were conducted on a single night in September, October and November at 14, 13 and 13 sites respectively around Penguin Island (Fig. 2). No penguins had been observed at the site missed in the October and November counts during the counts conducted in 2023 or the September count, 2024. Four of the sites were also used for the beach captures for the mark-recapture study. Using all these sites, most available landfall sites around the island were surveyed. A recent survey of all the nesting sites around the island has identified only a few burrows at the very northern and southern ends of the island (Clitheroe pers. comm.), indicating that only a few penguins may be arriving at the sites not surveyed.

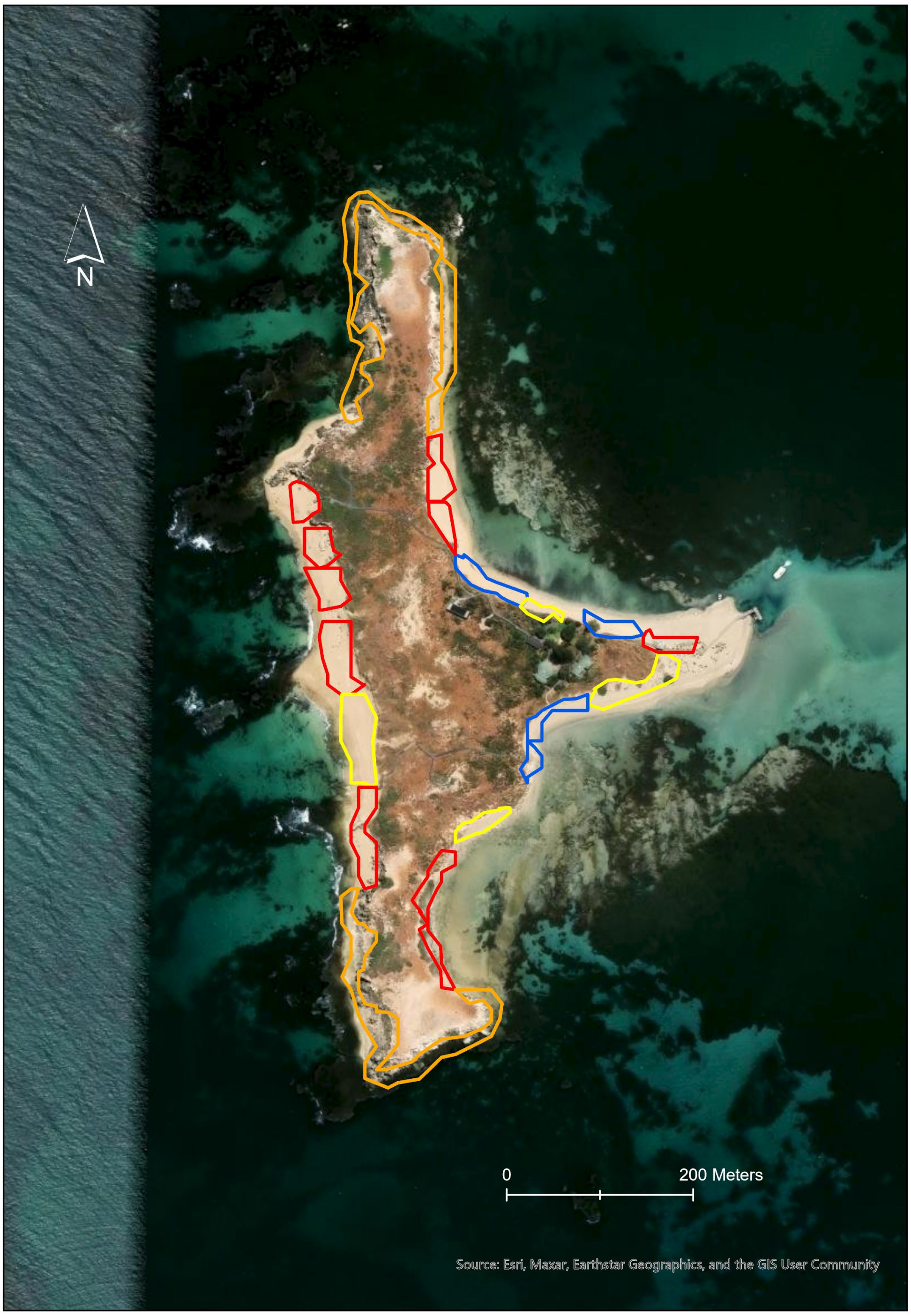

Fig. 2. The extent of the beaches covered by the RAN volunteers (red and blue polygons) counting Little Penguins arriving at Penguin Island on one night each in September, October and November in 2024, using night vision goggles. The beaches covered by the blue polygons were also used for the beach captures from September-November 2024. The yellow polygons represent areas that the penguins have not been observed to use as arrival areas. The orange polygons at the northern and southern ends cover 10-12 m high cliffs, however a few nest sites have been found amongst the rocks during other surveys not conducted as part of this study.

