Understanding the toll of consecutive years of warm waters on Little Penguins and refining their capacity as bioindicators of the marine coastal ecosystem.

Report Year 2

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Contents

Summary

During incubation, the home range of all penguins deployed with satellite tags extended from Rottnest to Geographe Bay. The home range was generally located within 20 km of the coastline. However, in Geographe Bay, it extended to a maximum distance of approximately 25 km from the coast. The home range for all birds combined covered an area of 1733 km^2. It lay within two jurisdictions, from nearshore waters to within Territorial Seas, and under different management regimes such as marine parks, ports, controlled navy waters and public open waters. The core foraging areas during the incubation stage of the breeding cycle were located in 1) Cockburn Sound; 2) west and north west of Garden Island; 3) Comet Bay, and 4) near Dalyellup. Together, core foraging areas covered 95 km^2 but this is likely to have been underestimated due to incomplete foraging trips being recorded by the satellite tags.

Due to very low numbers of penguins breeding, only one penguin was available for GPS tag deployment during the guard phase of chick rearing. A kernel density analysis for the penguin identified 2 core foraging habitats-1) within <500 m of the shore near Singleton, and 2) between 1-3 km offshore from Singleton- Madora. These areas covered a total of 1.3 km^2.

The home range of the penguin extended from Penguin Island to Comet Bay, and covered 10.3 km^2. However, this is underestimated due to the missing data of the return journey.

The daily sea surface temperatures in the vicinity of Penguin Island from May to December 2017 were greater than the long term average.

As in previous years, the penguin raising chicks remained within 20 km of the colony. The penguin guarding chicks, foraged within Comet Bay, and generally dived 7-14 m.

A population estimate for Penguin Island was undertaken in September-November 2017. The abundance of penguins is estimated at 518 penguins. This is approximately one quarter of the relative abundance of penguins in 2007. This decline is likely due to reduced prey stocks, poor breeding participation since 2011, poor breeding success since 2011 and penguins skipping breeding. Coastal development and climate change can potentially impact both the penguins' survival and reproductive success, especially given the penguins' limited flexibility in foraging range. These can be direct impacts on the penguins, such as mortality from watercraft injuries, or indirect impacts such as reduction in prey from climate change and loss of important fish habitat.

Community stewardship of the environment in general, and specifically the penguins, has been raised by posting blogs on my research facebook page and presentations in various fora.

Introduction

Little Penguins from Penguin Island have been comprehensively studied over the last two 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.

These penguins have also been identified as being under the highest threat of all marine fauna in the local region, whilst also having the highest conservation value. Moreover, they are key performance indicators for the Shoalwater Islands Marine Park.

One study stream has involved deploying satellite tags on Little Penguins from Penguin Island to investigate the habitats they use for travelling and feeding when they are incubating eggs. These data, obtained over a 5 year period (from 2008-2009, 2013-2015) have revealed that the penguins' home range extended from Two Rocks/Yanchep to approx. 230 km (shortest distance) away at Cape Clairault, though there was annual variation in the extent. The core foraging areas were generally in Cockburn Sound; west of Garden Island; Lake Clifton-Binningup; in and around Koombana Bay (Bunbury) and between Cape Naturaliste and Cape Clairault.

The project in 2013-2015 further investigated the resilience of Little Penguins to climate change and coastal development, with funding from the City of Rockingham, Australian Geographic, and Fremantle Ports. As well as the deployment of satellite tags during incubation, GPS tags were used during chick rearing to determine fine scale movement when the penguins must use areas closer to the colony. This is necessary so they can return each evening to feed their chicks. During this stage of their breeding cycle, the penguins foraged in Warnbro Sound; Comet Bay (especially adjacent to Singleton); the west side of Garden Island; and Cockburn Sound.

However, since 2010, many fewer penguins have been attempting to breed in the nestboxes which have been monitored for nearly 30 years, and the overall chick production has been low. This has largely been associated with sea surface temperatures (SST) remaining above average since the marine heatwave in late 2010. Despite average SST in some months in 2015 the penguins again travelled large distances during incubation and breeding success was low. Average to below average water temperatures prevailed for most of 2016, and the breeding success of the penguins improved. The size of both the core habitat and home range were much smaller in 2016 compared to 2014-2015, and this was consistent for both penguins incubating eggs and those raising chicks. The penguins also foraged slightly closer to the colony during incubation. Not surprisingly, the average duration of the foraging trips during incubation, was also shorter in 2016. Unfortunately the number of penguins participating in breeding was low. So this study identified that the penguins have been impacted by changes in the marine ecosystem. In essence, this coastal marine system has not supported a high proportion of breeding penguins and the penguins incubating eggs were often at sea for much longer than the average.

The size of a population is a reflection of the number of births, deaths, immigrants and emigrants and is affected by environmental and human-based processes (Cannell *et al.*2011). Previous estimates of the colony showed a decline between 2007 and 2008, and the decline was attributed to fewer adult penguins attempting to breed (Cannell *et al.*2011). Given the conservation status of this colony, and its tourism potential, it is paramount to estimate the population in order to assess its' long term viability.

In the current study, the foraging habitat of Little Penguins during incubation and chick rearing was investigated to determine 1) if the foraging habitats had changed compared to previous years, and 2) the efficacy of using Little Penguins as indicators of the health of the marine coastal ecosystem. The size of the colony was also estimated to determine the impact of the consecutive years of poor breeding success and/or reduced breeding participation.

