Insights into forest red-tailed black cockatoo movement on the Swan Coastal Plain and implications for conservation management of the Maddington-Kenwick Strategic Employment Area Precinct 3

A report for MKSEA Pty. Ltd.

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Ethics and Permit Statement:

All tracking took place with approval of the Western Australian Department of Biodiversity, Conservation and Attractions under permit number: SF010448; and with Murdoch University Animal Ethics permit RW2768/15 and Australian Bird and Bat Banding Scheme (ABBBS) Banding Authority Number 1862.

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Cover photograph by Karen Riley

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Definitions

RTBC	Forest red-tailed black cockatoo (*Calyptorhynchus banksii naso*)
SCP	Swan Coastal Plain
GPS tag	Geographic Positioning System tracking tag
Satellite PTT tag	Satellite Platform Terminal tag
Movement Ecology	The study of the movement of an organism defined as a change in the spatial location of the whole individual in time, and driven by processes that act across multiple spatial and temporal scales.
N	An abbreviation used to report the total number of a sample. For example, N=5 means five individuals.
Daily Movement Distance	The daily distance in metres or kilometres that an organism moves in a single day. This may be unidirectional or as a 'round trip' if the organism is moving within a home-range.
Range	An area that contains the distribution of an individual or a species.
Home-range	The area that an animal occupies on a daily basis.
Ranging Movement	A movement that exceeds the normal daily distance. It may be linked to a range shift but not a migratory movement.
Migratory Movement	A long distance movement that exceeds normal daily distance and may be seasonally linked to movement to a breeding area.
GCC	Great Cocky Count – Birdlife Western Australia. A citizen science project where one day per year black cockatoo counts

	are made at allocated sites across south-west Western Australia.
Peri-urban	Area surround metropolitan areas and cities - neither urban nor rural, but an urban transition zone combining the features of both town and rural uses.
R	A programming language and free software environment for statistical computing and graphics supported by the R Foundation for Statistical Computing.
BCPA	Behavioural Change Point Analysis.

Summary and Key Outcomes

In recent years, there had been an expansion of forest red-tailed black cockatoos (RTBC) from their traditional range in the Darling Scarp to the Swan Coastal Plain (SCP). Continued habitat conversion on the SCP and a projected increase in human population emphasises the need to understand flock movement and habitat use, and identify critical feeding and roosting sites to guide sustainable management of resources supporting populations into the future. In this study we datamine satellite and GPS data from 11 RTBCs, across three releases collected as part of ongoing movement ecology research by our research group, The Black Cockatoo Conservation Project - Murdoch University, to gain an understanding of RTBC movement dynamics across the urban and peri-urban areas of the SCP to inform likely space use of flocks using the Edward Street roost site contained within the footprint of the Maddington-Kenwick Strategic Employment Area (MKSEA P3) industrial development site. Key outcomes of this research are:

- Despite some track overlap, there was significant evidence that the flocks tracked (~N=8) spatially partition food and night roost resources.
- Home-range areas were 8 km^2 to 45 km^2, and sizes were not related to the time over which the birds were tracked.
- Birds foraged throughout their home-ranges, but key forage and roost sites were close together. Average distances between the top 20% of day foraging or roosting sites (0.46 to 1.04 km) and between night roosts (0.54 to 5.18 km) was small.
- Site visits showed that both foraging and roosting areas were dominated by marri *(Corymbia callophylla)* and other tall tree species such as jarrah *(Eucalyptus marginata)* and spotted gum *(Corymbia maculata)*. In all cases, trees were mature and ranged in height from 10 – 20m.
- 67% of key day foraging or roosting, and 40% of night roosts had water present. The remainder of sites had water nearby (≤ 500 m). In almost all cases, the source was a water trough. Only two sites in the metropolitan area had natural water.
- All key foraging and roosting sites were on land classified by Landgate as part of the Urban Forest Mesh Block network with canopy covers ranging from 17 – 59%.
- Several flocks showed distinct movement corridors, with a clear relationship between occupancy and vegetation including remnant stands, reserves, metropolitan parks, fringing roadside vegetation, or large trees retained on private residential properties.

- One flocked tracker bird moved in the vicinity of the Edward Street roost site. Unfortunately, this bird was killed by a vehicle while crossing Tonkin Highway only five days after release.
- With the exception of one Great Cocky Count (GCC) roost, all other GCC roosts were outside the modelled home-range boundaries when applied to the Edward Street roost site.
- Long-term satellite tracking showed that four of the birds released in either Murdoch or Kensington were tracked long enough to capture long distance ranging movement to the Darling Scarp. These movements all occurred in Spring. Notably, each of these birds belonged to a different flock.
- Spring ranging movements (September/October/November) may be related to breeding activity.
- Flight activity and speed suggest that birds move slowly through the landscape during day foraging, with the longest residence periods associated with morning foraging and night roosting.

Male (left) and female forest red-tailed black cockatoos (Calyptorhynchus banksii naso).

Background and Significance

The forest red-tailed black cockatoo (*Calyptorhynchus banksii naso*) is listed as a threatened species in federal and state legislation, and receives special protection as 'Matters of National Environmental Significance' (MNES) under the Environment Protection and Biodiversity and Conservation Act (1999) (Department of Environment and Conservation 2007, Department of Sustainability Environment Water Populations and Communities 2012, Western Australian Planning Commission 2010).