To assist in correctly observing and identifying the penguins, Royal Australian Navy (RAN) Night Vision Goggles were used by RAN volunteers. Using these, each counter was able to clearly see penguins within at least a 40 m radius. The counts were conducted around the first quarter moon phase, from sunset to two hours after Civil Twilight[2]. Both the number of penguins arriving in each group and the time of arrival were noted.

Mark-recapture study

Penguins were caught if they came ashore at each of four arrival sites, one site per night, over four consecutive nights. Each set of four nights is hereafter referred to as a session. The arrival sites used had previously been identified as having the greatest number of penguins arriving on any night (Cannell *et al.* 2011). However, one of the sites had not been used in 2019, and so was swapped for a new arrival site on the eastern side of the island that has only recently been used (Fig. 2) The captures were repeated on four occasions from September to November 2024 (Table 1).

Table 1. The dates of each Mark-recapture session on Penguin Island in 2024

Capture Session	Date
1	24/9/24-27/9/24
2	10/10/24-13/10/24
3	23/10/24-26/10/24
4	8/11/24-11/11/24

To catch the penguins, low fences were erected along either side of the major landfall site, with a corral at the centre of the landfall site (Fig. 3) Arriving penguins were herded into the corral, the corral was closed off and the penguins were removed. The corral was then re-opened as penguins continue to arrive for several hours, either in groups or alone (Klomp & Wooller 1991, Cannell unpubl. data). Each group of captured penguins was taken to an adjacent area that was 10-30 m from the corral area and not directly visible from the landfall site. Here the penguins were weighed in a bag to the nearest 10 g using Salter 2 kg*10 g scales. They were scanned for subcutaneous transponders with a Portable Reader (Iso Max IV, scanning distance up to 30 cm). If the penguins did not have a transponder, they were marked with one, and both maximum beak depth and length

[2] The instant in the evening when the sun is at a depression angle of 6° below an ideal horizon (http://www.ga.gov.au/earth-monitoring/geodesy/astronomical-information/astronomical-definitions.html)

were measured (to determine sex of the bird). The penguins were returned to an area between the landfall and measuring sites. The entire process of corralling newly arrived penguins, then weighing, scanning and marking unmarked penguins from each newly arrived group continued for a minimum of two hours from first capture.

Fig. 3. A typical fence and corral assemblage used to capture Little Penguins on Penguin Island.

Mark-recapture analyses

I used a Multi-State Open Robust Design analysis (Kendall *et al.* 2019) for a single season to determine the population estimate for 2024. The modelled parameters include the probability of entering the colony for the first time in a given session (*pent*), the probability of capture (*p)* for those that are present in a given session, and the probability of persisting at the colony from one session to another (ϕ). I included models where the probability of capture was constant between sessions or varied with time (when both *pent* and *p* were session dependent, we set $p_1 = p_2$ because p_1 cannot be estimated separately). The probability of entry either varied with time or was the same for each session. As it takes approximately 13 weeks from egg lay to chick fledge, we assumed that once a penguin had been captured in the colony it is reasonable to expect it will be caught again, unless it is not a breeding penguin. However, given the asynchronous nature of the penguins' breeding, the probability of a penguin being captured within the four sessions is dependent on when its clutch was laid. Thus, I modelled the probability of remaining within the colony (i.e. ϕ- persistence) to be constant over the four sessions, to vary over time, or to be dependent on when it arrived (e.g. a penguin will be less likely to depart shortly after its egg is laid than shortly before its chick fledges). I also considered models where there were arrivals but no departures, only departures but no arrivals, or no arrivals or departures (the population was closed) over the four sampling sessions.

Model selection was based on Akaike's information criterion corrected for small sample sizes (AIC_c) (Burnham and Anderson 2002) and model averaging was used to address model selection uncertainty. I used the median *c*-hat procedure in Program MARK (White and Burnham 1999) to estimate the overdispersion parameter, *c*, for the global model. As *c* was not greater than 1, there was no need to adjust the AIC model selection metric. The models were constructed and run in program MARK version 10.1 (White and Burnham 1999).

All estimates are presented as the mean ± SE unless otherwise stated.

