

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



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Summary

During incubation, the home range of all penguins deployed with satellite tags extended from Rottneest to Binningup. The home range was generally located within 20 km of the coastline. However, near Rottneest Island, it extended to a maximum distance of approximately 25 km from the coast. The home range for all birds combined covered an area of 1337 km². 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 – 1) Cockburn Sound, 2) between the northern end of Garden Island and Rottneest, 3) Comet Bay, 4) adjacent to Lake Clifton- Preston Beach, and 5) adjacent to Preston Beach-Myalup . Together, core foraging areas covered 140 km². The foraging trips lasted an average of 5.3 ± 2.5 days.

GPS tags were attached to Penguin Island penguins while they were raising young chicks, specifically during the guard phase. A kernel density analysis for all penguins combined identified several core areas during a foraging trip: -1) Warnbro Sound, 2) Comet Bay- within <500 m of the shore near Singleton, and between 1-3 km offshore from Singleton- Madora, 3) NW of Penguin Island, within the Sepia Depression and ranging from 1 – 5 km offshore, and 4) adjacent to the Five Fathom Bank, west of Garden Island. These areas covered a

total of 7 km². The home range of all the penguins extended from north-western Garden Island to Comet Bay, and covered 42 km². The foraging trips were all single- day trips.

The daily sea surface temperatures in the vicinity of Penguin Island generally equalled the long term average.

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. Not surprisingly, the average duration of the foraging trips during incubation, was also shorter in 2016. However, as in previous years, the penguins remained within 20 km of the colony whilst raising chicks. The location of a penguin's nest site on the island largely influenced whether they travelled south or north of Penguin Island. The penguins nesting on the north east of the island tend to head northwards, and those nesting elsewhere on the island tend to head southwards. When guarding chicks, the penguins that headed in a northerly direction from Penguin Island used areas associated with the Five Fathom Bank or the Sepia Depression and generally dived to depths ranging from <2 - 5 m. This is in contrast to the penguins that foraged within Comet Bay, which generally dived deeper to 5-14 m.

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 the City of Rockingham facebook page and the Fremantle Ports website, articles in newspapers and newsletters and presentations at a high school.

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. In 2015, the SST returned to average in some months, and there was some evidence that schools of whitebait, a preferred penguin prey, were in Warnbro Sound and Comet Bay in early autumn. This brought hope for a good breeding season, but the fish seemingly did not persist, and the penguins again travelled large distances and breeding success was again 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.

Unfortunately, it is rare to have had so many consecutive years with SST above average throughout the majority of the year. So even though the studies to date have shown that the coastal areas south of Mandurah have been consistently important during the incubation period, it has not been possible to identify where penguins feed during the incubation period in a “good” year. The previous studies have also shown that whilst the penguins utilise areas within a 30 km radius of the colony when they are feeding chicks, that this alone is not an indicator of a healthy marine coastal system. This is because penguins return each evening to feed their chicks, and hence are limited to forage within this distance.

The foraging habitat studies, in addition to necropsies on dead penguins, have also increased the current understanding of the threatening processes the penguins are exposed to. Watercraft injury is the major cause of mortality of the penguins from the Perth region, with starvation the second-most prevalent cause (Cannell *et al.*, 2016). Previous diving studies revealed that some penguins predominantly exploited shallow depths from 1-5 m, whilst others dived more frequently to 8-10 m depth (Ropert-Coudert *et al.*, 2003).

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 depths that the penguins were utilising during the chick guard stage were also determined in an effort to identify areas where they may be at an increased risk of interacting with watercraft.

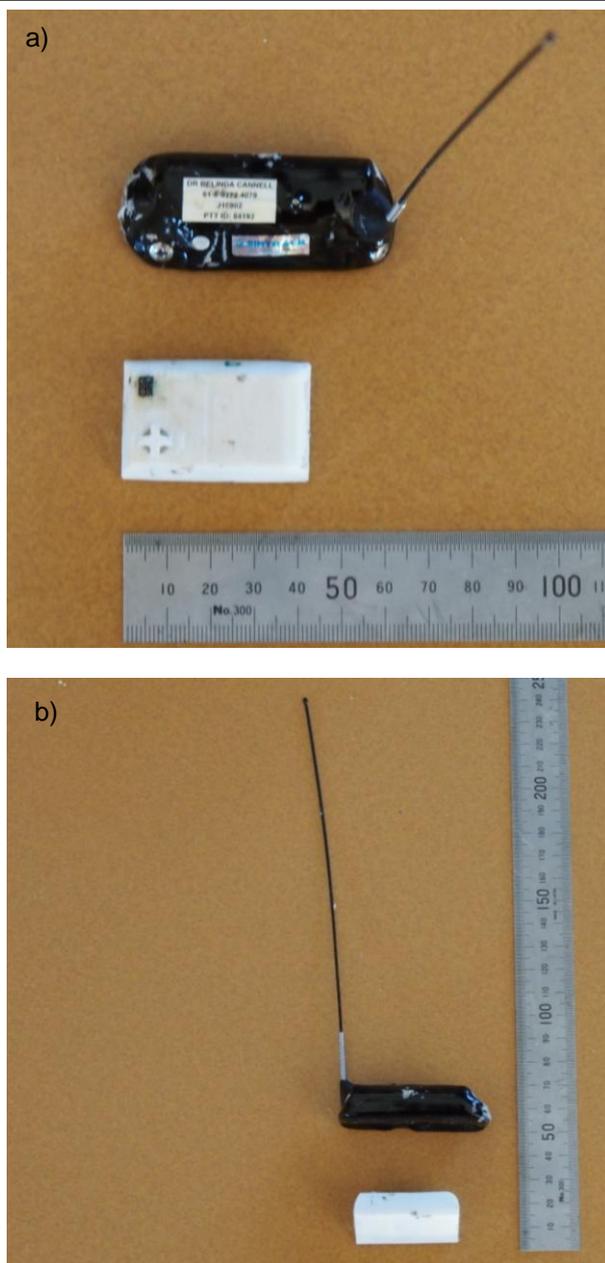
Materials and methods

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 600m 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.

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 (6 females, 8 males, Table 1). All 14 of the penguins were incubating eggs, but one tag was removed before the penguin departed due to a prolonged incubation shift, three tags failed to turn on (later diagnosed by the manufacturer as being due to firmware issues), and the chicks of two penguins hatched after the tag was deployed. 3D accelerometer tags that determine depth of dives and GPS position on the surface were attached to a further 14 penguins (8 females, 6 males, Table 1) 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).

Results

Incubation

Foraging trip parameters

During the incubation phase, penguins with attached satellite tags remained at the nest from 1-5 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. Additionally, three of the tags failed to turn on, so it is not known when these birds left the nest. The foraging trips ranged from 1-10 days. One bird (5, Table 1) undertook two single day foraging trips during the incubation phase. It is unclear if Penguin 5 abandoned the eggs for each of the one day trips. A second bird, Penguin 6, also completed two single day trips after completing a 4 day trip. Whilst one of these trips definitely occurred after one of the chicks hatched, it is not known if the previous single day trip occurred just prior to, or after, the chick hatched. The one day trips were thus removed in the calculation of the average length of a foraging trip, as was the trip during which the satellite tag was lost. The average duration of foraging trips during incubation was 5.3 ± 2.5 days.