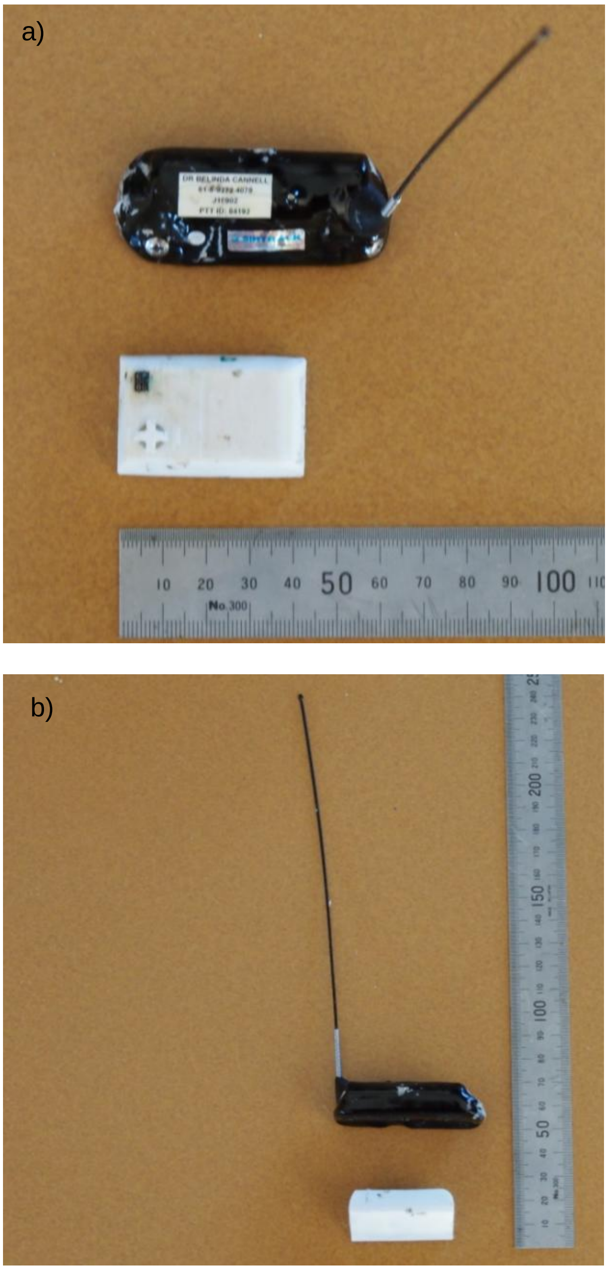
Materials and methods

The study was conducted on Penguin Island (31°58'S, 115°49'E), approximately 50 km south of Perth. At 12.5 ha, it is the largest in a group of islands in the Shoalwater Islands Marine Park, and is only 600 m offshore. The island substrate is too soft for the penguins to build burrows (Klomp *et al.*, 1991) hence, they either nest under bushes of *Tetragonia decumbens* or *Rhagodia baccata* (Dunlop *et al.*, 1988), or in nestboxes placed around the island from 1986 (Klomp *et al.*1991). The penguins in this study were breeding in the nestboxes. However, the penguins do not all breed at the same time, i.e. they are not synchronous breeders. Hence, I checked the boxes regularly once breeding was first observed in any of the nestboxes to 1) ensure that tags were attached to as many penguins as possible, and 2) obtain information on the success of pairs that did not have a tag attached to determine the impact of the tags.

Very few penguins attempted to breed, or bred successfully in 2017, severely limiting the number of penguins available to deploy tags on. To study the foraging movements of the birds, satellite tags (Kiwisat PTT 202 K2G 172A, 32g, 60x27x17mm, Antenna angle 60°, duty cycle 2000-1500 UTC, repetition rate 35s-Figs. 1a and b) were attached to Little Penguins during incubation (5 males 1 female, Table 1). Four of the 6 tags failed before the birds returned to the colony, two due to equipment failure and two due to the birds remaining at sea for longer than the duration of the battery. Only one male penguin was available for deployment of an accelerometer tag, which determines depth of dives and GPS position on the surface during the chick-guard stage (chicks up to two weeks old). Data from satellite tags are collected by Argos and are obtained from the Argos website, whereas the 3D tags log the location data. This means the data from 3D tags can only be obtained if the tag is retrieved and the data are then downloaded. Location data were analysed using different methodologies, dependent on two things:

a) the type of tag deployed on the penguins, and

b) if a satellite tag was deployed for single or multiple day trips.



Figs. 1a and b. Top and side view of the satellite tag (black) and 3D tag (white).

Satellite tags

The location data obtained from multiple day trips were analysed using a Bayesian State-space model (SSM) to account for location uncertainty. A hierarchical first-difference correlated randomised walk model was used in the SSM. For all the birds combined, the 50 and 95% kernel density areas were analysed using Home Range in Arcview 3.2. The 50% kernel density area represents core habitat, while the 95% kernel density area represents home range. For individual birds, these kernel density areas were calculated using the Brownian Bridge kernel method implemented in the function “kernelbb” of the R package “adehabitatHR” (Calenge, 2006).

As the data from the 3D tags had greater position accuracy, and the locations were obtained at a much high frequency rate, the raw data were analysed without preprocessing. The 50 and 95% kernel densities for all penguins combined, and for each individual penguin, were analysed using the hplugin value implemented in the function “kde” of the R package “ks” (Doung, 2014), and the volume of the kernel densities were calculated by implementing the function “getvolumeUD” of the R package “adehabitatHR”.

Data from satellite tags deployed on penguins that completed single day trips could not be analysed using the SSM due to the low number of total locations per trip. Hence, these data were analysed separately. The total time spent in different areas along the track was determined using the ‘trip’ package (Sumner, 2015) in R, but the core habitat and home range cannot be determined from this analysis.

Sea surface temperature data were downloaded from the NOAA coral reef watch virtual stations website (http://coralreefwatch.noaa.gov/satellite/vs_added/graphs_2yr_current/vs_wa_ts_2yr_ShoalwaterIslands_Australia.png).

Population estimate

To estimate the population for the entire colony I combined a mark-recapture sampling over the peak time of breeding on part of the island and counts of penguins arriving at night across the majority of the island (*sensu* Cannell *et al.*2011) in five different years (2007, 2008, 2010, 2011 and 2017). A robust design analysis (Pollock *et al.*1990).was then used to model the penguin abundance.

Mark-recapture study

The four arrival beaches used by the majority of penguins on Penguin Island have previously been identified (Cannell *et al.*2011). Penguins were caught at each of these major arrival sites, one site per night, over four consecutive nights. This was repeated on four occasions between September and November in 2017. The block of four night captures were repeated every two weeks.

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.2). Arriving penguins were herded into the corral, the corral was closed off and the penguins were removed. The corral was then reopened as penguins continue to arrive for several hours, either in groups or alone (Klomp and Wooller *et al.*1991, Cannell unpubl.data). Each group of captured penguins was taken to an adjacent area that was 10 to 30 metres from the corral area and not directly visible from the landfall site. Here the penguins were weighed in a bag to the nearest 10g using Salter 2 kg*10 g scales. They were checked for flipper bands and scanned for subcutaneous transponders with a Portable Reader (Iso Max IV, scanning distance up to 30 cm). If the penguins had neither form of identification, they were marked with a transponder (Reunite; 13.3 mm*2 mm; numeric identification code). Upon marking, the maximum beak depth and length were measured. 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 (Cannell *et al.*2011)

Fig. 2 Corral set up at one of the beaches used by Little Penguins returning to the colony on Penguin Island 2017.

Beach Counts

In August and September 2017, counts of arriving penguins were conducted once each month at 15 sites around Penguin Island, which covered the majority of available landfall sites around the island (Fig 3). Sites one to four were also used for the beach captures. To assist in correctly observing and identifying the penguins, Night Vision Monoculars were used by RAN personnel. Using these, each counter was able to clearly see penguins within a 40 m radius. The counts were conducted around the first quarter moon phase, from sunset to two hours after Civil Twilight. Both the number of penguins arriving in each group and the time of arrival were noted.