Total Island Population Estimation

The total island population was estimated by combining the information from the mark-recapture study and cumulative beach counts of all beaches. This is based on the equation modified from Williams *et al.* (2002):

$$\hat{N}_t = \frac{\hat{N}_c}{\hat{\alpha}}$$

$$SE(\hat{N}_t) = \hat{N}_t \sqrt{[SE(\hat{N}_c)]^2/\hat{N}_c^{\,2} + [SE(\hat{\alpha})]^2/\hat{\alpha}^2}$$

where $\hat{N}_c$ is the population estimate obtained from the mark-recapture study and $\hat{\alpha}$ is the fraction of area/population sampled by the mark-recapture study. The estimation of α uses the equation

$$\hat{\alpha} = \frac{x}{n}$$

$$SE(\hat{\alpha}) = \sqrt{\hat{\alpha}(1-\hat{\alpha})/n}$$

where x is the sum of the cumulative beach counts where the capture-recapture was done and n is the sum of all the cumulative beach counts on the whole island.

$SE(\hat{N}_c)$ is obtained from the Program Mark output

A Log-normal 95% confidence interval was calculated, with a lower limit of $\hat{N}^L_{total}=\hat{N}_{total}/C$ and upper limit of $\hat{N}^U_{total}= \hat{N}_{total}$ x C, where

$$C = \exp\left(1.96\sqrt{\ln\left(1+\left(\frac{SE(\hat{N}_{total})}{\hat{N}_{total}}\right)^2\right)}\right)$$

5. Results

5.1 Beach counts

An average of 1.9 ±4 (SD) penguins were counted coming ashore at all the counted sites over the three nights (Range: 0 - 21 penguins). The greatest number penguins arrived on a beach on the NE side of the island.

5.2 Mark-recapture analyses and island-wide population estimate

In 2024, 51 individual penguins were caught across the four sites over the four capture sessions. The model with the highest AIC_c weight and with 22% support was a fully open model, with new penguins (i.e. either unmarked or previously marked penguins not caught in previous sessions in 2024) arriving to the colony throughout the four sessions, a constant probability of capture in all sessions, and a constant probability of remaining within the colony (Table 2). The probability of new birds arriving to the colony was highest for the first session, i.e. in late September, with approximately 67% probability of arriving. No new birds arrived in the first October session. However, there was an approximate 17% probability of new birds arriving in session 3 (late October) and a similar probability in session 4 (early November) (Fig. 5). The capture probability was 0.51 ± 0.09, 95% CI: 0.34-0.69 for all the sessions. The probability of remaining in the colony after each of the session was 0.70 ± 0.08, 95% CI 0.52-0.83, meaning that only 30% of the penguins left after each session. The model-averaged population estimate for the nesting area accessed via the four beach capture sites was 74 ± 8.90 penguins. An estimated **97 ± 13,** 95% CI: 74-128, **individual** penguins were present on the whole island between September to November 2024.

Table 2. Model selection results using multistate open robust design mark-recapture models to evaluate demographic parameters of Little Penguins on Penguin Island from September–November 2023. Parameters are p, probability of recapture; pent, probability of entering the colony for the first time in a given session; phi, the probability of persisting at the colony from one session to another. Structures are (.), constant; t, time within season; tsa, time since arrival; linear tsa, linear time since arrival trend.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance	-2log(L)
{p(.),pent(t),phi(.)}	247.282	0.00	0.22060	1.0000	4	238.734	238.7339
{p(.),pent(t),phi(tsa)}	248.178	0.90	0.14095	0.6389	6	234.995	234.9946
{p(.),pent(t),phi(t)}	248.345	1.06	0.12966	0.5878	6	235.162	235.1616
{p(t1=t2),pent(t),phi(.)}	248.885	1.60	0.09898	0.4487	5	238.051	238.0513
{p(.),pent(linear),phi(.)}	248.910	1.63	0.09772	0.4430	3	242.586	242.5861
{p(.),pent(t),phi(linear tsa)}	249.269	1.99	0.08168	0.3703	5	238.436	238.4357
{p(t),pent(0.25t),phi(.)}	250.331	3.05	0.04802	0.2177	5	239.498	239.4978
{p(t1=t2),pent(t),phi(t)}	250.345	3.06	0.04769	0.2162	7	234.745	234.7451
{p(t1=t2),pent(t),phi(tsa)}	250.511	3.23	0.04389	0.1990	7	234.911	234.9111
{p(t1=t2),pent(t),phi(linear tsa)}	250.698	3.42	0.03997	0.1812	6	237.515	237.5151
{p(t1=t2),pent(t) births only}	252.377	5.10	0.01727	0.0783	4	243.829	243.8290
{p(t),pent(.25),phi(linear tsa)}	252.665	5.38	0.01495	0.0678	6	239.482	239.4815
{p(t),pent(0.25t),phi(t)}	252.908	5.63	0.01324	0.0600	7	237.308	237.3082
{p(t),pent(0.25),phi(tsa)}	254.712	7.43	0.00537	0.0243	7	239.112	239.1118
{p(.),pent(0.25t),phi(.)}	270.791	23.51	0.00000	0.0000	2	266.631	266.6307
{p(.),pent(0.25),phi(linear tsa)}	272.043	24.76	0.00000	0.0000	3	265.719	265.7190
{p(.),pent(0.25t),phi(t)}	272.223	24.94	0.00000	0.0000	4	263.675	263.6745
{p(.),pent(0.25),phi(tsa)}	272.983	25.70	0.00000	0.0000	4	264.435	264.4352