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, 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	26/5/16			2	2
2	Male	Incubation	Sat	22/6/16	23/6/16	5	2	2
3	Male	Incubation	Sat	29/6/16	2/7/16	3	2	2
4	Male	Incubation	Sat	4/7/16	8/7/16	6	2	2
5	Female	Incubation	Sat	6/7/16	8/7/16	1,1	2	2
6 ^b	Male	Incubation	Sat	6/7/16	11/7/16	4,1,1	2	2
7	Male	Incubation	Sat	12/7/16	14/7/16	4	2	2
8 ^b	Female	Incubation	Sat	10/8/16	13/8/16	1,1	2	2
9 ^c	Female	Incubation	Sat	19/8/16	22/8/16	>5	2	2
10	Male	Incubation	Sat	23/8/16	25/8/16	10	1	1
11 ^d	Female	Incubation	Sat	21/9/16	?		0	0
12 ^d	Female	Incubation	Sat	21/9/15	?		2	0
13 ^d	Female	Incubation	Sat	4/10/16	?		0	0
14	Male	Incubation	Sat	17/10/16	20/10/16	5	0	0
15	Male	Guard	3D	22/6/16	23/6/16	1 ^b	2	2
16	Male	Guard	3D	29/6/16	30/6/16	1 ^c	2	2
17	Female	Guard	3D	29/6/16	30/6/16	1 ^c	2	2
18	Female	Guard	3D	4/7/16	5/7/16	1	2	2
19	Female	Guard	3D	15/7/16	16/7/16	1	2	?
20	Female	Guard	3D	15/7/16	16/7/16	1	2	2
21	Female	Guard	3D	27/7/16	28/7/16	1	2	2
22	Female	Guard	3D	5/8/16	6/8/16	1	2	2
23	Male	Guard	3D	5/8/16	6/8/16	1	2	2
24 ^e	Female	Guard	3D	10/8/16	11/8/16	1	2	2
25 ^e	Male	Guard	3D	19/8/16	20/8/16	1	2	2
26	Female	Guard	3D	19/10/16	20/10/16	1	2	2
27 ^f	Male	Guard	3D	28/10/16	29/10/16	?	2	0
28 ^c	Female	Guard	3D	5/12/16	6/12/16	1	2	2

^aHadn't left nest by 3/6/16 so removed tag as concerned about risk of abandonment

^bEggs hatched between deployment and retrieval

^cTag was lost prior to completion of trip

^dTag failed to turn on

^eIncomplete tracks

^fBird didn't return to nest

During incubation, the 95% contour of all penguins combined extended from Rottneest to Binningup (Fig. 2). The home range was generally located within 20 km of the coastline. However, near Rottneest Island, it extended to a maximum distance of approximately 25 km from the coast. The home range for all birds combined covered an area of 1337 km². The maximum foraging range from the colony to areas used by the penguins varied from a minimum of 7 km south, in Warnbro Sound, to a maximum of 86 km south to between Preston Beach and Myalup (Fig. 2, Table 2). A kernel density analysis for all the birds combined identified several important foraging areas. These areas, in which there was a 50% probability of finding the penguins, were located in Cockburn Sound; west and north west of Garden Island; Warnbro Sound; Comet Bay, and nearshore and adjacent to Lake Clifton/ Preston Beach. This core habitat covered an area of 140 km².

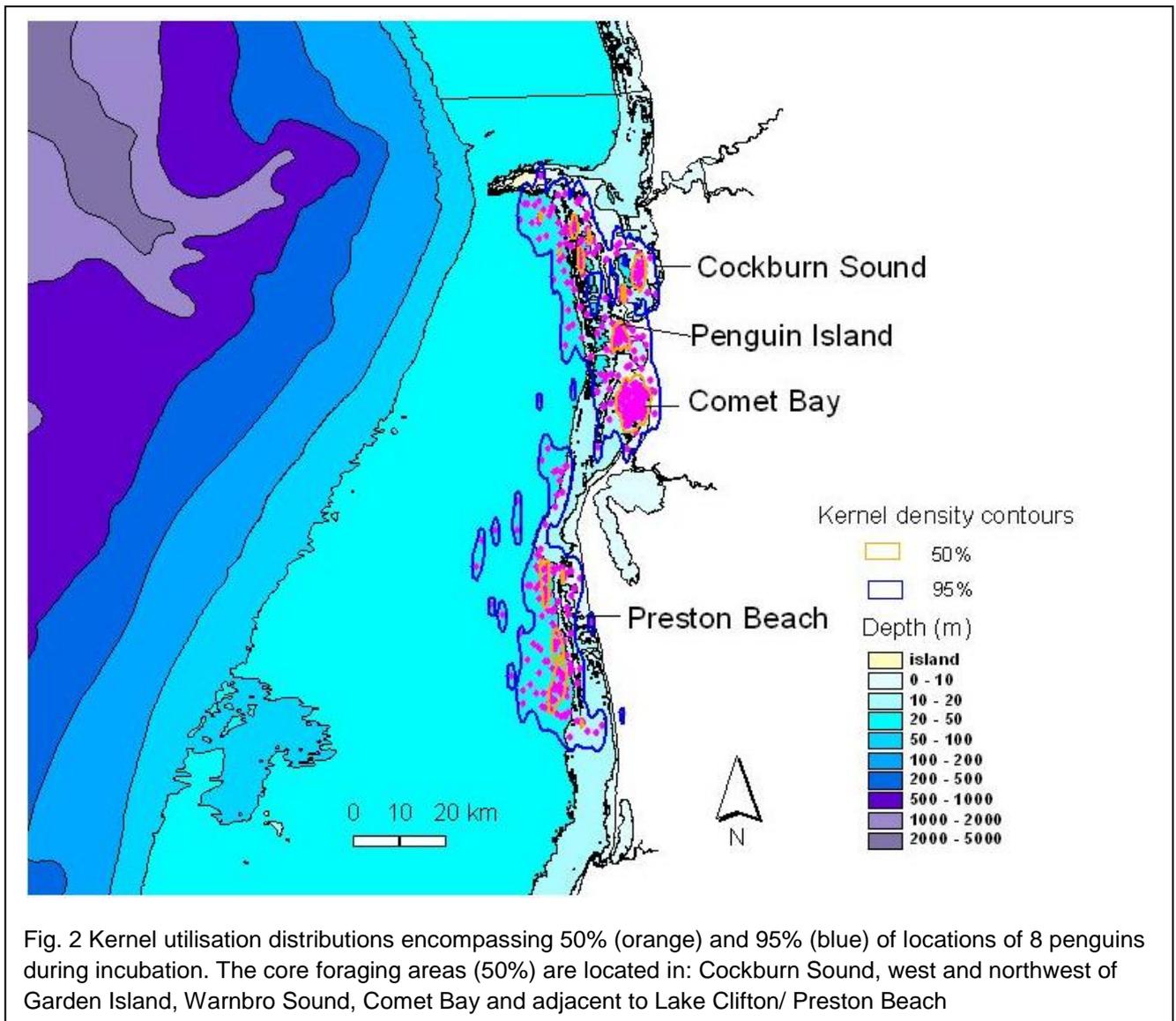


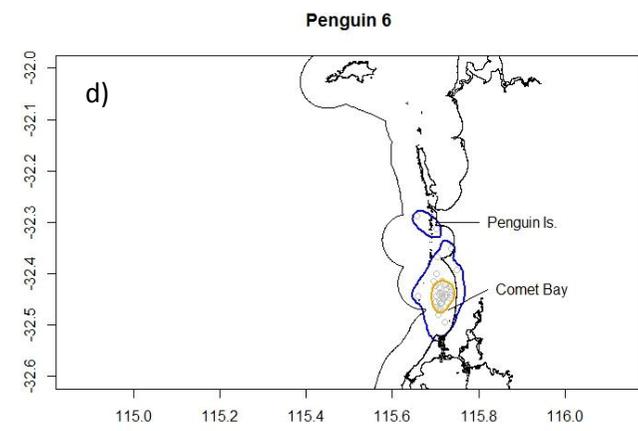
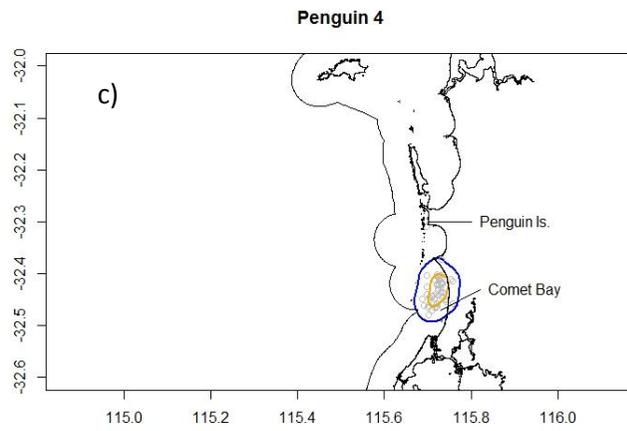
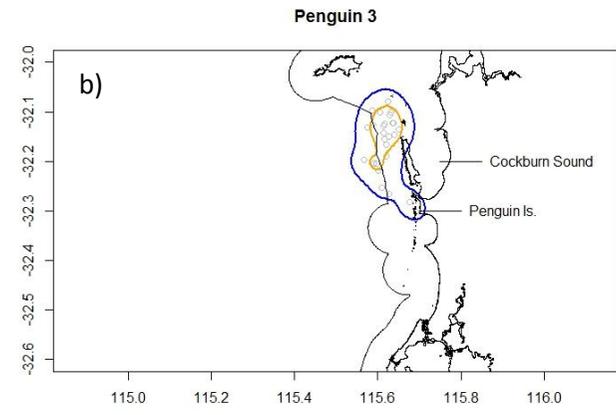
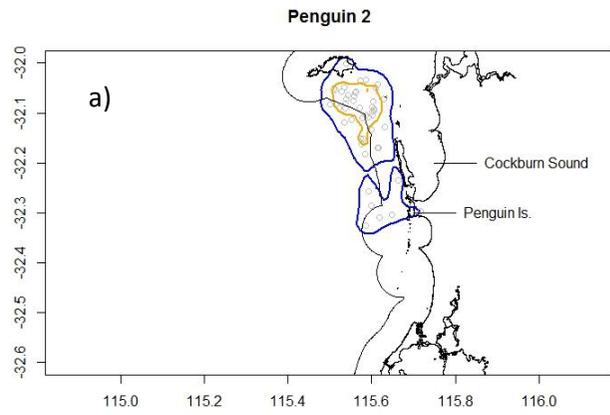
Fig. 2 Kernel utilisation distributions encompassing 50% (orange) and 95% (blue) of locations of 8 penguins during incubation. The core foraging areas (50%) are located in: Cockburn Sound, west and northwest of Garden Island, Warnbro Sound, Comet Bay and adjacent to Lake Clifton/ Preston Beach