Forest red-tailed black cockatoos (RTBCs) are endemic to south-western Australia, have declined in range by 30% as a result of habitat loss, and have suffered a marked decline in population numbers since the 1950s (Johnstone et al. 2013a, Mawson and Johnstone 1997). The species is listed as Vulnerable under Australian Federal law (Environment Protection and Biodiversity Conservation Act 1999; Department of Environment and Conservation 2007). At the state level they are specially protected as 'fauna that is rare or likely to become extinct' under the Western Australia *Wildlife Conservation Act 1950*. The forest red-tailed black cockatoo fits the IUCN Red List Criteria for 'Vulnerable' due to a projected or suspected decline in the population of more than 30% within the next 10 years or three generations (Department of Environment and Conservation 2007).

Threats to the species' survivorship are well documented, and include: habitat loss and modification, urban and industrial expansion, displacement by competing species, and climate shifts (Department of Environment and Conservation 2007, Department of Sustainability Environment Water Populations and Communities 2012, Western Australian Planning Commission 2010). These threatening processes are exacerbated by the rapidly increasing urban and industrial development in the Perth and Peel regions and the south-west of Western Australia (Department of Environment and Conservation 2012). Perth's human population is projected to nearly double to 3.5 million by 2050 (Western Australian Planning Commission 2010), emphasising the need to understand flock movements and habitat use, and identify critical feeding and roosting sites, which still remain largely unknown despite earlier research (Johnstone et al. 2013a, b, Mawson and Johnstone 1997, Weerheim 2008). Accordingly, key information required to address the National Recovery Plan or to address local management issues remains outstanding (Department of Environment and Conservation 2007).

The overall development footprint of the Maddington-Kenwick Strategic Employment Area (MKSEA P3) industrial development site is 139 ha of which 57 ha is directly managed by Linc Property (Linc Property 2018). At the southern end of this site there is a RTBC roost that has consistently supported flocks since 2017 (Peck et al. 2018) and occupies approximately 1.5 ha. Bird counts (N = 16; Appendix 1) at the roost site between 2017 and 2019 showed a large variation in the number of birds present ranging from zero to 335 (Glenn Coffey - Linc Property, pers. comm.), with notable seasonal shifts. Consistently large counts across years suggests that the site is an important one. Of the 16 surveys, only three counted zero birds. RTBC are known to use a network of roost sites within an area, so zero counts on a single night are not unexpected.

The roost is identified within the Birdlife Western Australia Great Cocky Count (GCC) as GOSKENR001, and is principally red river gum (*Eucalyptus camaldulensis*) thought to have been planted 20 years ago (Linc Property 2018). Up to 4.49 hectares of the nearby area containing contiguous scattered marri canopy or isolated marri trees was cleared in 2017, and part of the roost stand was removed in November 2018 retaining 70% of the original stand (Linc Property 2018). The most recent consultancy report specifically addressing the values of the site to black cockatoos, suggests that there are 766 ha of native vegetation within a 5km radius of the site (9.7% of the area) and 17,862 ha within a 15 km radius (25% of the area; Bancroft et al. 2017).

Research Aims

Since 2015, the Black Cockatoo research team has successfully deployed 29 satellite and GPS tagged RTBCs on the Swan Coastal Plain (SCP), in the Northern Jarrah Forests and in the south-west region of their distribution with a focus on contrasting movement patterns between urban and forest areas.

Here we use tracked movements of RTBCs in the urban and peri-urban areas of the SCP to inform likely space use of RTBC flocks using the Edward Street roost site contained within the footprint of the Maddington-Kenwick Strategic Employment Area (MKSEA P3) industrial development site. Of 11 birds released on the SCP, eight supplied movement tracks across the study region. We specifically aimed to address the following:

1. Understand and quantify bird movement across the SCP.
2. Determine the relative importance of vegetation corridors on movement.
3. Gain insight into the type of vegetation characteristics associated with key roost or foraging resources including the presence of water.
4. To model home-range sizes across identified flocks and use these data to predict potential movement of birds using the Edward Street roost site.

Methods

Study birds and tag attachment method

Birds used in this study were wild birds injured on the Swan Coastal Plain (SCP) and admitted to the Perth Zoo Veterinary Department for assessment and primary care. The birds were transferred to Kaarakin Black Cockatoo Conservation Centre for rehabilitation and to undergo flight conditioning, until they were determined fit for release by the Western Australian Department of Biodiversity, Conservation and Attractions. The birds were released between 2015 and 2017 at three locations on the SCP in three group releases (Table 1). Additional untagged birds were included in the release groups. We chose release locations on the basis that they had a resident night roosting flock at the time of release. A minimum of four tagged birds were included in each release group.

RTBCs were tagged with a separate satellite and GPS unit using a custom double mounting procedure (Yeap et al. 2017). Of the 11 birds tagged, six removed their GPS tag before or just after release and so carried a satellite tag only.

The Telonics ARGOS Satellite PTT (Platform Transmitter Terminal) tag (TAV-2617) was tail-mounted and weighed 17 g (tag dimensions: 6.43 cm × 2.1 cm × 1 cm; Telonics, Mesa, AZ, USA). The solar GPS tag (Bouten et al. 2013; UvA-BiTS, Amsterdam, The Netherlands; 2CDSe, tag dimensions: 52 mm × 22 mm × 9 mm) was back-mounted and weighed 7.5 g. We attached the satellite tags to the two central tail feathers using braided nylon fishing line (Fireline®, Berkley®, Spirit Lake, IA, USA). The GPS tags were joined to a mounting plate attached with cloth tape to approximately four feathers just below the shoulder joints. The GPS tags were tied to the mounting plate using braided nylon fishing line (Fireline®, Berkley®), and reinforced with glue (Selleys Ultra Repair Glue; Selleys, Padstow, NSW, Australia) (Fig. 1). The combined weight of the tags was less than 5% of the birds body mass, and meets ethical requirements (Cochran 1980, Kenward 2001). All tag attachment was performed under anaesthesia (Yeap et al. 2017).