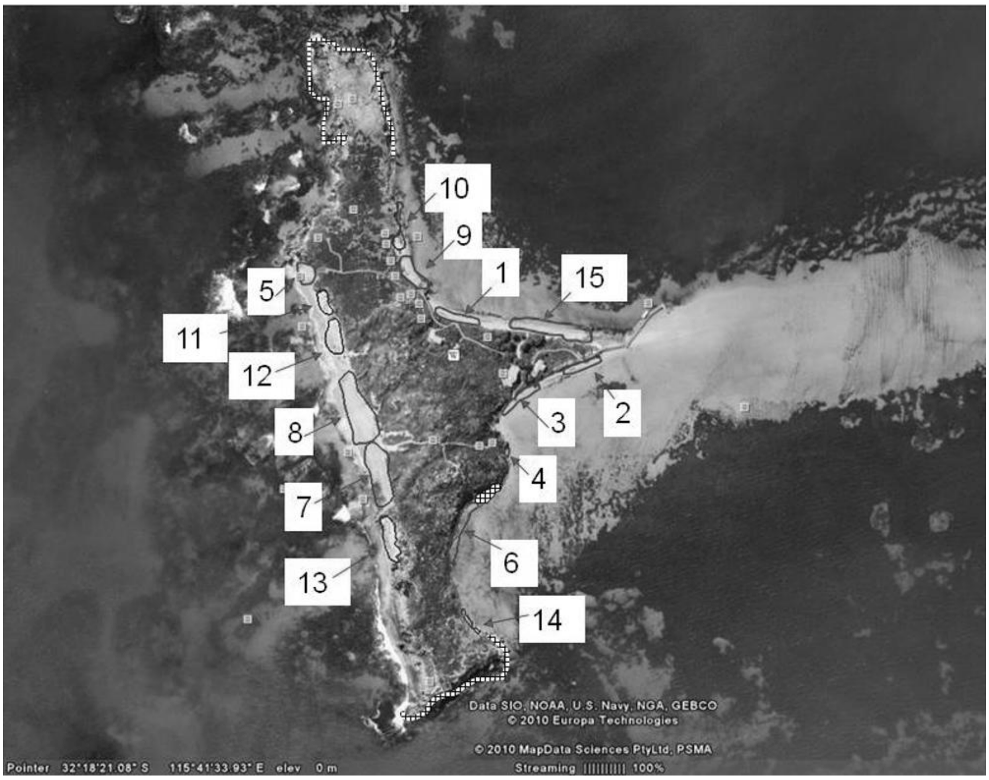


Fig. 3. The location of the 15 sites on Penguin Island where penguins were counted coming ashore after civil twilight. The counts were conducted one night in August and September 2017, and coincided with the first quarter moon phase .

Results

Incubation

Foraging trip parameters

During the incubation phase, penguins with attached satellite tags remained at the nest from 4-10 days following the tag attachment before departing on a foraging trip (Table 1). This represents a minimum duration of each incubation shift, given that it is not known how long the penguin had been on the nest prior to tag attachment. The foraging trips ranged from 1->10 days. One of the birds incubating eggs (Bird 5, Table 1) returned after a five day trip and one day after his first egg began hatching. However, he departed the next day and did not return for at least 11 days. His chicks were found dead in the nest, with no parent. Another incubating bird (Bird 6, Table 1) undertook a single day foraging trip, returned for a day, then departed for two days, returned in the evening and then departed the next day. He had not returned before the tag stopped working. It is unclear if Penguin 6 abandoned the eggs for each of the shorter trips, but they were found abandoned during the last trip.

Table 1. Trip information, including sex, tag type, duration of trip and breeding success. For trips where the satellite tags failed before the bird returned to the nest and no other data were available to determine return date, the duration was listed as greater than (>) the number of days for which data were available.

ID	Gender	Breeding Stage	Tag type	Date of Attachment	Date of Departure	Duration of trip (days)	No eggs hatch	No chicks successful
1[a]	Male	Incubation	Sat	16/6/17	20/6/17	7	2	2
2[a]	Male	Incubation	Sat	16/6/17	24/6/17	>6	2	0
3[b]	Female	Incubation	Sat	26/6/17			2	2
4	Male	Incubation	Sat	3/7/17	6/7/17	5	2	2
5[c]	Male	Incubation	Sat	10/7/17	14/7/17	5,>10	2	0
6[c]	Male	Incubation	Sat	17/7/17	27/7/17	1,2,>9	0	0
7	Male	Guard Phase	3D	29/8/17	30/8/17	1	2	1

[a] Tag was lost prior to completion of trip
[b] Tag removed due to equipment failure of previous two attachments (birds 1 and 2), thereby preventing unnecessary loss of a satellite tag
[c] Last track undertaken is incomplete as the bird was away for longer than then duration of the battery

During incubation, the home range (95% contour) of all penguins combined extended from near Rottnest to Geographe Bay (Fig. 4). The home range was generally located within 20 km of the coastline and within waters with a maximum depth of 20 m. However, in Geographe Bay, the home range extended to a maximum distance of approximately 25 km from the coast. The home range for all birds combined covered an area of 1733 km^2. It lay within two jurisdictions, from nearshore waters to within Territorial Seas, and under different management regimes such as marine parks, ports, controlled navy waters and public open waters .The maximum foraging range from the colony to areas used by the penguins varied from a minimum of 22 km north, in Cockburn Warnbro Sound, to 145 km south to Geographe Bay near Dalyellup (Fig. 4, Table 2). A kernel density analysis for all the birds combined identified four important foraging areas. These areas, in which there was a 50% probability of finding the penguins, were located in 1) Cockburn Sound; 2) west and north west of Garden Island; 3) Comet Bay, and 4) near Dalyellup. This core habitat covered an area of 95 km^2. The size and location of both the core habitat and home range however are potentially underestimated due to the inclusion of data from incomplete foraging trips.