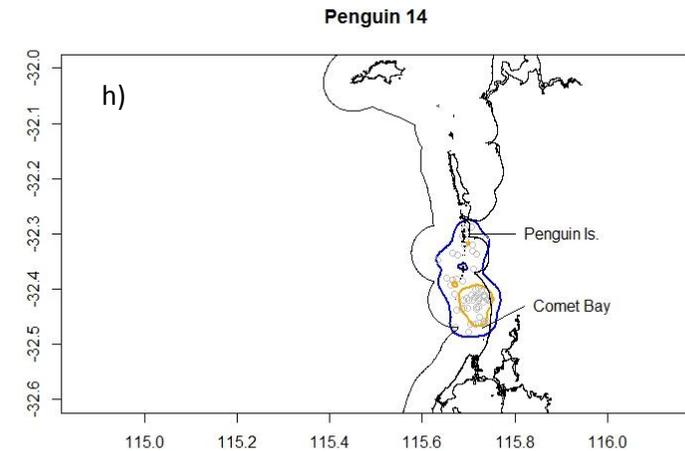
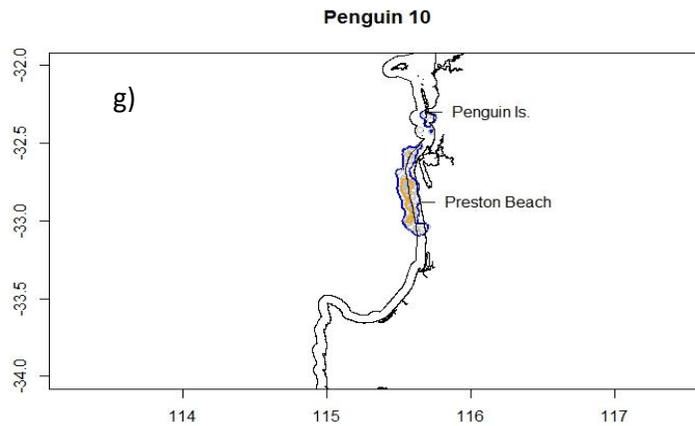
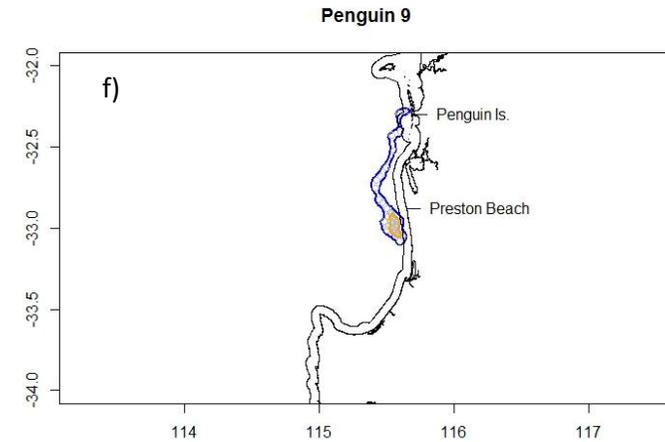
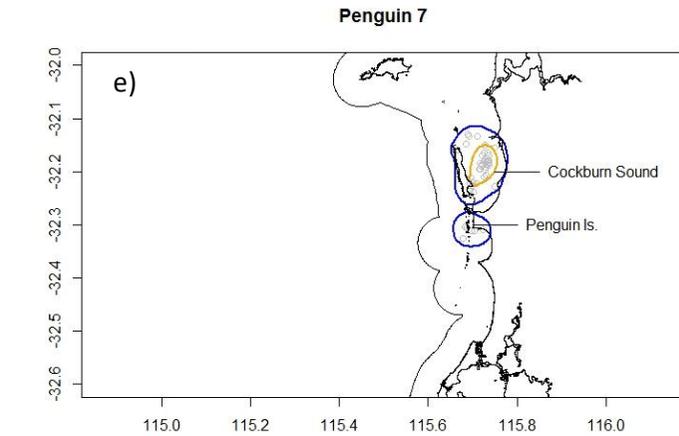
Each penguin generally concentrated foraging effort in one area (Table 2, Figs 3 a-h), and the penguins remained within their core area of foraging from 2 -8 consecutive days. The size of these core areas ranged from 22 – 127 km² (Table 2). Core habitat was also occasionally located around Penguin Island (Figs. 3d and h).

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, 2016. Excludes single day foraging trips (Penguins 5 and 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 (km)
2	Incubation	85	383	Between N end of Garden Island and Rottnest	37
3	Incubation	66	292	Between N end of Garden Island and Rottnest	26
4	Incubation	22	104	Comet Bay	19
5 (trip 1)	Incubation				7
5 (trip 2)	Incubation				7
6 (trip1)	Incubation	26	172	Comet Bay	24
7	Incubation	37	199	Cockburn Sound	19
9	Incubation	82*	561*	Between Preston Beach and Myalup	86*
10	Incubation	127	674	Lake Clifton to Myalup	85
14	Incubation	52	226	Comet Bay	19

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





Figs. 3a-h 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 1 was removed as it been incubating eggs for at least 10 days, Penguins 5 and 8 undertook single day trips and the tags failed on Penguins 11-13.

One penguin (# 5) completed two single day foraging trips during incubation. On each trip, Penguin 5 foraged within Warnbro Sound, spending 3-4 hours in localised areas in nearshore waters (Figs. 4a and b). The maximum distance of these trips was 7 km from the colony.