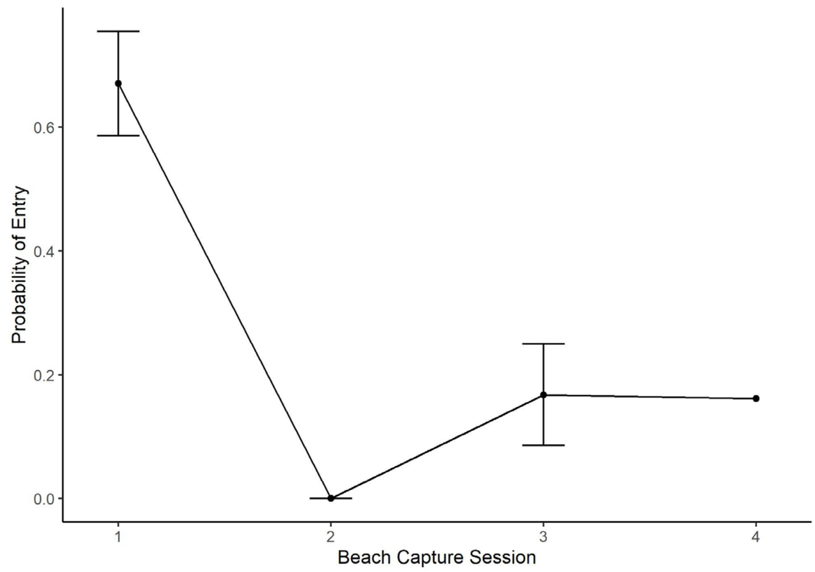

Fig. 5. The probability of Little Penguins entering the Penguin Island colony in beach capture sessions 1-4, 2024.

5.3 Comparison between 2023 and 2024

In 2023, an average of 1 ±3 (SD) penguins were counted coming ashore on all the beaches, i.e. almost half that counted in 2024. A similar number of penguins were estimated to be using the nesting area accessed via the four beach capture sites (75 ±17.55 and 74 ± 8.9 individual penguins in 2023 and 2024 respectively). The island-wide population estimate for September to November in 2023 was slightly higher than in 2024 (**114 ± 29,** 95% CI: 69-188 in 2023 and **97 ± 13,** 95% CI: 74-128 in 2024), but there was not a statistically significant difference between the two estimates (95% CI on the difference: -45.3 - 78.3).

Even though there were more penguins counted coming ashore in 2024 compared to 2023, a higher proportion came ashore at the four arrival sites compared to all the other beach sites in 2024. As the model-averaged population estimate is divided by the proportion coming ashore at the four arrival sites, this resulted in the lower island-wide estimate for 2024.

The top model differed between the two years. In 2023, there was an equal probability of capture in sessions 1 and 2, and then in 3 and 4, and a linear trend for a penguin to remain within the colony since it arrived i.e. a penguin will be less likely to depart shortly after its eggs are laid than shortly before its chicks fledge. In contrast, in 2024, there was a constant probability of capture in all sessions, and a constant probability of remaining within the colony. In both years, the greatest proportion of new penguins (i.e. either unmarked or previously marked penguins not caught in previous sessions) arrived at the colony in the first session. The probability of capture was higher in 2024 compared to 2023 in the first two sessions but there was no statistically significant difference in sessions 3 and 4 (Fig. 6a). The probability of persisting in the colony was higher between sessions 1 and 2 in 2024, but persistence was higher in 2023 between sessions 2 and 3 and sessions 3 and 4.

All of the penguins that had arrived in sessions 2 or 3 in 2023 remained in the colony, i.e. had a persistence probability of 1.00 (Fig. 6b). In 2023, approximately two thirds of the penguins that arrived in the first session left after that session and did not return, whereas only 30% of penguins did so in the first session in 2024 (Fig. 6b). The probability of a penguin arriving at the colony was highest for the first session in 2023, but thereafter declined, with no additional penguins entering the colony in sessions 3 and 4. In contrast, additional penguins were arriving at the colony in sessions 3 and 4 in 2024 (Fig. 6c).