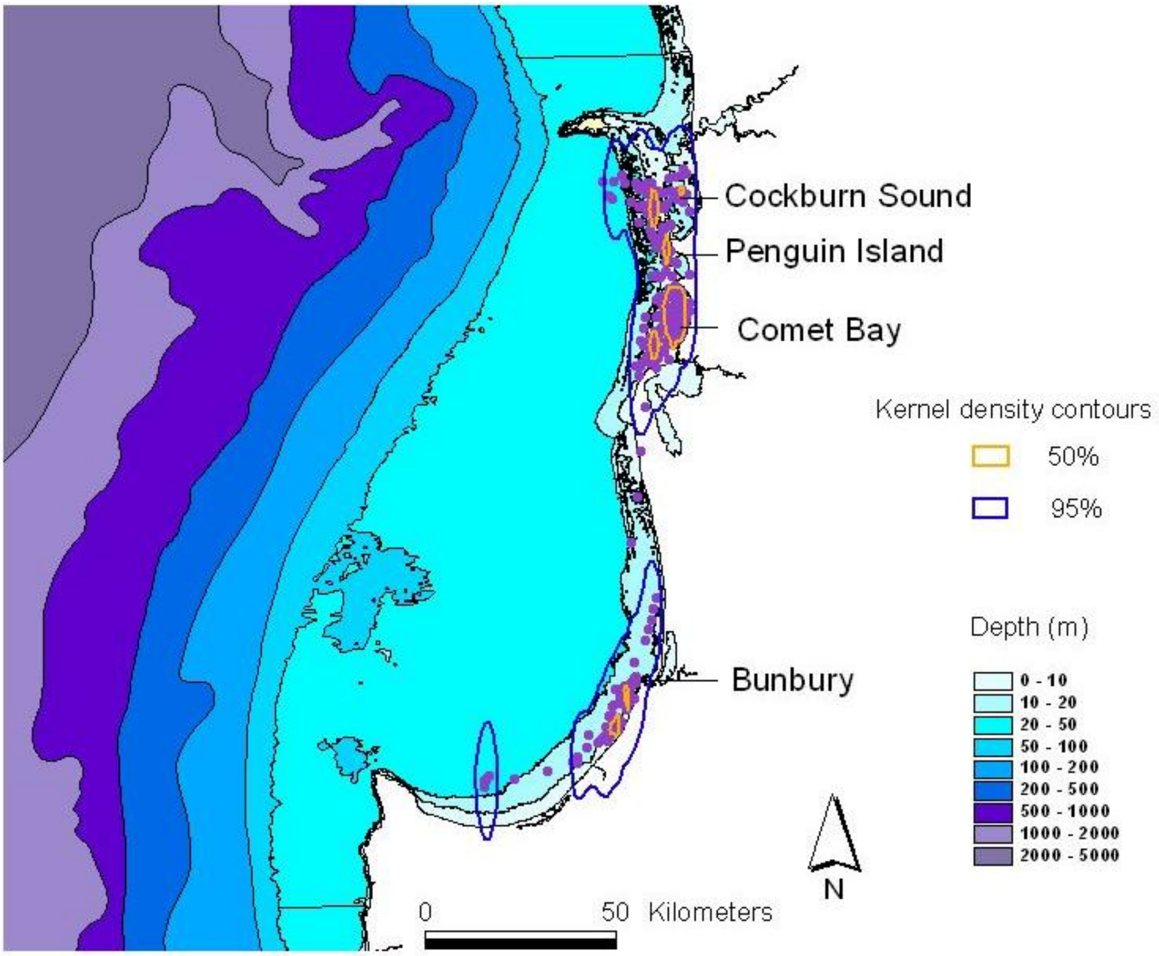


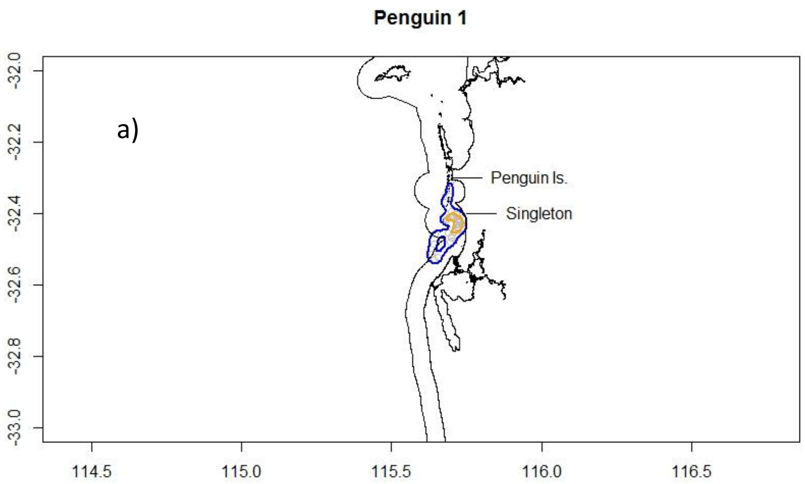
Fig. 4 Kernel utilisation distributions encompassing 50% (orange) and 95% (blue) of locations of 5 penguins during incubation. The core foraging areas (50%) are located in: Cockburn Sound, west and northwest of Garden Island, Comet Bay and adjacent to Dalyellup

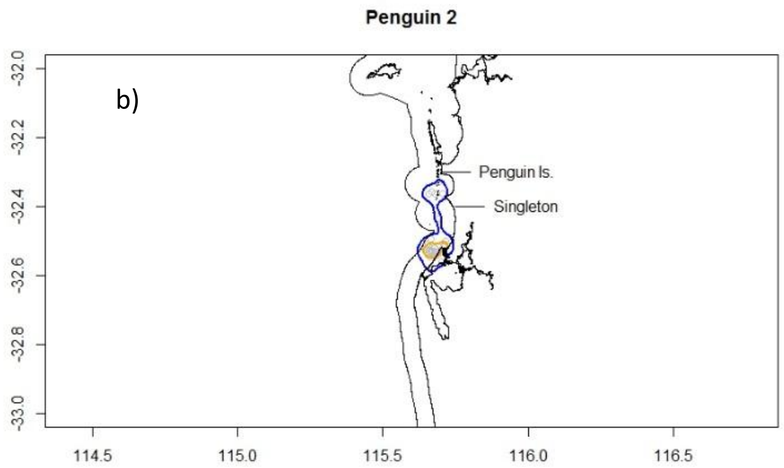
Each penguin generally concentrated foraging effort in one area (Table 2, Figs 5 a-g), and the penguins remained within their core area of foraging from 2 -7consecutive days, though this could be underestimated due to incomplete trips. The size of these core areas ranged from 18 – 62 km^2 (Table 2).

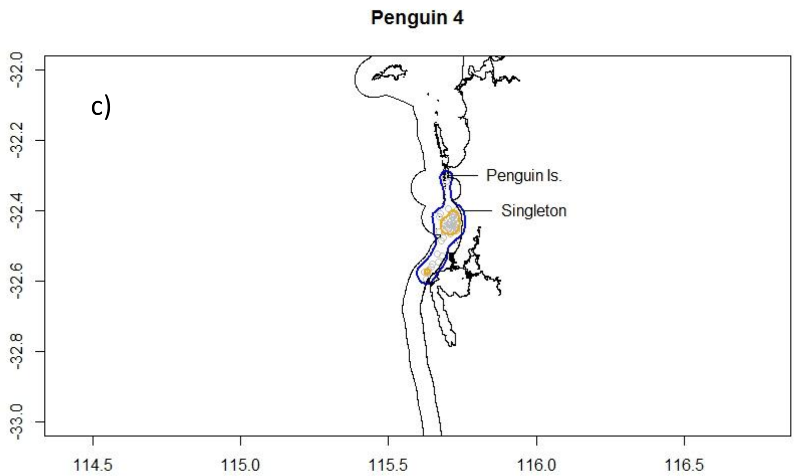
Table 2. The size of the core foraging habitat (50% kernel density) and home range (95% kernel density) and maximum foraging range of penguins incubating eggs at Penguin Island, 2017. Excludes single day foraging trips (Penguin 6).