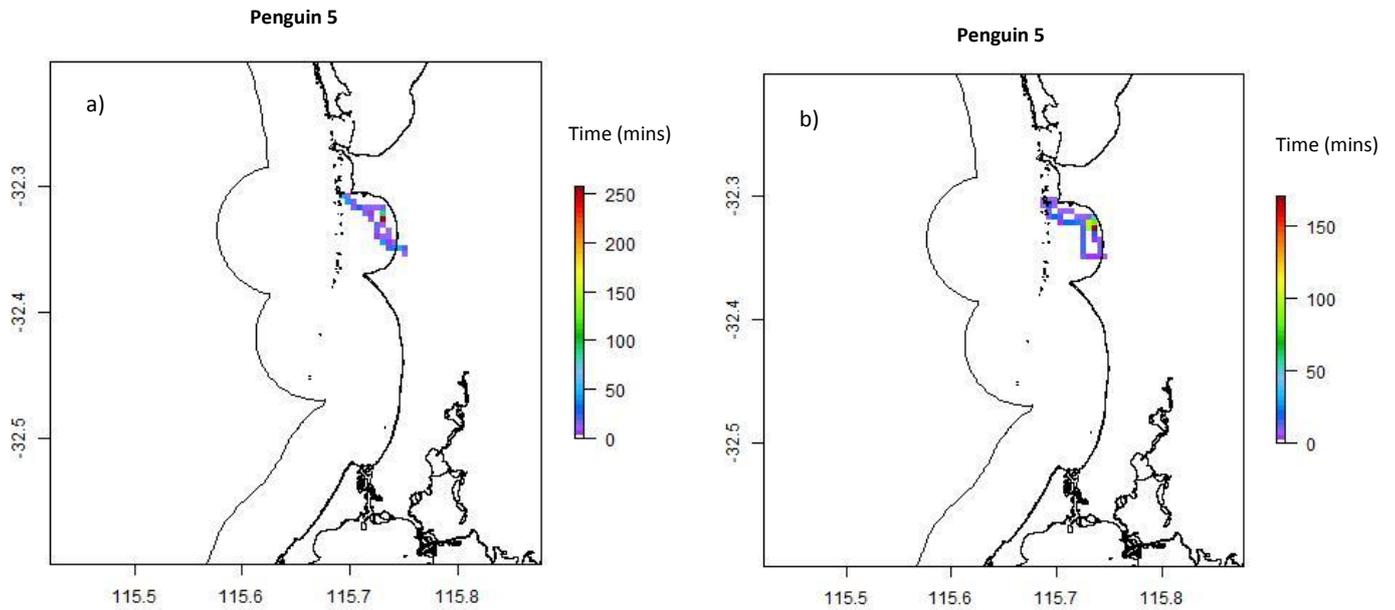


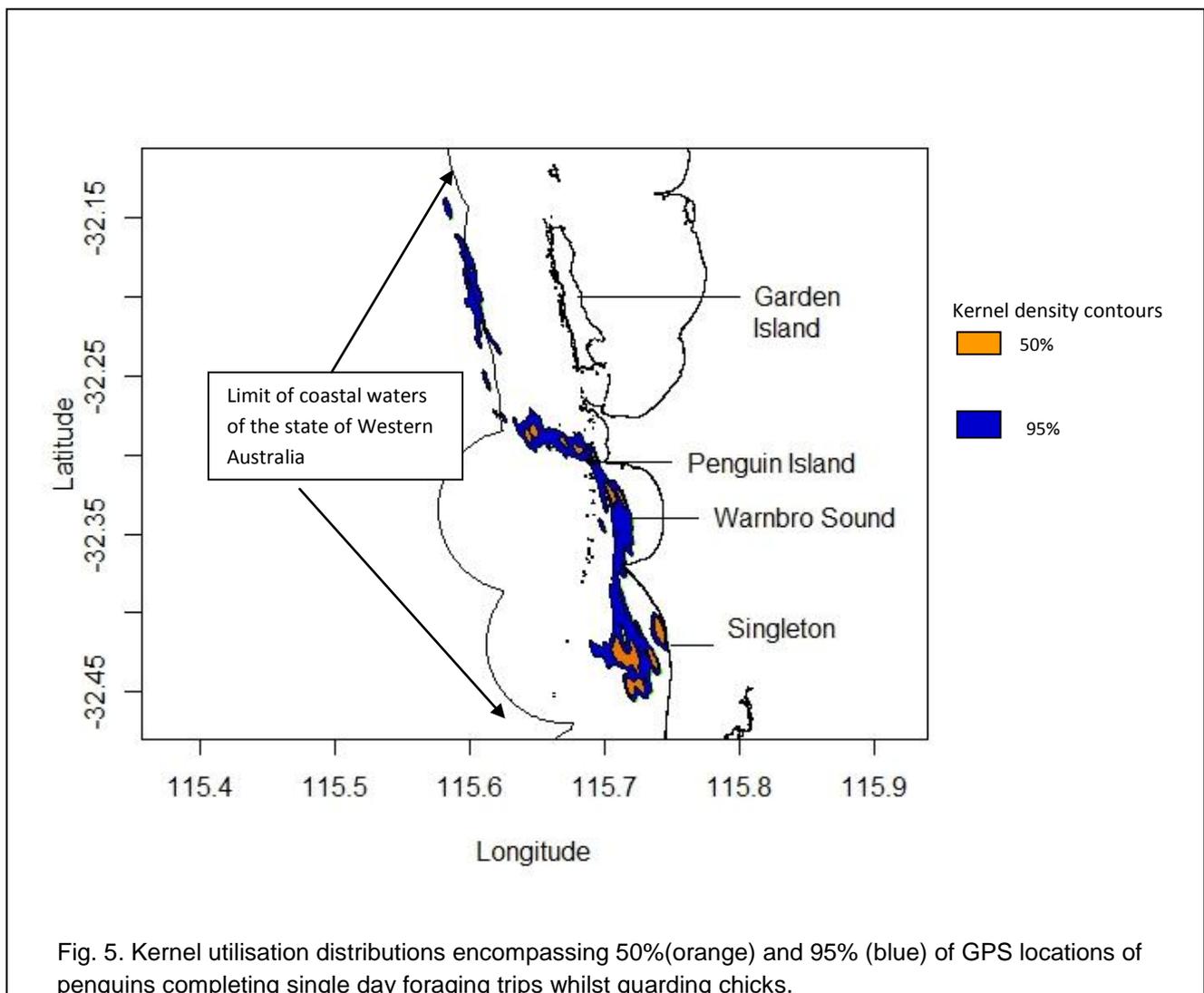
Fig 4 Single day foraging trips completed by Penguin 5 from Penguin Island during incubation: a) trip1 on 8/7/16 and b) trip 2 on 10/7/16

Guard Phase

GPS locations

Tags were deployed on 14 Little Penguins, and tracks were obtained for eight of the single day trips. Four tags failed during the morning of the foraging trip, one penguin did not return to the nest, and one tag was lost. Of the eight single day trips, multiple locations were obtained every hour in four of the trips, whilst data were missing for 2-6 hours in the other four trips.

A kernel density analysis for all penguins combined (Fig. 5) identified several areas of core habitat -1) Warnbro Sound, 2) Comet Bay- within <500 m of the shore near Singleton, and between 1-3 km offshore from Singleton-Madora, 3) NW of Penguin Island, within the Sepia Depression and ranging from 1 – 5 km offshore, and 4) adjacent to the Five Fathom Bank, west of Garden Island (Fig. 5). These areas covered a total of 7 km². The home range of all the penguins extended from north-western Garden Island to Comet Bay, and covered 42 km².



The maximum distance the penguins travelled from the colony ranged from 8-21 km (Table 3). However, the penguins headed in one of three directions from the colony 1) south (72 % of trips), 2) west (10%) and 3) northwest (18%) (Fig. 6). There was no difference in the foraging areas used by males and females (Fig. 6). The trips were typically divided into 3 phases, with the penguins initially leaving the colony before dawn and spending long periods of time on the surface of the water whilst heading in the direction towards their foraging grounds. The penguins then spent several hours foraging, identified by areas of high residence and sinuosity often interspersed by slower travel between areas. The third phase typically was a straight line movement back to the colony. The size of the core habitat (i.e. 50% kernel density area) for individual penguins ranged from <1-5 km². The home range (i.e.95% kernel density) area ranged from 4-20 km² (Table 3).

Table 3. Size of both the core foraging habitat (50% kernel density) and home range (95% kernel density), and the maximum foraging range of penguins guarding chicks at Penguin Island

ID	50% kernel density area (km²)	95% kernel density area (km²)	Maximum foraging range (km)
18	0.4	4.1	14.3
19	4.7	20.3	15.2
20	3.7	14.4	20.7
21	1.9	10.4	17.1
22	1.1	5.3	15.3
23	0.8	5.3	15.7
24*	0.8	3.6	8.0
26	0.4	3.7	16.0

*The kernel densities are potentially underestimated due to missing data.