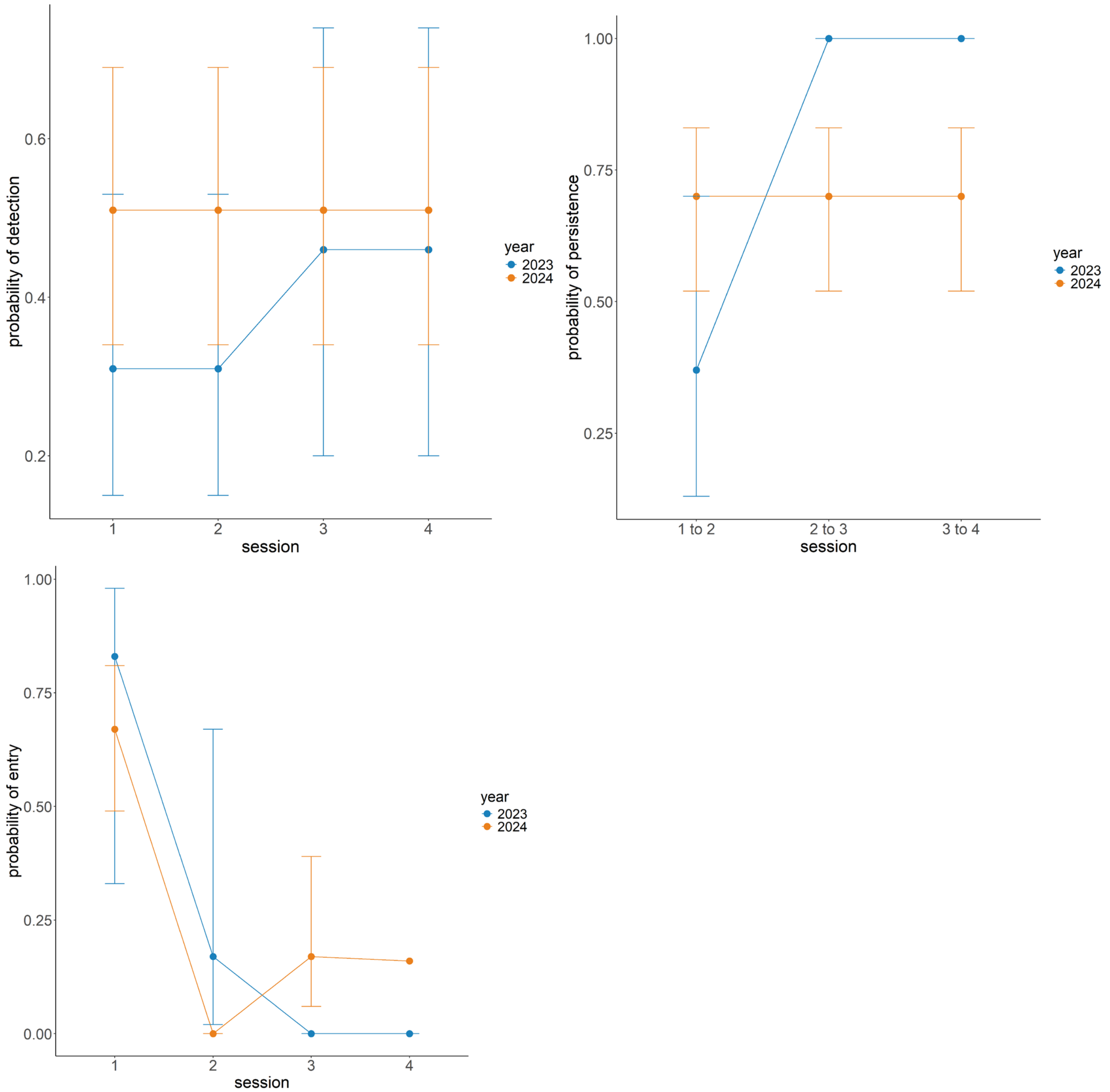

Fig. 6 The probability (with 95% confidence intervals) of a) detecting a penguin given it is available for detection, b) a penguin persisting at the colony from one session to another, and c) a penguin entering the colony for the first time in a given session, on Penguin Island in 2023 and 2024.