In addition each bird was fitted with a metal numbered ABBBS (Australian Bird and Bat Banding Scheme) band on the right leg, and a unique colour combination of two metal leg bands on the left leg, to facilitate identification in the field. Some birds were also tail painted to assist with field identification in the short term (Fig.1).

Fig.1 - a) Tag attachment in forest red-tailed black cockatoos is performed under anaesthesia; b) the satellite tag is attached to the underside of the two central tail feathers. Here the antennae is just visible extending beyond the central tail feathers; c) the GPS tag is attached to a plate that is taped to a number of feathers on the back. Some birds released on the Swan Coastal Plain had their tail feathers painted to assist with identification in the field in the first weeks after release; d) RTBC1 photographed in the field a month after release. The tail-paint has nearly worn off; the satellite antennae is clearly visible (photo credit: Sam Rycken); e) RTBC6 photographed in the field with its flock. Birds are fitted with a unique colour coded two-band combination on the left leg and a ABBBS metal band on the right leg to assist with identification (photo credit: Margaret Owen).

Data retrieval and tag programming

Data were collected via the ARGOS satellite based positioning system and downloaded from the Telonics ARGOS satellite tag using the web-based user interface (ARGOS CLS System 2018; https://argos-system.cls.fr/argos-cwi2/login.html). ARGOS data are classified to location accuracy classes (LC): 3, 2, 1, 0 and A, B, Z. Location classes 3 to 1 are accurate to between < 250m to 1500m, LC0 is > 1500m, LC A and B have no accuracy estimations, and LC Z is considered invalid (CLS 2007-2016). We only used LC 2 (< 250m) and LC3 (< 500m) locations. We programmed the satellite tag schedule to communicate in blocks of four hours on either mornings (0600–1000) or nights (2000–2400). Specifically we used LC 3 locations to locate tagged birds at night roosts to facilitate the manual download of high-resolution GPS data to a base station. The morning communication block allowed for field-based flock follows and visual observation when the birds would likely be foraging. On average, we collected up to three LC 2 or LC 3 location fixes during communication periods. We programmed the GPS tag to record location fixes every 30 minutes (accuracy ± 20 m) during the night and every 2.5 – 15 minutes during the day depending on solar battery charge. The satellite and GPS tags had different functions in this study. The satellite tag was programmed to capture landscape scale movement and roost locations by using a conservative programming schedule that maximised tag life, as well as identified night roost locations to facilitate GPS data download. The GPS data captured fine-scale movement at a resolution appropriate to current statistical analysis methods. Accordingly, data from the two tag types were captured at different spatial and temporal resolutions (Fig. 2). The GPS data were post-processed using the University of Amsterdam Bird Tracking System (UvA-BiTS) Virtual Lab and downloaded from the Virtual Lab portal (www.UvABiTS.nl/virtual-lab; Bouten et al. 2013) for analysis.

Data analysis

Satellite and GPS data were checked for errors with summary plots for distance, time and duration between relocations using the ‘adehabitatLT’ package (Calenge 2006). Daily movement statistics were calculated for each bird and data were coded to day and night using the ‘sunriset’ method in the ‘Maptools’ package which codes the data based on the times of dawn and dusk according to algorithms provided by the National Oceanic and Atmospheric

Administration (NOAA; Bivand and Lewin-Koh 2019). Night locations were used to locate night roosts across the SCP.