The maximum foraging range of the two penguins undertaking single day trips recorded by a satellite tag during guard phase (7 and 15 km for Penguin 6 and 8 respectively) were similar to that recorded for the penguins with GPS tags. Penguin 6 spent between 1-2 hours in a localised area just west of the Murray Reef system off Warnbro Sound (Fig. 7a). Penguin 8 spent approximately 5 hours nearshore, adjacent to Singleton (Fig. 7b).

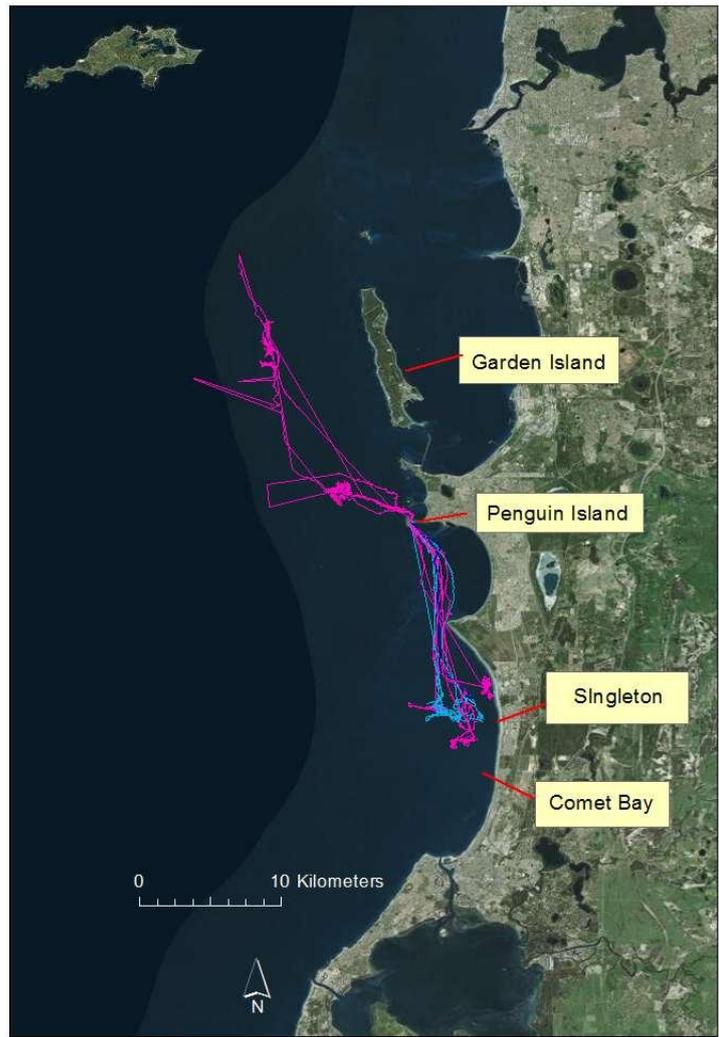


Fig. 6 GPS tracks of male (blue) and female (pink) Little Penguins from Penguin Island during the chick-guard phase, 2016.

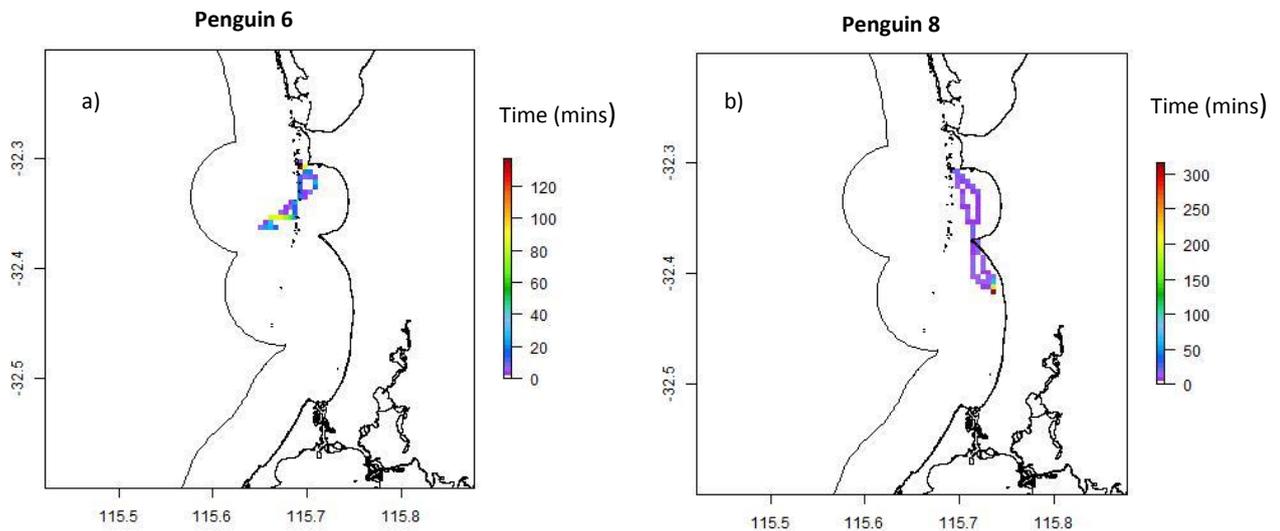


Fig. 7 Single day foraging trips undertaken by a) Penguin 6, a male and b) Penguin 8, a female. The chicks of both these penguins had hatched several days after each satellite tag was attached to the adult.

Dividing behaviour of the penguins

Whilst the GPS locations were not obtained every hour for all the tags, diving data were available for the complete trips from 10 penguins.

The penguins that headed in a northerly direction from Penguin Island, and used areas associated with the Five Fathom Bank or the Sepia Depression, generally dived to depths ranging from <2 - 5 m. This is in contrast to the penguins that foraged within Comet Bay, which generally dived deeper to depths ranging from 5-14 m. The penguins post-dive surface intervals typically lasting for 1-5 seconds. However, longer intervals also occurred after a series of dives (Fig 8).

All the penguins travelled within the top 0.5-1 m of the surface, and their return journey generally took at least one hour. During the return travel, the penguins dived for short durations and surfaced only briefly.