6. Discussion

Using a combination of Mark-Recapture analyses and the beach counts, the population of Little Penguins using the island between **September to November 2024** has reduced by approximately 68% from the estimates for a comparable time of year in 2019, 84% since 2017, 94% since 2007 and 95% since 2008 (Cannell *et al.* 2024). Whilst fewer penguins were estimated in 2024 compared to 2023 (Cannell 2024), this was not statistically significantly different. It is pertinent to note that as the estimate is only for the penguins on the island from September to November. Thus, any penguins that bred earlier in the year, and whose parental duties were completed before the first capture session, were potentially not returning to the colony and thus **not included** in the estimate. This was evident in 2010, when the population estimate was considerably lower than in 2007, 2008 and 2011, and was due to a mismatch between timing of breeding and the mark-recapture program (Cannell *et al.* 2024). However, any change in population estimates between recent years is comparable. This is because:

- In 2017 and 2019, peak egg lay occurred in June, and eggs were laid in September (and October in 2017) (Cannell *et al.* 2024 [Supplement]). In 2023, egg laying began in June and finished in October (LPWG meeting notes)
- Breeding success was relatively high in 2023 (LPWG meeting notes) but was higher in 2019 and lower in 2017 and 2008 (Cannell *et al.* 2024). As the population estimates in 2008 and 2017 were higher than in 2019 and 2023, then breeding success is not a good indicator of the population estimate.
- A few clutches were laid in May 2024, but the breeding outcomes for these early attempts was either poor or good, and peak egg lay occurred in September (LPWG meeting notes). Overall breeding success was similar to 2023 (LPWG meeting notes).
- Incubation and chick rearing covers approximately 13 weeks, thus there was a good chance that any penguins laying eggs would be encountered during at least one of the mark-recapture sessions.

The low population estimate for September to November in 2024 could partly be due to early failed breeding attempts and the penguins potentially not returning to breed (and hence not counted in the estimate for September – November), or those that did finish breeding before September. However, due to the low number of breeding attempts in May, this would only account for a small proportion of the penguins. As such, the low estimate in 2024 is likely to be due to either a number of penguins choosing not to breed, i.e. taking a sabbatical from breeding and/or a declining population.

What causes fewer penguins to participate in breeding? This will be driven by a poor body condition of potentially breeding adults due to reduced prey availability, disappearance of a mate (different to changing a mate when the previous partner is still alive - the divorce rate of Little Penguins is approximately 20-30% in cases (Johannesen *et al.* 2002, Saraux & Chiaradia 2022), fewer chicks returning to their natal colony as breeding adults, or interrupted breeding attempts due to impacts on nest sites or arrival areas on the island. Furthermore, more penguins from Penguin Island are likely to participate in breeding as the biomass of baitfish in the SW region increases, combined with a weaker annual Leeuwin Current (specifically when the mean annual Fremantle Sea Level (FSL, a proxy for the Leeuwin Current) is < 825 mm), a weaker Leeuwin current in winter (specifically the mean winter FSL was 800−875 mm), and the winter rainfall the previous year >400 mm (Cannell *et al.* 2024). The mean annual strength of the Leeuwin Current in 2024 was 857 mm, and the mean in winter was 973 mm, meaning that it was a strong Leeuwin Current in 2024. Furthermore, the winter rainfall in 2023 was 305 mm (data from http://www.bom.gov.au/climate/data/index.shtml?bookmark=136&zoom=1&lat=-26.7905&lon=121.3165&layers=B00000TFFFFFFFTFFFFFFFFFFFFFFFFFFFFFFTTT&dp=IDC10002-d at station 9977). These three factors would indicate that there was a decreased likelihood of breeding participation in 2024.

Even though there were environmental variables that were associated with fewer penguins attempting to breed in 2024, it is also very likely that there has been a real population decline, especially given the downward trend observed since **2011** (Cannell *et al.* 2024). This is highlighted with a reduced proportion of penguins attempting to breed in 2011 compared to 2017, and yet the population was lower in 2017 by 60% (Cannell *et al.* 2024). The population decline can be due to multiple factors: 1) fewer penguins participating in breeding across multiple years, which results in fewer chicks available to recruit back into the population, 2) a reduction in breeding success across multiple years, which results in fewer chicks available to recruit back into the population, 3) a reduction in the survival of fledglings, which results in fewer two to three year old adults returning to the colony and 4) changes in the mortality rate of the adults. There is evidence to support that all these factors have influenced the population on Penguin Island.