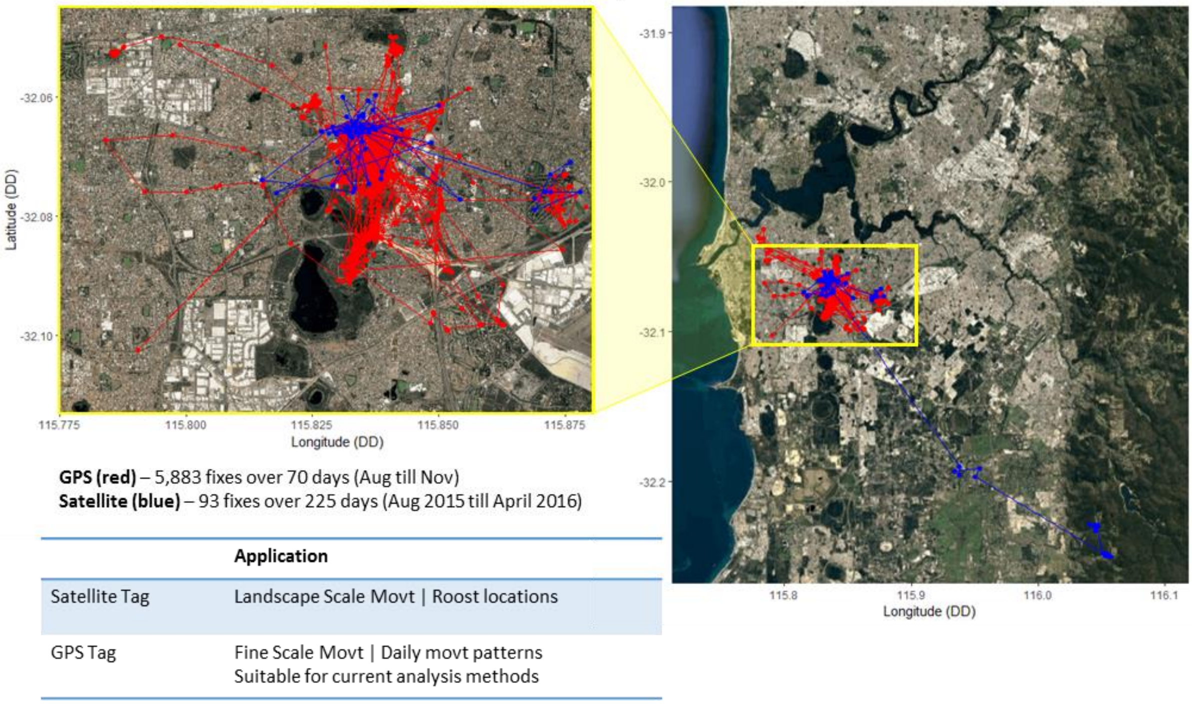

Fig. 2 - The difference in data resolution for a forest red-tailed black cockatoo (RTBC4) tagged with both a satellite tag (blue tracks) and GPS tag (red tracks). The data density is many orders of magnitude greater in the GPS download, which captures a detailed picture of fine scale movement. The longer tracking period afforded by the satellite tag has captured a ranging movement southeast to the Darling Scarp in spring.

We used behavioural change point analysis (BCPA) in the 'bcpa' package (Gurarie 2014, Gurarie et al. 2009), following the protocol of Rycken et al. (2018), to confirm that released GPS tagged birds were moving with a flock and therefore that individual bird movement was representative of flock movement. This had the added advantage of allowing us to quantify the number of flocks tracked, and their spatial partitioning and distribution. Where GPS data were not available, flock integration was confirmed by visual observation.

Track visualisation showed that birds released in Waroona (Table 1) stayed in this region or moved east across the Darling Scarp and were not included in further analysis (Fig. 3).

Home-range areas were estimated for each bird using area corrected autocorrelated kernel density estimation (AKDEc; Fleming and Calabrese 2017a), applying the Ornstein-Uhlenbeck F (OUF) model implemented with the continuous-time movement modelling (CTMM) R package v0.4.1(Fleming and Calabrese 2017b). AKDEc was used in preference to traditional kernel density estimators as it considers autocorrelation associated with high-resolution GPS data and estimates bandwidth using a method purported to substantially reduce area estimate bias. As the method assumes equal probability of movement in all directions it is only suitable for analysing resident behaviour. Accordingly, tracks were subset to resident and ranging movement and checked with diagnostic periodograms (Fleming and Calabrese 2017b) to ensure this assumption was not violated. Resident movement was classified as all daily foraging movement with return movement to roosting areas. Ranging movement was typically unidirectional up to or exceeding 10km and often occurred between resident areas.

Home-range sizes were used to predict the area that birds could use if based at the Edward Street roost site (GCC site: GOSKENR001; Peck et al. 2018).

Preferred night roost, and day foraging or roosting sites as well as movement corridors were identified using revisitation rates for birds released into metropolitan flocks using the R package ‘recurse’ (Bracis et al.). The method works by taking a circle of user specified radius and moving it along the movement trajectory (Bracis et al. 2018). Movement into and out of the circle counts as a single visit. Circles of high use, that is, areas of high revisitation, have many independent visits. The revisitation rate can be manipulated by changing the size of the circle. Therefore, the circle needs to be both ecologically appropriate to the species, and appropriate to the activity targeted. For example, a small circle may capture the location of a foraging site, but may be too small to capture a night roost; which for RTBCs may be as large as 1km^2 depending on flock size (Glossop et al. 2011). Data were analysed in total and then subset to ‘day’ and ‘night’ and reanalysed to target day and night activity independently. We used a circle radius of 500m for all data considered together and the night data set. The day data were analysed using a circle radius of 100m to capture movement corridors and foraging and drinking activity. In addition, we applied a threshold of 60 minutes to the revisit data. This allowed a bird to leave the circle and return within a 60-minute period without the revisit being counted. This accounted for small excursions that may be due to flushing or disturbance. It was considered that a bird that had been absent for longer than 60 minutes had left the area or had time to take part in another activity elsewhere. Using revisitation rates, we also calculated activity and residence time in a 24 hour period (circle radius 500 m; threshold 60 minutes) using all data to identify periods of high and low activity representing foraging and day or night roosting.

We used cluster analysis with the top 20% of locations identified by the number of revisits, to identify key day foraging or roosting locations and night roost locations. Clustering was done using the ‘k-means’ method (Hartigan and Wong 1979) in the R ‘stats’ package (R Core Team 2019) specifying either three or four clusters depending on the number of data points. We then visited these sites to identify the dominant vegetation characteristics and the presence/absence of water.

Average pairwise distances between key day clusters and key night clusters as well as distances between day and night clusters were calculated for each bird and its flock. To gain additional insight to the spatial partitioning of resources by flocks, we also calculated pairwise differences between all day and night sites identified by the cluster analysis.

Except where noted, all data processing, analysis and map production was conducted in R (version 3.5.3; R Core Team 2019) using RStudio (version 1.0.153; RStudio Team 2009-2017).

Results

Across all releases, 11 birds were satellite tracked for 1,225 days, from which 230 days of data were collected. This difference in the number of days was due to the programme schedule, which was designed to identify night roost locations and to maximise battery life. Five of these birds were also GPS tracked over 201 days and collected 197 days of data (Table 1). Missed days were a result of poor weather, which caused the solar battery level to deplete. Under these conditions the tag ‘goes to sleep’ until the battery level is recharged. The satellite tags collected 741 LC 2 or LC 3 location class fixes; by comparison, 19,874 GPS locations were received at 5-20 minute intervals. Satellite tagged birds were tracked for an average 101 days (range: 2 to 226 days), and GPS tagged birds were tracked for an average 40 days (range: 2 to 73 days).