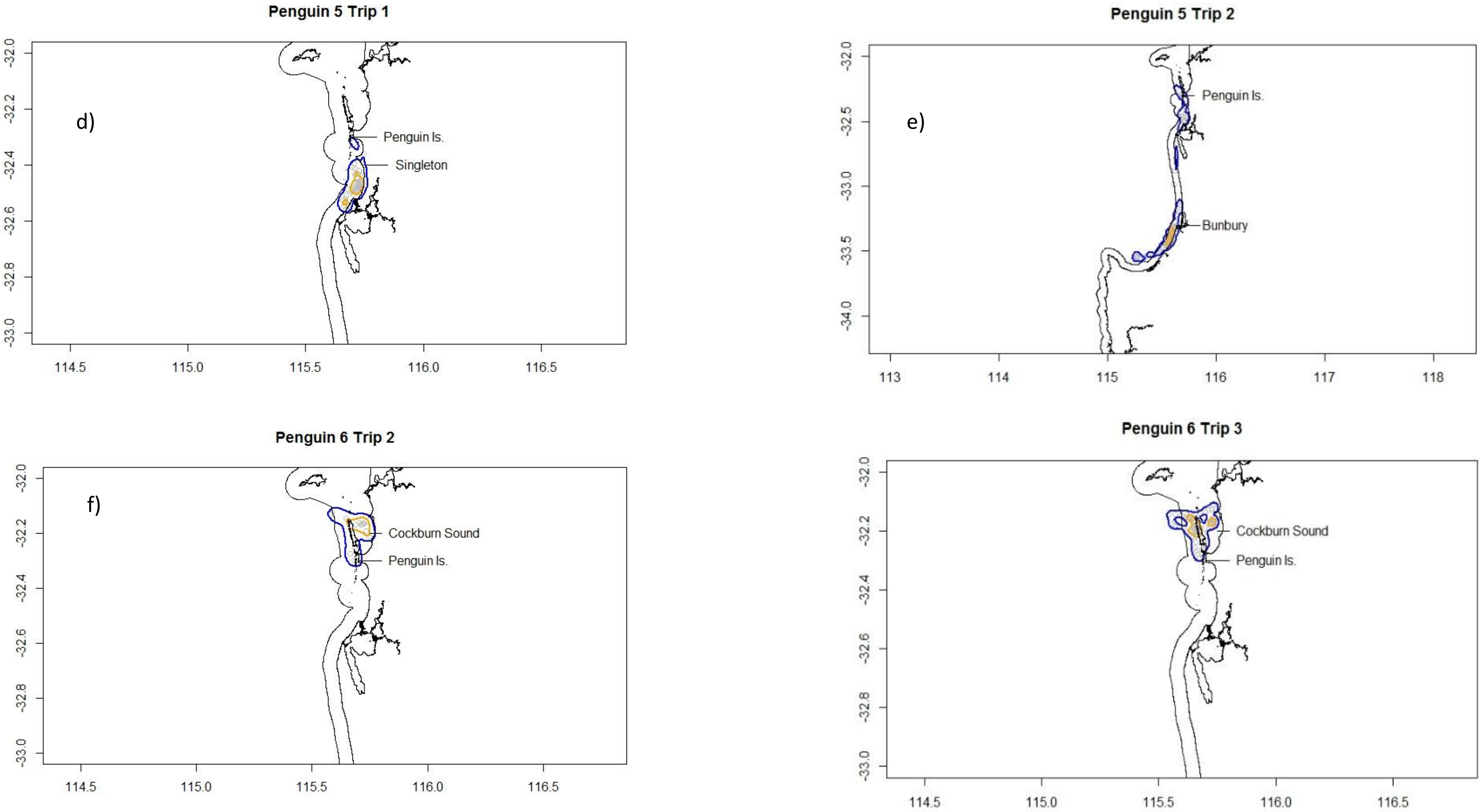
Penguin ID	**Breeding stage**	**50% kernel density area (km^2)**	**95% kernel density area (km^2)**	**Location of 50% kernel density**	**Max foraging range from Penguin Island (km)**
1*	Incubation	18	115	Comet Bay, adjacent to Singleton	25
2*	Incubation	27	159	Comet Bay, adjacent to Halls Head	31
4	Incubation	38	200	Comet Bay, adjacent to Singleton and Dawesville cut	33
5 (trip 1)	Incubation	32	156	Southern Comet Bay	28
5 (trip 2) *	Incubation	62	592	Geographe Bay, adjacent to Bunbury-Dalyellup	145
6 (trip 2)	Incubation	46	222	Northern Cockburn Sound/Jervoise Bank	22
6(trip 3) *	Incubation	36	203	Northern Cockburn Sound/Jervoise Bank and North west Garden Island in the Sepia Depression/Five Fathom Bank	23

*Potential underestimate as tag was lost before the bird returned home


Penguin 1
a)
Penguin Is.
Singleton
-32.0
-32.2
-32.4
-32.6
-32.8
-33.0
114.5
115.0
115.5
116.0
116.5


Penguin 2
b)
Penguin Is.
Singleton
-32.0
-32.2
-32.4
-32.6
-32.8
-33.0
114.5
115.0
115.5
116.0
116.5


Penguin 4
c)
Penguin Is.
Singleton
-32.0
-32.2
-32.4
-32.6
-32.8
-33.0
114.5
115.0
115.5
116.0
116.5



Figs. 5 a-g Kernel utilisation distributions identifying areas with a 50% (orange) and 95% (blue) probability of finding a penguin at sea, using the state-space position estimates (grey circles)of Argos satellite tag data. The tag from Penguin 3 was removed to prevent potential loss of the tag from equipment failure. The trips undertaken by Penguins 1, 2, 5 (trip2) and 6 (trip 3) are potentially underestimated. The first trip for Penguin 6 was a single day trip and is modelled separately

One penguin (# 6) completed a single day foraging trip during incubation to the waters adjacent to the south western edge of Garden Island (Fig. 6). The maximum distance of this trip from the colony was 10 km.

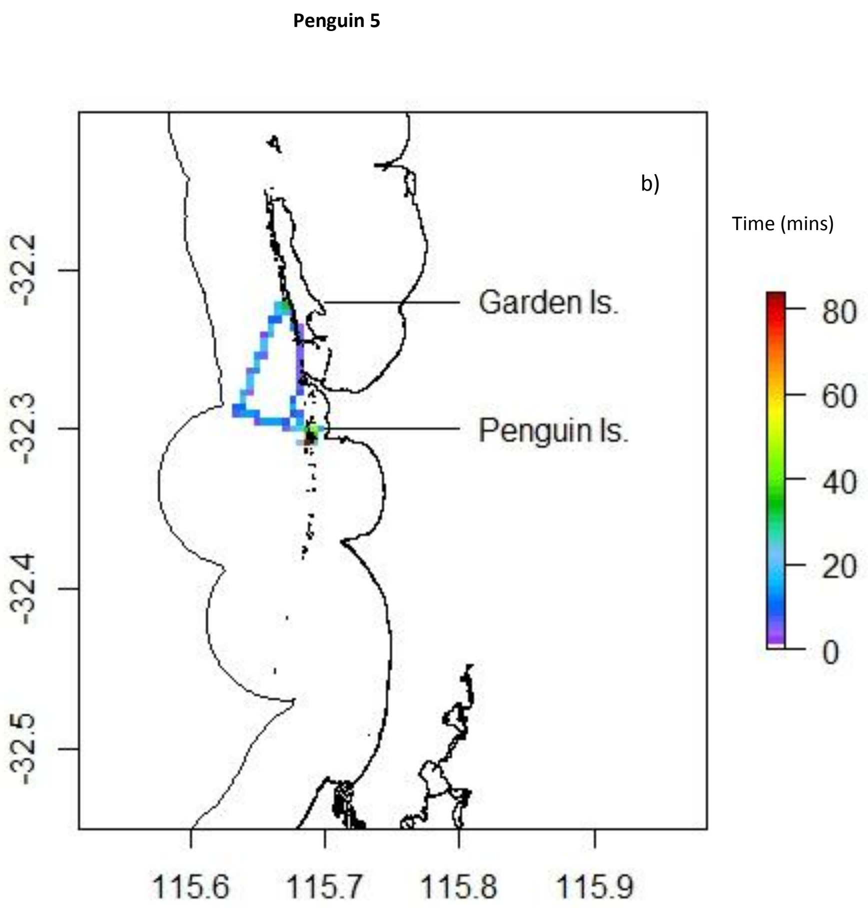


Fig 6 Single day foraging trip completed by Penguin 6 from Penguin Island during incubation:

Guard Phase

GPS locations

A tag was deployed only on one Little Penguin, due to very low numbers of penguins raising chicks in the nestboxes. A complete track was obtained from this bird with data missing only for 2 ½ hours during his return journey.