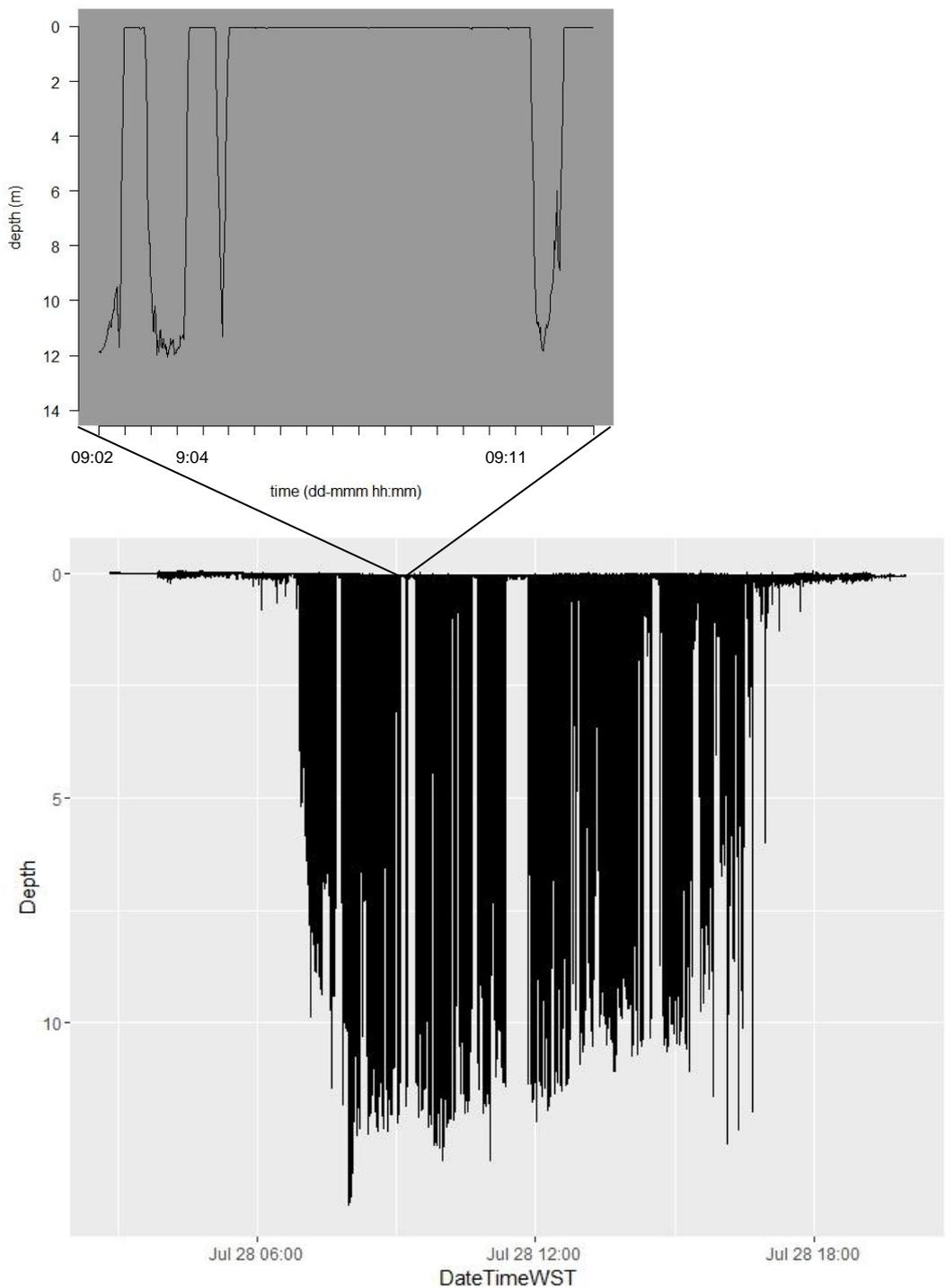


Fig. 8 Diving behaviour of Penguin 21, and (inset) 4 dives in detail interspersed with extended post-dive surface intervals.

Impact of tag deployment on breeding success

The breeding was not successful in approx 30% of the nests in which one penguin was tagged, either during incubation or guard phase. The eggs had been abandoned in three of these unsuccessful breeding attempts, and the chicks hatched but later died in the fourth unsuccessful attempt. However, there was no difference in the breeding success of penguin pairs, regardless of whether a tag had been deployed on a penguin or not ($\chi^2=1.278$, $df=1$, $p>0.1$).

Sea Surface Temperatures 2016

The daily sea surface temperatures (SST) in the vicinity of Penguin Island generally equalled the long term average (Fig. 8).

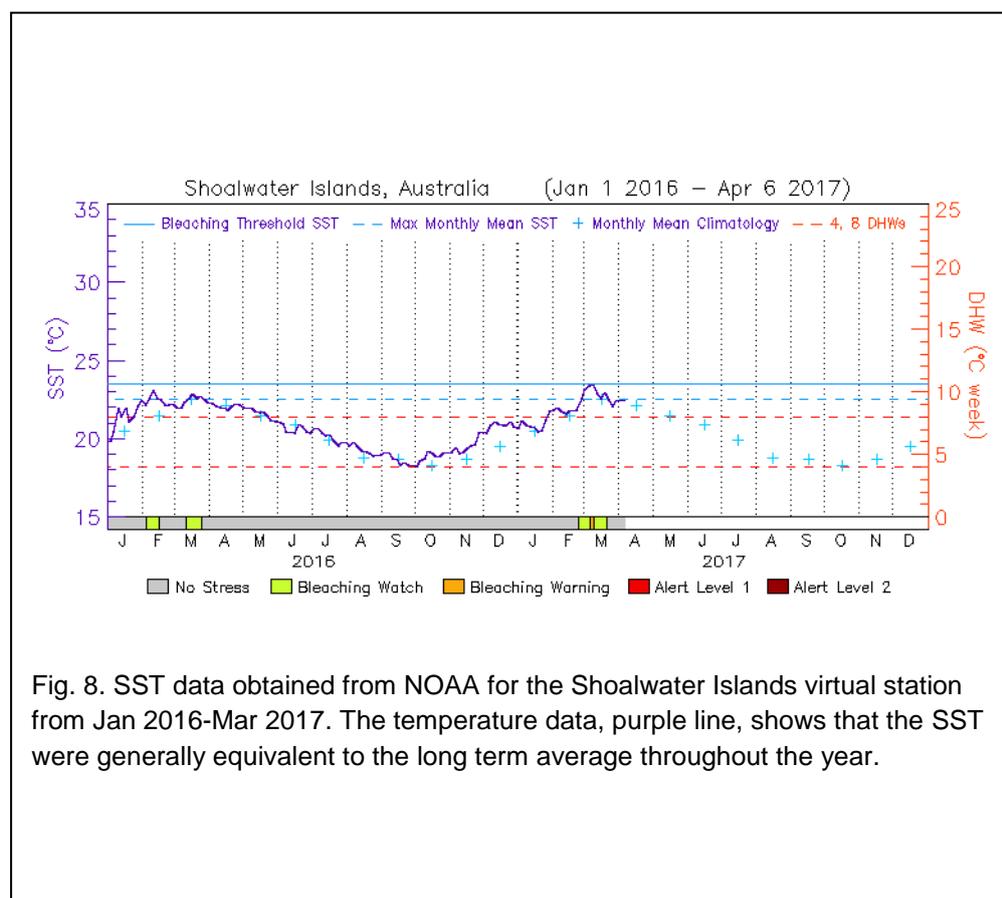


Fig. 8. SST data obtained from NOAA for the Shoalwater Islands virtual station from Jan 2016-Mar 2017. The temperature data, purple line, shows that the SST were generally equivalent to the long term average throughout the year.

Community awareness

From July 2016-January 2017, four blogs were sent to both the City of Rockingham and the Fremantle Ports. The City of Rockingham posted the blogs (from 3/8/16-15/2/17) onto their facebook page, with each post liked” by up to 13 people (Appendix 1). The Fremantle Ports posted all the blogs onto www.fremantleports.com.au/Visiting/Pages/Dolphin-news.aspx. (Appendix 2).

Comparison in size of core habitat and home range between years

The core habitat and the home range during both incubation and guard phase were much smaller in 2016 compared to the other years (Table 4).

Table 4. Size of home range and core foraging habitat of Little Penguins from Penguin Island in 2014-2016.

	Incubation		Guard Phase	
	Home range (km ²)	Core habitat (km ²)	Home range (km ²)	Core habitat (km ²)
2014	2587	258	134	21
2015	2450	281	155	25
2016	1337	86	42	7

Discussion

Little penguins on Penguin Island do not all lay eggs at the same time, i.e. they are asynchronous breeders, and in 2016 eggs were laid in any month from May-November. This range includes both first and second clutch eggs, and is typical for the colony on Penguin Island (Wooller *et al.* 1991). Although the egg lay period was typical, the numbers of penguins observed attempting to breed in the nestboxes was lower than average, and even lower than 2015. Fewer birds attempting to breed also impacts the numbers of penguins available for tag deployment, hence the sample size of tagged birds during incubation or guard phase was reasonably low, and there were very few occasions when multiple tags could be deployed simultaneously. Even though a reduced number of penguins were attempting to breed, the overall breeding success for all the pairs breeding in the nestboxes was higher than it has been since the marine heatwave in 2011, and indeed the long term average (Cannell unpubl. data). It would therefore appear that the food availability was generally adequate for the reduced number of breeding penguins.

Little Penguins incubating eggs can remain at sea for longer than those having to feed chicks, and hence can travel much further from the colony. Despite the much larger home range and core habitat areas of the penguins incubating eggs, there was some degree of overlap in the core habitat between penguins incubating eggs and those guarding chicks. This, coupled with the better breeding success of the penguins in 2016, would indicate that food resources were often available relatively close to Penguin Island in 2016. Nevertheless, some penguins incubating eggs did travel much further, i.e. into Cockburn Sound and to Preston Beach area during incubation, highlighting the patchy distribution of the fish prey both in space and time.