Table 1 - Track and Daily movement summaries for forest red-tailed black cockatoos Calyptorhynchus banksii naso *on the Swan Coastal Plain. Birds that were double tagged have both Satellite and GPS Data. Satellite data reports LC 2 and LC 3 relocations only. The number of data days for satellite data reflects the programming schedule, which was designed to capture overnight roost locations to facilitate GPS download to a mobile base station. The satellite tags were also turned off for long periods to maximise battery life and capture movement over the long term. See methods for programming schedule. Integration to a flock was determined with Behavioural Change Point Analysis using the methods of Rycken et al. 2018, or visually for single mounted birds, and flock sizes were estimated by field based flock follows.*

ID	Year	Release Site	Sensor	Tag ID	Est. flock	Start date	End date	No.Reloc	No. days	No. data	% days data	Distance travelled per day (km)			Distance (km)
		Lat/Long (DD)			Size				tracked	days		Min.	Max.	Av.	
RTBC1	2015	Murdoch	Sat	151396	50	26/08/2015	08/04/2016	108	226	36	16	-	-	-	119.98
		S32.069 E115.83	GPS	2177		26/08/2015	07/11/2015	5949	73	73	100	0.68	17.14	7.03	492.02
RTBC2	2015	Murdoch	Sat	151397	< 50	26/08/2015	09/10/2015	56	44	10	23	-	-	-	46.73
		S32.069 E115.83	GPS	-		-	-	-	-	-	-	-	-	-	-
RTBC3	2015	Murdoch	Sat	151398	50 +	26/08/2015	08/04/2016	80	225	23	10	-	-	-	162.90
		S32.069 E115.83	GPS	2178		26/08/2015	30/09/2015	6717	36	36	100	1.57	38.34	16.41	590.80
RTBC4	2015	Murdoch	Sat	151399	50	26/08/2015	08/04/2016	93	225	31	14	-	-	-	93.84
		S32.069 E115.83	GPS	2176		26/08/2015	04/11/2015	5883	70	70	100	0.10	25.86	8.36	593.89
RTBC5	2016	Kensington	Sat	159158	20-70	20/07/2016	02/03/2017	111	225	38	17	-	-	-	167.88
		S31.988 E115.89	GPS	2264		20/07/2016	03/08/2016	775	15	13	87	0.083*	14.14*	9.26*	74.09
RTBC6	2016	Kensington	Sat	159159	120 +	20/07/2016	25/07/2016	14	5	4	80				16.03
		S31.988 E115.89	GPS	2265		20/07/2016	25/07/2016	550	7	5	71	0.15*	9.1*	4.56*	13.67
RTBC7	2016	Kensington	Sat	159160	120 +	20/07/2016	02/08/2016	22	12	8	67	-	-	-	21.32
		S31.988 E115.89	GPS	-		-	-	-	-	-	-	-	-	-	-
RTBC8	2016	Kensington	Sat	159161	120 +	20/07/2016	28/08/2016	60	39	19	49	-	-	-	52.39
		S31.988 E115.89	GPS	-		-	-	-	-	-	-	-	-	-	-
RTBC9	2017	Waroona	Sat	163582	> 100	23/09/2017	19/10/2017	53	26	17	65	-	-	-	129.40
		S32.793 E116.01	GPS	-		-	-	-	-	-	-	-	-	-	-
RTBC10	2017	Waroona	Sat	166163		21/09/2017	23/09/2017	6	2	1	50	-	-	-	5.38
		S32.793 E116.01	GPS	-		-	-	-	-	-	-	-	-	-	-
RTBC11	2017	Waroona	Sat	166175	50	21/09/2017	06/04/2018	138	196	43	22	-	-	-	92.45
		S32.793 E116.01	GPS	-		-	-	-	-	-	-	-	-	-	-
						Totals	**Sat**	741	1225	230					908.30
							GPS	19874	201	197					1764.47

* Min, Max and Av. distance travelled per day for RTBC5 and RTBC6 used data subsets from the time that the birds were flocked based on the BCPA analysis. This reduced the number of days used in the home range and recurse analysis to eight days for RTBC5.

Average daily movement distances were not calculated for the satellite data as points were only collected in the morning or at night. Average daily movement for GPS tagged birds was 11 km, but ranged from 4 km to 16.5 km. This described return movement to roost locations following daily foraging activity.

Overall, the satellite data described 908 km of movement and the GPS data described 1,764 km of movement (Fig. 3). RTBC6 (Tag 2265) released in Kensington, was the only bird with tracks in the vicinity of the Edward Street roost site (Fig. 3). This bird was seen in the field with a flock of more than 120 birds, but unfortunately five days after release it was killed by a vehicle while crossing Tonkin Highway. Its body and trackers were recovered.

The satellite tracking showed ranging movement by four birds south-east to the Darling Scarp (Fig. 4). Three of these stayed on or near the Darling Scarp through summer and until the start of autumn at which point the batteries in the satellite tags became depleted and no further fixes were received (Fig. 4; Table 2).