A kernel density analysis for this penguin identified two areas of core habitat both in Comet Bay -1) within <500 m of the shore near Singleton, and 2) between 1-3 km offshore from Singleton-Madora (Fig. 7). These areas covered a total of 1.3 km^2. The home range of the penguin extended from Penguin Island to Comet Bay, and covered 10.3 km^2. However, this is underestimated due to the missing data of the return journey.

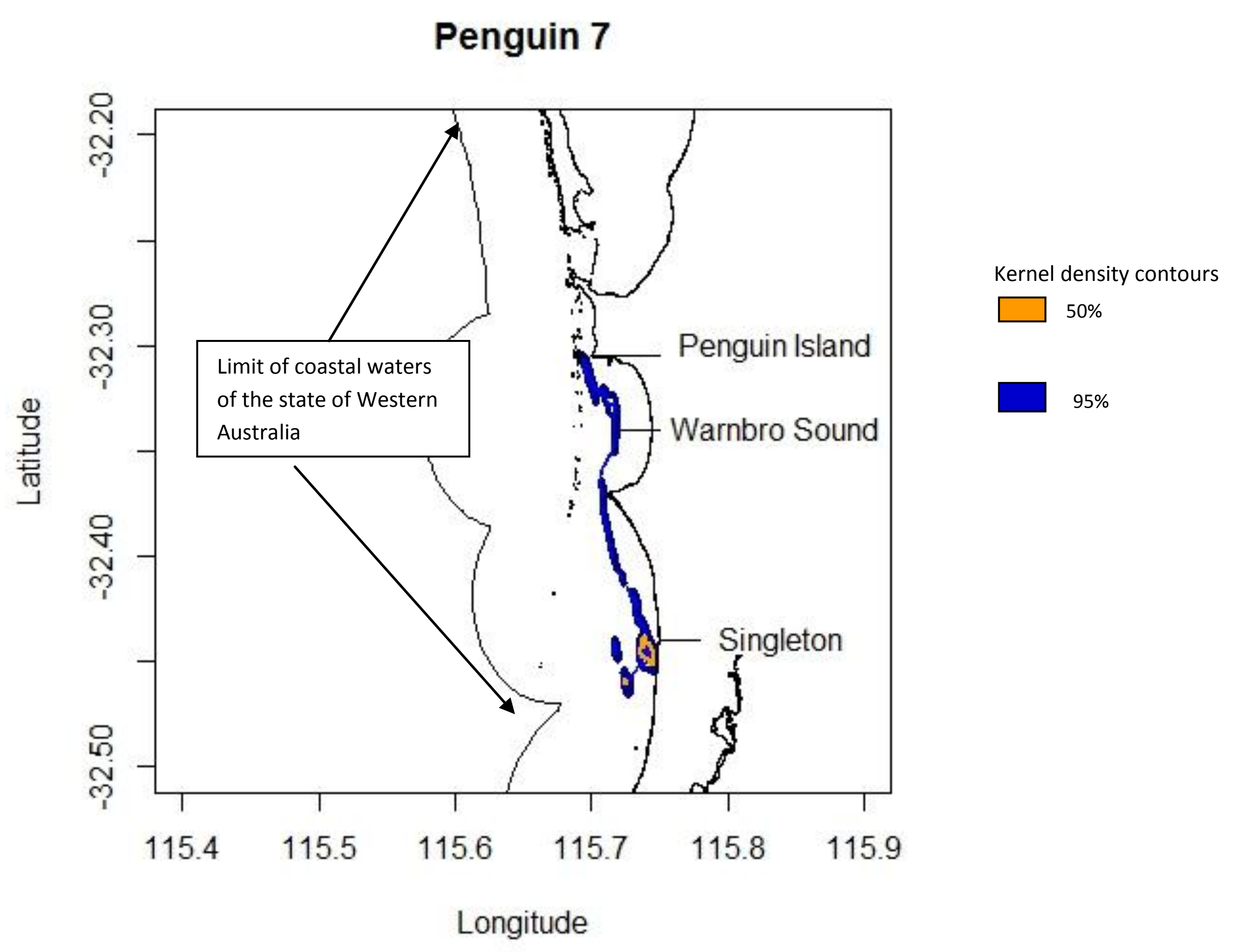


Fig. 7. Kernel utilisation distributions encompassing core habitat (50%-orange) and home range (95%- blue) of GPS locations of a penguin completing a single day foraging trips whilst guarding chicks.

The maximum distance the penguin travelled from the colony was 18 km. As in previous years, the trip was divided into 3 phases, with the penguin initially leaving the colony before dawn and spending long periods of time on the surface of the water whilst heading in the direction towards its foraging grounds. It then increased its travelling speed until it reached its foraging grounds, offshore from Singleton. The penguin then spent approximately 9 hours foraging, identified by areas of high residence and sinuosity often interspersed by slower travel between areas. The third phase was likely a straight line movement back to the colony with the penguin spending very little time on the surface. As a result if this behaviour, there were no GPS locations between the last foraging area offshore from Singleton and a location close to the colony (Fig. 8).

Fig. 8 GPS tracks of the male Little Penguin from Penguin Island during the chick- guard phase, 2017.

Diving behaviour of the penguin

Whilst the GPS locations were not obtained every hour for the tag, diving data were available for the complete trip.

The penguin foraged mainly offshore from Singleton, and generally dived deeper to depths ranging from 7-14 m. The penguin's post-dive surface intervals typically lasted for 1-5 seconds. However, longer intervals also occurred after a series of dives (Fig 9).

The penguin travelled within the top 0.5-1 m of the surface. During the return travel, the penguin dived for short durations and surfaced only briefly.