Reduced food availability is implicated in reduced breeding success, reduced survival of fledglings and juveniles (i.e. up to two to three years of age), and increased mortality of adults. If food is scarce, then there are a number of possible outcomes for the breeding penguins 1) they may bring back less food to chicks, 2) they may take longer foraging trips to find food which leaves the chicks hungry for longer and affects their growth rate (Chiaradia & Nisbett 2006, Cannell unpubl. data), 3) they may take a greater number of post-guard long foraging trips (Saraux *et al.* 2011), which is related to the mass of the adult, or 4) they may abandon the breeding attempt completely. Less prey means fewer chicks surviving (Chiaradia *et al.* 2010), lighter chicks at the fledge stage (Chiaradia & Nisbet 2006, Cannell *et al.* 2012), or chicks taking longer to fledge (Wienecke *et al.* 2000, Chiaradia & Nisbet 2006, Cannell unpubl. data). Clearly fewer chicks surviving means that there will be fewer sexually mature adults two to three years later. But survival of chicks in their first year of life is correlated with their mass at fledging (Dann 1988). Thus, lighter chicks also mean fewer recruiting back to the colony when they are sexually mature adults two to three years later. However, breeding success can also be impacted by terrestrial temperatures, with chicks present on the island in the late spring and summer months potentially dying from hyperthermia. As our climate warms, there is an increasing probability of terrestrial temperatures negatively impacting chick survival. Breeding success is also influenced by penguin access to their nest sites. As mentioned, Little Penguins are very faithful to an arrival beach and will not use another beach to get to their nest. Storm damage, overgrowth of plants and anthropogenic changes to arrival sites can all impact a penguin's ability to get back to its nest (Wienecke *et al.* 1995, Cannell 2001, Stevenson & Woehler 2007, Cannell pers. obs.).

For fledglings, mortality rate in their first year is higher than that of adults. For example, Sidhu *et al.* (2007) estimated that 17% of Little Penguins at Phillip Island survive their first year, compared to an average survival of 83% for three to nine year old penguins, and declining to 76% at age 13. As noted above, the better body condition they have when they first leave the island (which is due to the parents feeding them well during chick rearing), the greater the chance they will survive. This decreased survival in their first year is partly driven by their initially poor foraging skills (Cannell 1994), which is then exacerbated in years of reduced prey availability. But climate effects on juvenile penguin survival operate for the first one to three years of their life due to indirect effects on prey (Cannell *et al.* 2024). Therefore, even in the years when reproductive success and chick mass at departure is high, adverse conditions in the following years can result in decreased survival. There will be other threats to the juveniles, which remain at sea except to moult. For example, juveniles are particularly susceptible to parasitic disease (Harrigan 1992). It is not currently known where the fledglings and juveniles forage, nor where they go to moult (although occasionally some will return to Penguin Island to moult). This is a critical missing piece of information. Unfortunately, the tags deployed on adults are considered either too large to remain on the inexperienced foraging youngsters for an extended period of time, or have limited battery capacity rendering them inefficient for appropriate data collection. With continued improvements in this technology, hopefully this lack of knowledge can be rectified soon.

Mortality in adult Little Penguins is generally low, with an estimated 86% survival for Penguin Island penguins (Tavecchia *et al.* 2016). However, climate effects on prey can impact adult mortality. Indeed, in 2011 and 2012, when SST were very high, more malnourished penguins were found dead compared to any other year since necropsies began in 2003 (Cannell *et al.* 2016, Cannell *et al.* 2024). Elevated SSTs are not the only factor which influence prey abundance. Nutrient levels, particularly nitrogen levels, are also important as they are associated with primary productivity- the base of the food chain for many fish. Within the WA coastal ecosystem, nitrogen mostly comes from discharges (Mitchell *et al.* 2024) due to the low nutrients carried within the Leeuwin Current. With the discharges being well managed in recent years, the coastal waters may have become too "clean" to support an abundant penguin prey stock. However, reduced food availability isn't the only cause of mortality in penguins. When terrestrial temperatures are ≥ 35°C, penguins can die of hyperthermia, and this can occur during the breeding season or during the moult period (Cannell *et al.* 2011, Cannell *et al.* 2016). Importantly, recreational watercraft injury had been shown to cause just over a quarter of all deaths of Perth's Little Penguins and was the most prevalent cause of their mortality (Cannell *et al.* 2016). Of the deceased penguins collected since 2017, 32% were due to watercraft injury (Cannell unpubl. data). Furthermore, penguins are more likely to be injured by watercraft in spring and summer when recreational boating activities within the penguins' foraging areas are at their highest (Cannell *et al.* 2020). Predators can also impact adult survival, and low levels of predator attacks, i.e. 5-15 birds killed per attack, can increase the risk of extinction of small colonies (100 birds) in 10-15 years if there were >20 attacks/50 years (Blamey *et al.* 2024). There are no dogs, foxes or cats on Penguin Island, which are all known to predate on adult Little Penguins (Cannell 2001 and references within). However, rats did become problematic on the island in the early 2010s, and there was evidence that they did predate on both chicks and adult penguins (Clitheroe pers. comm.). An intensive baiting program was conducted and the rats were removed, but this highlights the importance of management of feral predators on Penguin Island. Additionally, predation by dogs, as per Blamey *et al.* (2024), can be equated to other causes of mortality for the Penguin Island colony such as watercraft collisions, starvation, hyperthermia and chemical contaminants (Cannell *et al.* 2016). Thus, it is important to reduce any causes of annual adult mortality wherever possible.