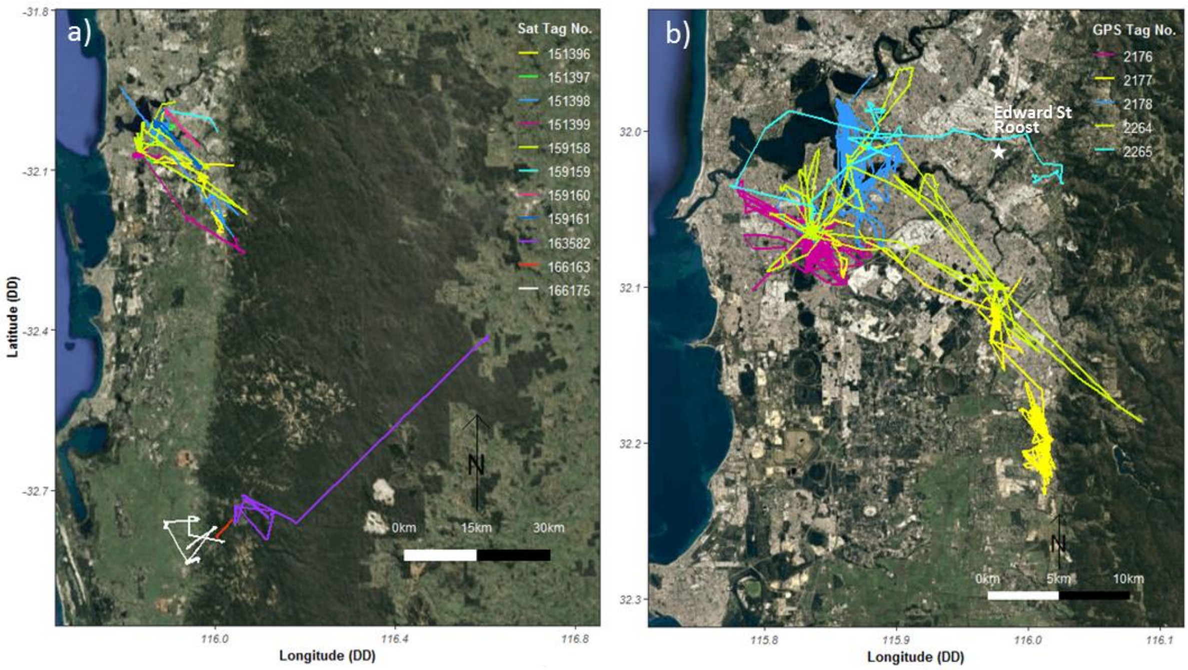

Fig. 3 - Movement tracks of forest red-tailed black cockatoos Calyptorhynchus banksii naso *a) satellite tagged and b) GPS tagged birds. The colours are the same for birds that were double- tagged. For example RTBC1 (Table 1) carries satellite tag 151396 and GPS tag 2177. The satellite data describes 908 km of movement and the GPS data describes 1764 km of movement. The location of the Edward Street roost site (Great Cocky Count site: GOSKENR001) is shown with a star.*

Flight speed was very low for this species, with 90% of all daytime relocations occurring at less than or equal to 1m/s. At this speed the average distance travelled was 48 m between relocations (the distance between two consecutive GPS points) which could take up to an average 13 minutes; suggesting that birds were either resting, day roosting or foraging within a limited area for a large part of the day, or moving through the landscape relatively slowly most of the time.

Male (a) and female (b) forest red-tailed black cockatoos (Calyptorhynchus banksii naso) *feeding on marri* (Corymbia calophylla) *and illyarrie* (Eucalyptus erythrocorys).