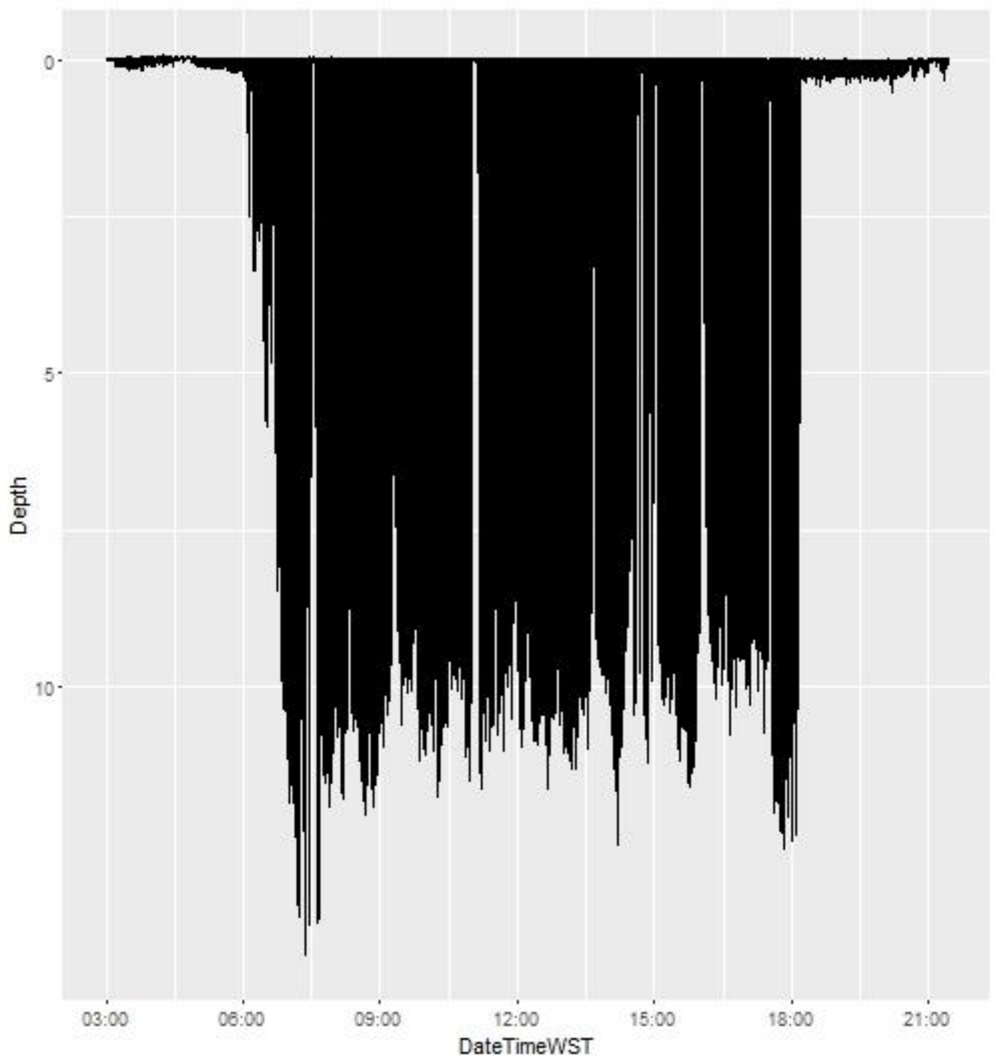


Fig. 9 Diving behaviour of Penguin 7.

Impact of tag deployment on breeding success

The breeding was not successful in approx 60% of the nests in which one penguin was tagged, and in 74% of nests where neither penguin was tagged. However, there was no significant difference in the breeding success of penguin pairs, regardless of whether a tag had been deployed on a penguin or not (Fisher's exact test, odds ratio=1.9, p=0.3093).

Sea Surface Temperatures 2017

The daily sea surface temperatures (SST) in the vicinity of Penguin Island were above the long term average (Fig. 10).

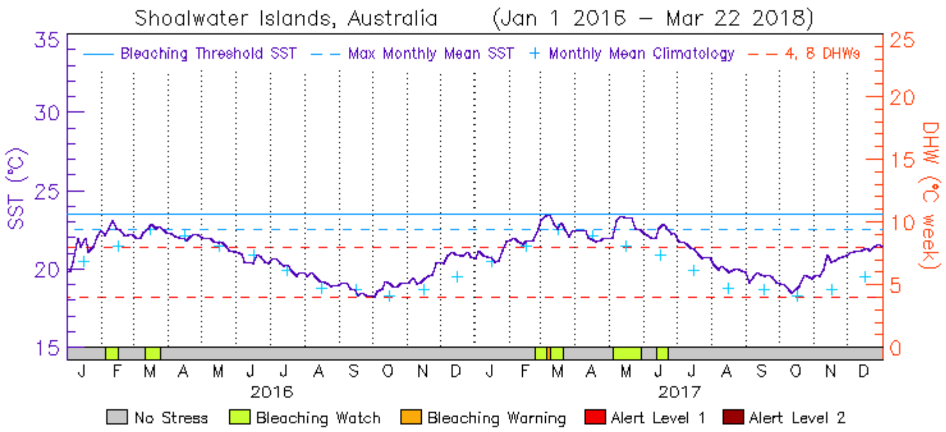


Fig. 10. SST data obtained from NOAA for the Shoalwater Islands virtual station from Jan 2016-Mar 2018. The temperature data, purple line, shows that the SST were generally equivalent to the long term average from January- April in 2017, then above average for the remainder of the year..

Population estimate

The estimated abundance of penguins using Penguin Island in 2017 is estimated at 518 penguins (95% CI: 224-1195).

Community awareness

Throughout the year I wrote 23 posts related to this project on my research Facebook Page. The link to my page was shared with the City of Rockingham and Fremantle Ports. There were between 7-23 likes for each post, the number of people reached ranged from 17-605, at least 12 of the posts had at least 1 comment, and five of the posts were shared. I also gave presentations which included results from this project at several fora.

Comparison in size of core habitat and home range between years

The home range of the penguins in 2017 was at least 1.3 times larger than that of 2016. However, it is not possible to meaningfully compare the size of the core habitat used by the penguins between years, due to the small number of tracks, some of which are incomplete trips.

Discussion

The breeding cycle of the Little Penguins in 2017 began well, with the first eggs laid in May. However, the penguins on Penguin Island do not all lay eggs at the same time, i.e. they are asynchronous breeders, and in 2017 eggs were laid in any month from May-October This range includes both first and second clutch eggs, and was slightly shorter than typical for the colony on Penguin Island (Wooller *et al.*1991, Wienecke 1993). Although the breeding year began well, the numbers of penguins observed attempting to breed in the nestboxes markedly reduced from July. The annual number of penguins attempting to breed in the nestboxes was lower than average, and much lower than recent “poor” years. The breeding success of the penguins was also lower than average. This very poor breeding year is likely associated with the above average SST of the coastal waters near Penguin Island that generally persisted from May through to December 2017. The higher SST, which reached approx. 3°C above average at times, presumably affected the presence and abundance of baitfish in the coastal area, as has been shown for SE Australia (Carroll *et al.*2016). Fish catch data from local commercial fisherman also support a reduced fish abundance in a similar area. It would therefore appear that prey availability was generally inadequate for <u>even</u> the reduced number of breeding penguins.

Regardless of the breeding stage or time of year, penguins swam to areas both north and south of Penguin Island. As in previous years, the location of a penguin’s nest site on the island influenced whether they travelled south or north of Penguin Island. The penguins nesting on the north east of the island made trips to the north, and those nesting elsewhere on the island made trips to the south.