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. Not surprisingly, the average duration of the foraging trips during incubation, was also shorter in 2016, though this does not take into account the one tag that was lost during a foraging trip, and the 3 tags that failed to turn on. It is likely that the cooler SST in 2016 had positively influenced the presence of fish prey. Yet anecdotal evidence from local commercial fishermen suggests that baitfish were not present in large schools between Penguin Island and Mandurah. This may explain the lower proportion of penguins attempting to breed in 2016 compared to 2015. The smaller core habitat during chick rearing indicates that fish prey were generally more concentrated in 2016.

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 largely influenced whether they travelled south or north of Penguin Island. The penguins nesting on the north east of the island tended to head northwards, and those nesting elsewhere on the island tended to head southwards. But even if penguins head in the same direction, they do not necessarily utilise the same habitat for foraging. This is exemplified by Penguins 4 and 5, who both headed south on the same day, but one foraged in Warnbro Sound and the other in Comet Bay. Interestingly, the penguins that utilise Cockburn Sound during incubation or chick rearing do not enter at the southern end of Cockburn Sound. In all years, penguins foraging in Cockburn Sound have swum along the west side of Garden Island and entered the Sound from the northern end.

The diving behaviour of the penguins was similar to that observed in 2001, with some penguins generally diving to depths 1-5 m, and others diving more deeply. The depth utilised depended on the foraging area. The penguins foraging near the Five Fathom Bank and the Sepia Depression utilised shallower depths compared to those foraging south. However, the shallower diving penguins were not foraging towards the bottom of the water column, unlike the deeper diving penguins. It is likely that those heading north are thus feeding on more pelagic fish such as pilchards. Benthic fish, such as sandy sprat, are more likely to be caught by the penguins diving more deeply south of the island. 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.

Regardless of the depth of dives, all penguins travelled back to the colony, diving to only very shallow depths and briefly porpoising up 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)

Resilience to climate change and coastal development

High SST in April and May in the waters around Penguin Island have been shown to affect the breeding performance of the penguins (Cannell *et al.*, 2012). From January to May 2016, the sea surface temperatures were below average, and the breeding success of the penguins was better than in recent years and their foraging range was smaller. However, overall participation in breeding was lower than average. It would thus appear that the local coastal marine system has experienced some resilience, but it cannot currently be

determined if this is throughout the ecosystem. For example, has sandy sprat presence and abundance returned to levels similar to that prior to the marine heatwave, or have other fish species moved into that space? If there has been a shift in the penguin's diet, then the overlap between the fish and penguins in both time and space must be known before predictions on possible effects of climate change can be made. Regardless of the diet composition of the penguins, their breeding success and participation in breeding is correlated with their abundance, but this is a lagged correlation. This is because fledgling penguins depart the colony when they are approximately 8 weeks old, and return to the colony they came from when they are 2-3 years old. However, mortality of fledglings is very high, with only approximately 20% surviving their first year (Sidhu *et al.*, 2007). Mortality of the fledglings is related to their body mass, with heavier fledglings more likely to survive. So with 5 consecutive years of reduced breeding and fish prey close to the colony, there will be fewer juveniles to return to the breeding population on Penguin Island.

The data collected over the past 4 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 must consider likely impacts on the penguin colony. But it is also important to consider potential impacts of development outside the penguins' home range. 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 the City of Rockingham facebook page and the Fremantle Ports Community Newsletter. 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 2016, I was invited to present my research to two different classes at St Mary's High School, and articles about the Little Penguins from Penguin Island appeared in the West Australian and Science Network WA. Thus, this project has succeeded in raising community stewardship of the environment.

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Appendix 1

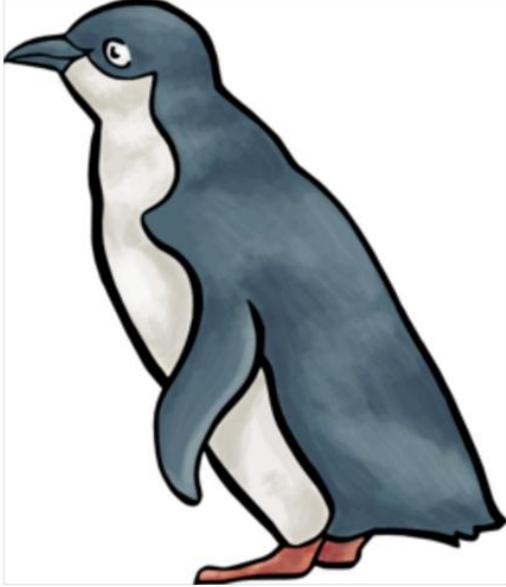
City of Rockingham Facebook blogs

 **City of Rockingham – Local Government**
August 3, 2016 · 🌐

Fun Fact Day and a [Penguin Journey](#) update – the first one for this time of year!

Dr Belinda will be continuing to use satellite and GPS tags to locate the penguins when on the surface of the water as well as a special tag about the depth and location on where they are catching fish. These tags have only recently been developed to be small enough to fit the Little Penguins.

The breeding season has recently begun and it's a bit later than the long term average, however not much different to recent years so we will check in with Dr Belinda Cannell to see how she is going!



👍 4 1 Comment

👍 Like 💬 Comment ➦ Share



City of Rockingham – Local Government

September 21, 2016 · 🌐

Fun fact Day and checking in with Dr Belinda and the Little Penguin study. The breeding season is underway, a bit later than the long term average but not much different to recent years. Although the numbers that are breeding are still low, the birds that are breeding are all in great condition.

Some luck occurred when a penguin that Dr Belinda tagged in 2007 was located in one of the nesting boxes – although her exact age cannot be confirmed as she was an adult when tagged – she can estimate that when they do return to the island for breeding they are usually 2-3 years old so this would mean that she is approximately 10 years old now. A new tag has been attached to her (we will call her Hope) and she is now swimming in Comet Bay not far off from Singleton and she has been away for 4 days.

The map shot is of her swimming pattern – noting she spent a lot of time in the water and the raw data points and location may not be accurate (she didn't stop inland for shopping that is!)

This research is funded by the City of Rockingham and Fremantle Ports



👍 8

👍 Like 💬 Comment ➦ Share

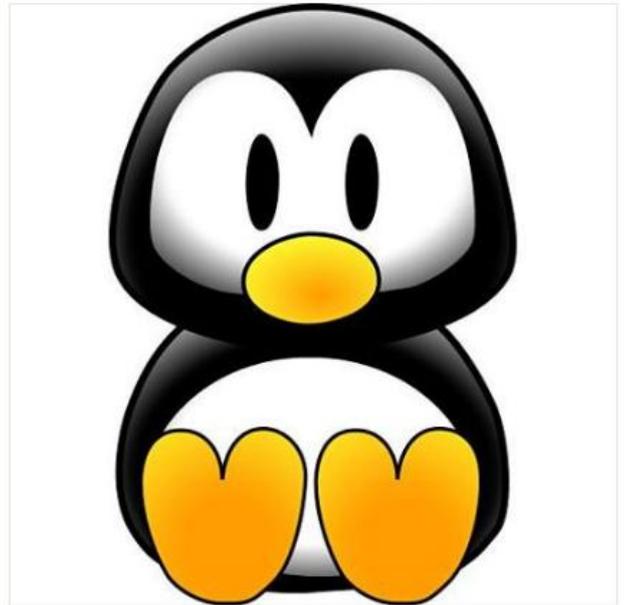


City of Rockingham – Local Government

October 12, 2016 · 🌐

An update from Dr Belinda Cannell on the Penguin Journey for 2016. Last time we checked-in the previously tagged penguin Hope was swimming and feeding around Singleton and Madora Bay while her partner Pinguino (Spanish Ole) incubated the eggs. Hope returned a couple of days later. This was a much shorter foraging trip during incubation than has been noted in the past three years.

This project has been funded by City of Rockingham and Fremantle Ports.



👍 5

👍 Like 💬 Comment ➦ Share

Penguin Journey Posts from 09.11.16 to 15.02.17 (*current)

09.11.16



City of Rockingham – Local Government
Published by Savash'n Katrina Mohseni (7)
Page Liked · 9 November 2016 · Edited ·

Fun Fact Day and checking in with Dr Belinda and a Penguin Journey update.

Hope and Pinguino's eggs have now hatched and when Dr Belinda checked them they had very full bellies which means lots of food is being brought to them by their parents.