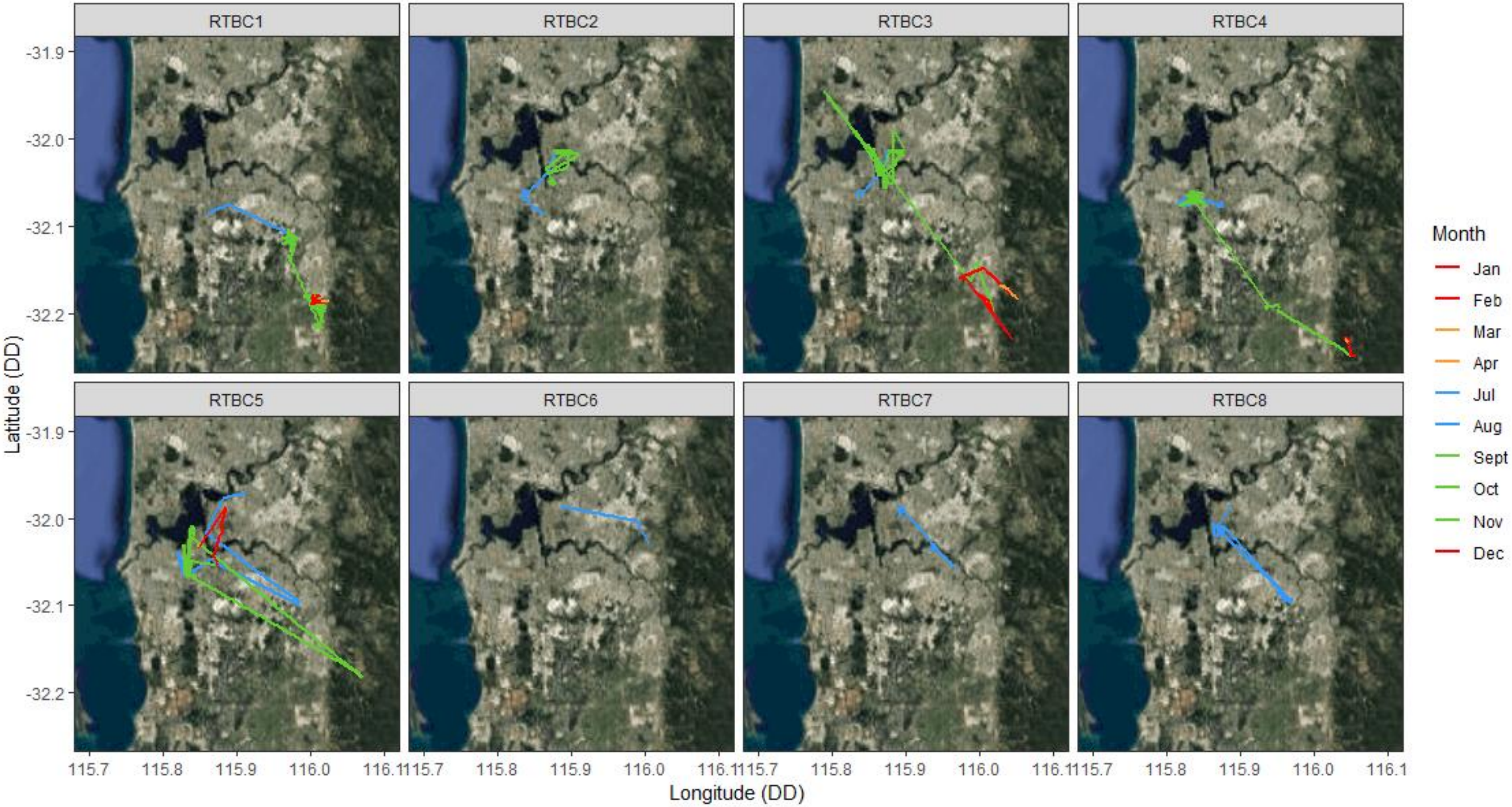

Fig. 4 – Satellite tracks for eight forest red-tailed black cockatoos Calyptorhynchus banksii naso *showing southeast movement of four birds to the Darling Scarp during spring. Those birds not showing this movement were tracked until the end of winter or the start of spring (see Table 2). Winter = June to August; Spring = September to November; Summer = December to February; Autumn = March to May.*

Table 2 - Tracking timeline for 11 forest red-tailed black cockatoos released between 2015 and 2017. The four birds with an asterix were tracked across seasons and all made ranging movements away from urban and peri-urban regions on the Swan Coastal Plain in spring (see Fig. 4). Three of these stayed on or near the Darling Scarp through summer and until the start of autumn at which point the batteries in the satellite tags became depleted and no further fixes were received.

				Year 1						Year 2			
	Start Year	Release Site	No. days tracked	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RTBC1*	2015	Murdoch	226										
RTBC2	2015	Murdoch	44										
RTBC3*	2015	Murdoch	225										
RTBC4*	2015	Murdoch	225										
RTBC5*	2016	Kensington	225										
RTBC6	2016	Kensington	5										
RTBC7	2016	Kensington	12										
RTBC8	2016	Kensington	39										
RTBC9	2017	Waroona	26										
RTBC10	2017	Waroona	2										
RTBC11	2017	Waroona	196										

Winter		Jun-Aug
Spring		Sept-Nov
Summer		Dec-Feb
Autumn		Mar-May

Breeding recorded in all months - peak periods April-June and August-October (Johnstone et al. 2013b)

Flock partitioning and distribution on the Perth-Peel Coastal Plain

Movement paths suggest that there was significant spatial overlap between birds in the Murdoch and Kensington releases (Fig. 3). All birds carrying GPS tags were confirmed to be flocked using the BCPA method. Two of the three birds released in Waroona were tracked for enough time that flock integration could be confirmed in the field. All birds (excepting RTBC10 which gave only one day of data (last fixes were received from an orcharding area) were observed in flocks ranging in size from 20 to more than 120 birds at different times during the tracking period (Table 1).

Despite spatial overlap between daytime tracks, analysis of the long-term track data suggests that while RTBC2, RTBC4 and RTBC5 may have integrated to the same flock on the Murdoch Campus for at least some part of the tracking timeline, all other birds appear to have joined different flocks, and so these data describe movement of at least eight flocks. Night roost locations also show some overlap in roost use, but also significant variation in night roosts used over time and between flocks, confirming that flocks spatially partition food and night roost resources across the SCP (Fig. 5).