Given the range of factors involved in the decline of the penguins, it is imperative that any management strategies developed be aligned in both the state and local government agencies to ensure that the recreational needs of the people are matched with the conservation needs of the Little Penguins from Penguin Island. For example, given the high mortality from watercraft injury, it would be prudent for all boats to be fitted with propeller guards. Furthermore, to avoid serious impact on the penguin population, it will be necessary to consider the implications of additional structures, such as boat ramps, jetties and other infrastructure, using robust methods such as decision-support tools. Importantly, their home range extends from Cockburn Sound to Geographe Bay. Finally, it is important to measure the effectiveness of all management strategies.

Changes in distribution on Penguin Island

Similar to the mark-recapture study in 2023, 0 – 4 penguins were caught during each mark-recapture session at the two southern sites. This is much lower than in previous years, e.g. in 2008 I caught 105 penguins coming ashore during one session at the most southern site (Cannell *et al.* 2024). The numbers caught at these two sites has been decreasing since 2017 (Cannell *et al.* 2024). Whilst the numbers caught on the NE side are also lower than in previous years, the proportion of penguins arriving at the NE arrival site and the new arrival site accounted for 90% or more of the penguins returning on any evening in both 2023 and 2024. As such, any plans for future changes to the jetty on Penguin Island must consider the importance of these areas, not just on Penguin Island itself, but also the adjacent offshore areas used by the penguins to access these arrival beaches.

Penguins that use the NE arrival beach are more likely to forage in Cockburn Sound during incubation and on the west side of Garden Island during chick rearing. It is presumed that those arriving at the new arrival site will also be foraging in Cockburn Sound and on the west side of Garden Island. Contrary to this, penguins that arrive at the beaches on the SE and SW side of the island typically forage in coastal areas from Comet Bay to Geographe Bay (and occasionally beyond) during incubation, and in Warnbro Sound and Comet Bay during chick rearing (e.g. Cannell 2016, 2017, 2018). The continued higher proportion of penguins arriving on the NE side of the island highlights the importance of the foraging areas west of Garden Island and in Cockburn Sound for the penguins and may be pivotal in the maintenance of the population on Penguin Island (Cannell *et al.* 2024).

Comparison in demographic parameters between 2023 and 2024

The capture probability is the probability that an individual present at the colony and thus available to be captured, is actually detected. This probability differed within sessions in 2023 and between years. The temporal variability is not a reflection of a difference in recapture effort, as the same protocol was used in every mark-recapture session. The lower probability of capture in the first to sessions of 2023 compared to later that year, and indeed all sessions in 2024, could be due to a greater proportion of the available penguins either foraging at sea for longer before returning to the island, or being on land for longer, i.e. incubating eggs.

In comparison to 2024, a larger proportion of penguins left after session 1, i.e. late September, in 2023. This could be due to more penguins either completing breeding or abandoning their attempt at this time. For the small proportion of penguins that remained after session 1 or arrived in session 2, they had a 100% probability of remaining for the rest of the sessions. This would indicate that these penguins were likely breeding. In 2024, approximately 20% of penguins entered the colony in each of sessions 3 and 4 i.e. late October and early November, and the majority of them remained. These birds could have been involved in a late breeding attempt, and indeed chicks were still present on the island in January (LPWG meeting notes). It is also possible that some of the penguins entering the colony could have been birds that either bred earlier in the season, or took a sabbatical, but were returning during their premoult stage. During this stage, the birds fatten up over two to three weeks prior to moulting. Whilst moulting generally occurs from December to February in any year, moulting penguins have been observed in November (Cannell unpubl. data).

Conclusion

The population of Little Penguins on Penguin Island from September to November 2024 is estimated at **97 ± 13,** 95% CI: 74-128, **individuals**. The decline reflects lower breeding participation and/or fewer penguins available to breed. However, Little Penguins are resilient, and the population can recover with appropriate environmental conditions and threat mitigation strategies. For this to occur, a concerted effort from all levels of the community is required to reduce all threatening processes that this colony is exposed to both on land and at sea and spanning from Cockburn Sound to Geographe Bay. Every breeding attempt by a penguin pair is critical for the future of the population. Further work to determine the habitat used by fledglings and juveniles before they return to the island as sexually mature adults is also important.

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