On the next trip out there a satellite tag was attached to another penguin that had been micro-chipped in 2007 (we will call him SeaSalt) – SeaSalt weighed in at 1510g. This is larger than the average Penguin Island male weight of around 1400g.

The photo shows the satellite tag attached to SeaSalt and that two eggs can be seen in his nest, penguins occasionally lay one egg but is not uncommon to lay two.

This project has been funded by the City of Rockingham and Fremantle Ports.

Write a comment...

25.01.17



City of Rockingham – Local Government
Published by Savash'n Katrina Mohseni (7)
Page Liked · 25 January · Edited ·

Fun Fact day. Checking in on the penguins to see how they are going.

Dr Belinda attached a tag to a large male penguin (called Seasalt). She estimated his age to be about 9 years. (Although Little Penguins can live for approximately 20 years survival rates start to reduce from around 9 years of age.) Seasalt left a couple of days later and swam into Cockburn Sound where he stayed for 5 days.

The tag was removed and 3 weeks later 2 chicks (Seespray and Rockpool) were found in the nestbox. They were estimated to be 3-5 days old.

This project has been funded by the City of Rockingham and Fremantle Ports.

Tag photo · Add location · Edit

Like · Comment · Share

Mandy Coakley, Michael Boom Morton and 11 others

Write a comment...

Penguin Journey Posts from 09.11.16 to 15.02.17 (*current)

15.02.17



Appendix 2

Fremantle Ports Dolphin and Penguin News

News from Dr Belinda Cannell:

4/11/16:

Hi, fellow penguinphiles, Dr Belinda from Murdoch University here with an update on the penguins on Penguin Island. Back to the chicks with the huge dad - I deployed a GPS tag (circled) onto the mum for a single day foraging trip when the chicks were about 5 and 7 days old. Usually the chicks hatch 2-3 days apart. This gives the older chick an advantage as it can outcompete its younger, smaller sibling when begging for food from their parents. So when fish prey are scarce, the older chick is more likely to be fed, but when fish prey are abundant both chicks will be fed and survive.



Only one chick can be seen in the photo, near mum's head. The other chick is tucked under the mum's abdomen.

3/10/16:

Hi, fellow penguinphiles, Dr Belinda from Murdoch University here with an update on the penguins on Penguin Island. I had attached a tag to a huge male, who was at least 9 years old - penguins can live for approximately 20 years, but survival starts to reduce around 9 years. He left a couple of days after I attached the tag, and swam into Cockburn Sound, where he stayed for 5 days.



I removed the tag, and 3 weeks later we found 2 delightful little chicks in the nestbox. The chicks are around 3-5 days old.

5/8/16:

Hi, fellow penguinphiles, Dr Belinda from Murdoch University here with an update on the penguins on Penguin Island. Last time we saw that a female was swimming and feeding around the Singleton-Madora Bay area, while her partner incubated the eggs. I was so pleased to see her return to her nest site just a couple of days later. So this was a much shorter foraging trip during incubation than we have typically seen the past three years. Her eggs have now hatched and the chicks are about five days old with very full little bellies. This means they are getting well fed. About a week later, I attached a satellite tag to another penguin that I had also microchipped in 2007. He weighed in at a whopping 1510g. The average weight for males on Penguin Island is around 1400g, larger than male penguins at most of the other colonies in Australia. So he was heavier than average, but this penguin is a particularly large bird. You can see the satellite tag attached to the feathers on his back, and two eggs, which he would normally have tucked away under his belly. Penguins occasionally only lay one egg, but usually lay two eggs. Stay tuned to find out where he heads to.



1/7/16:

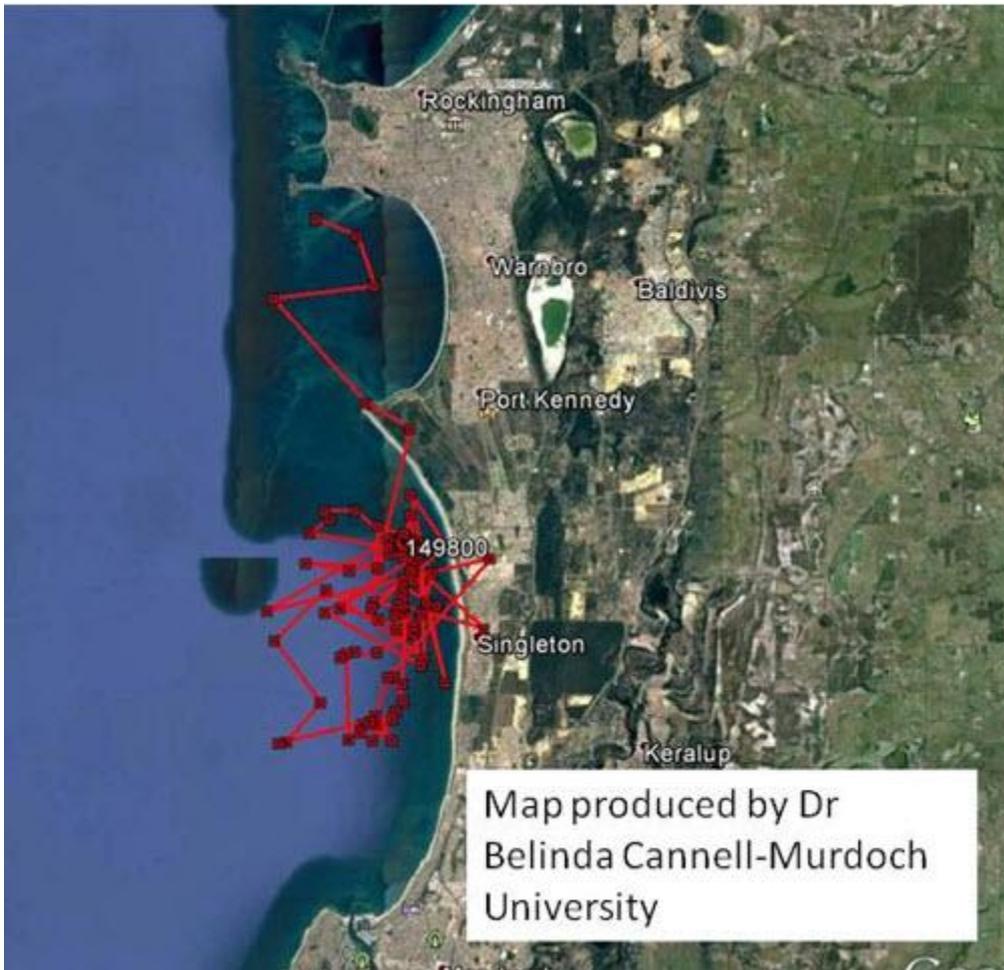
Hi folks, Dr Belinda from Murdoch University here, and it is with great pleasure that I can be writing about the Little Penguins again in 2016. I am very grateful for the research support provided by both the City of Rockingham and Fremantle Ports. So now I begin the work to investigate the toll of the past five years of generally warmer than average local waters, and coastal development, on the penguins.

This year I am again using satellite and GPS tags to locate penguins when they are on the surface of the water. Excitingly, I will also be using some special tags that give information not only on the depth the penguins are diving to, but also where they are catching their food. These tags have only recently become small enough for Little Penguins.

So the breeding season has recently begun - a bit later than the long term average, but not much different to recent years. I was really beginning to get very worried that it was going to be another abysmal year. Although the numbers breeding are still low, the birds that are breeding are all in great condition. I am quietly hopeful that there will be a surge in breeding soon. I will let you know in coming weeks how it progresses.

I was delighted last week to find a female in one of the nestboxes who I microchipped in 2007. I don't know her exact age as she was microchipped as an adult, and penguins are usually 2-3 years old when they return to the island to start breeding. They can come back when they are about one year old though, but physically they all look the same, so this means she is at least 10 years old. I attached a tag to her, and she is now swimming in Comet Bay, not far from Singleton. She has been away for four days now.

Here is a map of her movements. Note the locations that are on land. The penguin didn't really leave the water! These points are raw data, and sometimes the locations aren't the most accurate. These points would be removed when the data are analysed.



Stay posted for the next instalment. This research is funded by the City of Rockingham and Fremantle Ports.