The diving behaviour of the penguin guarding a chick was similar to that of the penguins that fed in the same general area in 2016. The depth that the penguin dived to was consistent with it feeding on benthic fish such as sandy sprat. However, the fish species cannot be verified without an analysis of the prey eaten by these penguins. This analysis is currently not possible due to limited funding.

All penguins return to the colony, and presumably the behaviour of the penguins is consistent despite the breeding stage. During their return journey, the penguins only dive to very shallow depths and briefly surface for air. This is in direct contrast to their departure from the colony, marked by a meandering trajectory, mainly on the surface. As the penguins are vulnerable to being struck by watercraft when they are on the surface or within the top 2 m of water (depth of vulnerability is dependent on the draft of the craft), then the penguins that used areas both north and south of the colony can be impacted by watercraft. But time of day also has an influence on vulnerability, and the penguins are less likely to be impacted by watercraft during their departure from the colony. This is because the penguins generally depart from the colony 1 – 2 hours before sunrise when it is less likely for watercraft to be using the waters around Penguin Island. However, penguins will potentially be impacted by watercraft throughout the rest of the day. The penguins are at an increased risk of collisions with watercraft on their return journey to the colony. The penguins’ return journey is either from Comet Bay and through Warnbro Sound, or from the west side of Garden Island and through Shoalwater Bay. Given increases in both the ownership of watercraft in the Rockingham area, and the use of watercraft in waters from Woodman Point to Geographe Bay, it is not surprising that injuries from collisions are the main cause of mortality of Little Penguins in the Perth region (Cannell *et al.*2016)

Population estimate

Each capture-recapture estimate of abundance reflects the number of animals using a particular area within a given period rather than an absolute population. Importantly, the timing of the capture –recapture was similar to that undertaken in previous years, so it is possible to determine relative change in abundance. The estimate for 2017 is almost a quarter of that for the same time of year in 2007. This reduction in relative numbers of penguins using the island in September-November each year is alarming, and it is important to identify the likely cause/s of this decline.

The four processes that determine the size of a population are the number of births, deaths, immigrants and emigrants. For the Penguin Island colony, four factors have likely contributed to the decline 1) some penguins skipped breeding for the year, exemplified by the presence of nonbreeding penguins in nestboxes early in the year that were not then observed breeding, 2) low annual participation in breeding every year since the marine heatwave in 2011, 3) poor breeding success in every year since 2011, with the exception of 2016, and 4) changes in survival. As penguins have a very strong fidelity to a colony, and permanent emigration of the birds skipping breeding is unlikely, the decline is due to temporary emigration, a reduction in the number of births and increased mortality.

The consequence of the generally low participation in breeding and poor breeding success, is that many fewer penguin chicks hatched each year. Of the chicks that hatch, less than 20% are estimated to survive (Sidhu et al 2007), and it is possible that the apparent poor prey fish stocks near the colony would have further reduced the survival rate. As the surviving chicks do not return to their natal colony until they are sexually mature, i.e. at 2-3 years old, then the number of young penguins recruiting back into the colony will have been low since 2013, i.e two years after the marine heatwave. Breeding success was higher in 2016, but few penguins bred that year, so recruitment may be slightly better in 2018 and 2019. Even if the numbers of young penguins returning to the colony increases, they must breed successfully for the population to grow, and this is inextricably linked to prey abundance in close proximity to the colony.

During the marine heatwave of 2011 there was a four fold increase in mortality of penguins, many dying from starvation. Furthermore, in 2011 and 2012 several penguins died from an infection by a protozoan parasite (Cannell *et al.*2016). Very few dead penguins have been found in recent years, and this could either reflect fewer penguins dying, or fewer carcases found. Therefore it is not possible to determine if mortality of adults has increased recently. Regardless of the cause of the population decline, it is imperative that all current and potential impacts to the colony are reduced where possible.

Conclusion

The data collected over the past 5 years have identified 1) a relatively consistent core habitat and home range of the penguins, generally within 20-30 km of the coast, but more often within 10 km, and 2) a reduction in overall size of home range and core habitat when SST are similar to the long term average. With these data, we can surmise that:

1. Little Penguins have limited areas where they can forage;
2. coastal activities and developments can impact both the penguins' survival and reproductive success;
3. these impacts can be direct, for example:
    a. injuries and mortality from collisions with watercraft , particularly faster moving craft,
    b. entanglements in fishing line,
    c. interaction with pollution such as oil;
4. the penguins can be indirectly impacted, via
    a. bioaccumulation of pollutants by ingesting prey that have concentrations of heavy metals, organochlorines, tributyl tin (an antifoulant) etc,
    b. reduction in fish prey from
        i. increased fishing,
        ii. climate change,
        iii. loss of important fish habitat such as seagrass/ reef,
        iv. changes in water quality;
5. the indirect impacts may occur outside the home range of the penguins.

Thus, for the colony to have a chance of remaining viable, future coastal development situated anywhere within the consistent home range of the penguins from Penguin Island i.e. Rottnest to Geographe Bay**, must consider likely impacts on the penguin colony.** But it is also important to consider potential impacts of development outside the penguins' home range, particularly if they impact prey abundance. It is also imperative to not just consider impacts associated with each development in isolation, but rather the cumulative impacts of multiple developments. Finally, other activities already occurring within their home range must also be considered when assessing potential impacts of developments on the penguins. Naturally, cumulative impacts should also now be including those impacts that are associated with climate change. However, it is currently difficult for management options to effectively tackle impacts in the marine environment associated with climate change. Therefore, for the colony to have a chance of surviving, it is necessary to limit additional anthropogenic based impacts on the penguins.

The multiple years of data on the foraging habitats of the penguins during incubation and early chick rearing has shown that the penguins have limited plasticity for where they can forage. Additionally, the penguins cannot adjust for a lack of prey by increasing their foraging time without affecting either their partner or their chicks. So impacts in the marine environment between Fremantle and Geographe Bay will be revealed by the penguins, in their breeding participation, success, and longer term population trends. Hence, the penguins are indeed good bioindicators of the health of the coastal marine system. However, it is often difficult to determine the exact cause of change in a response. As such additional research on the diet composition, fish abundance and oceanographic variables is necessary to strengthen the power of the penguins as bioindicators.

Community awareness

The community awareness of the penguin's existence in the local marine environment was raised through posting regular blogs on my research Facebook page. These blogs included both maps and descriptions of the location of specific penguins, as well as the success of their breeding attempts. The issues about the impacts of climate change on both the marine environment and the penguins were also described in these blogs.

In 2017, I presented my research

- to the board of Fremantle Ports,
- at the WA Seabird Conservation Forum in Albany
- to the Environment Management Branch of the Department of Biodiversity, Conservation and Attractions
- to the Murdoch University Animal Ethics Committee
- at a preliminary event to *In the Zone: The Blue Zone* Western Australia's premier forum on questions of regional significance, hosted by the Perth US Asia Centre
- at the Matariki Network Conference: Marine Extremes

My research also involved many volunteers, including RAN personnel and students from both Murdoch University and UWA. Thus, this project has succeeded in raising community stewardship of the environment.

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