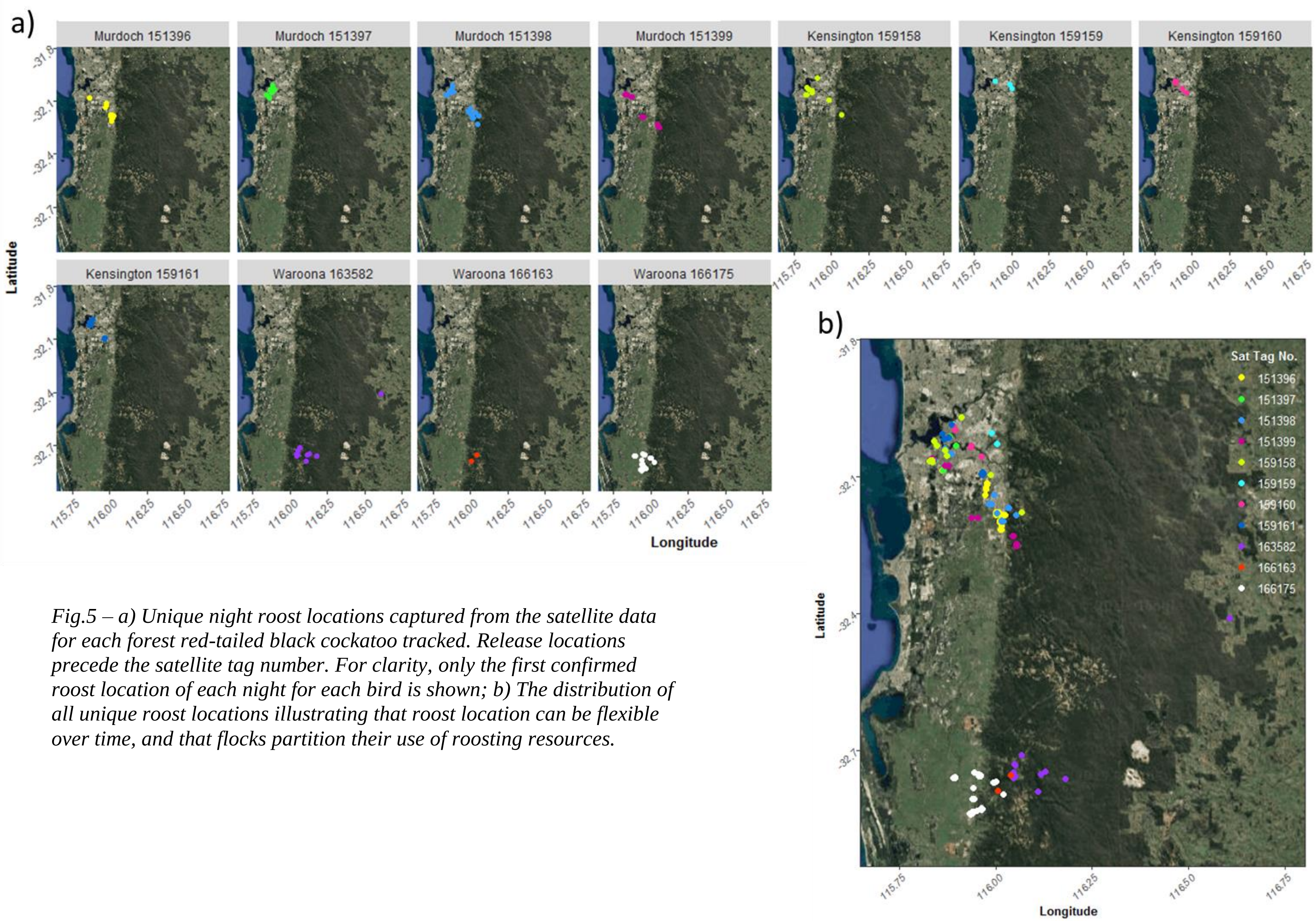

Fig.5 – a) Unique night roost locations captured from the satellite data for each forest red-tailed black cockatoo tracked. Release locations precede the satellite tag number. For clarity, only the first confirmed roost location of each night for each bird is shown; b) The distribution of all unique roost locations illustrating that roost location can be flexible over time, and that flocks partition their use of roosting resources.

Home-range size and space utilisation among GPS tracked birds

Four of the five birds with GPS tags met the criteria for home-range analysis. Although RTBC1 was released on the 26th August 2015, nearly the first month of data was excluded from analysis as this bird made several ranging movements with its flock in the weeks preceding the 19th September after which the flock settled to a resident pattern (Fig. 6). The cut-off date was established through sequential iteration and visualisation using diagnostic periodograms.

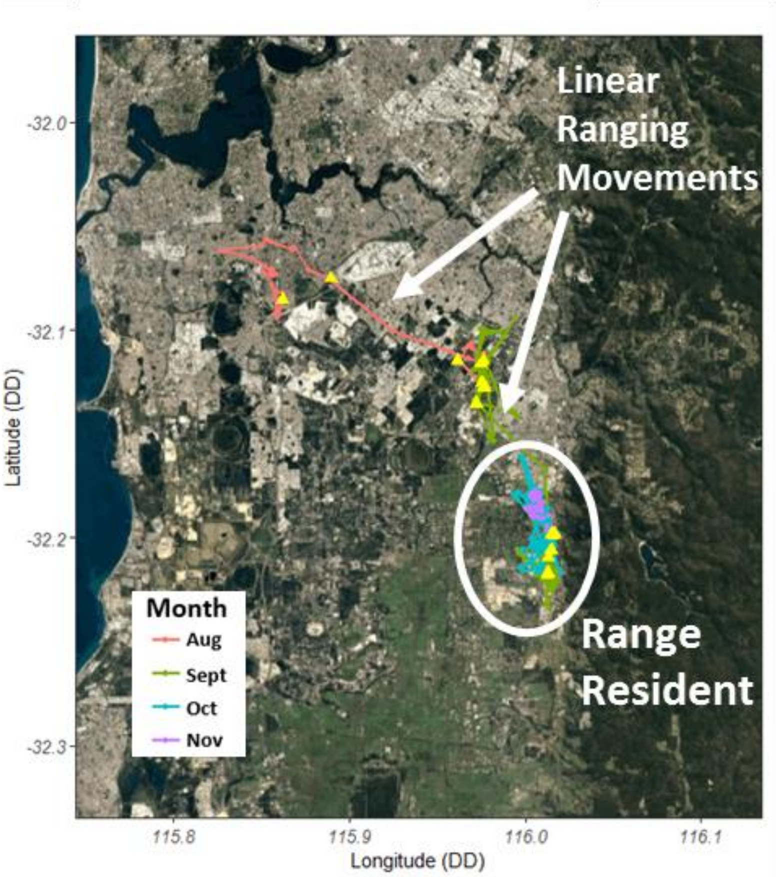

Fig. 6 - Movement track for RTBC1 between August and November 2015. The first part of the track until the 19th September was excluded, as during this time the bird with its flock made consecutive ranging movements. The home-range analysis is only valid when applied to resident movement (Fleming and Calabrese 2017b).

Home-range sizes ranged from 8 – 45 km^2. Depending on the number of days tracked, maximum-likelihood analysis suggested birds crossed their home-ranges between 14 and 329 times during the sample period, but the number of crossings were not related to home-range size (Table 3). Utilisation plots showed clear preference to parts of these home-ranges once routine movements were established and maintained around the middle of the tracking timeline (Fig. 7).

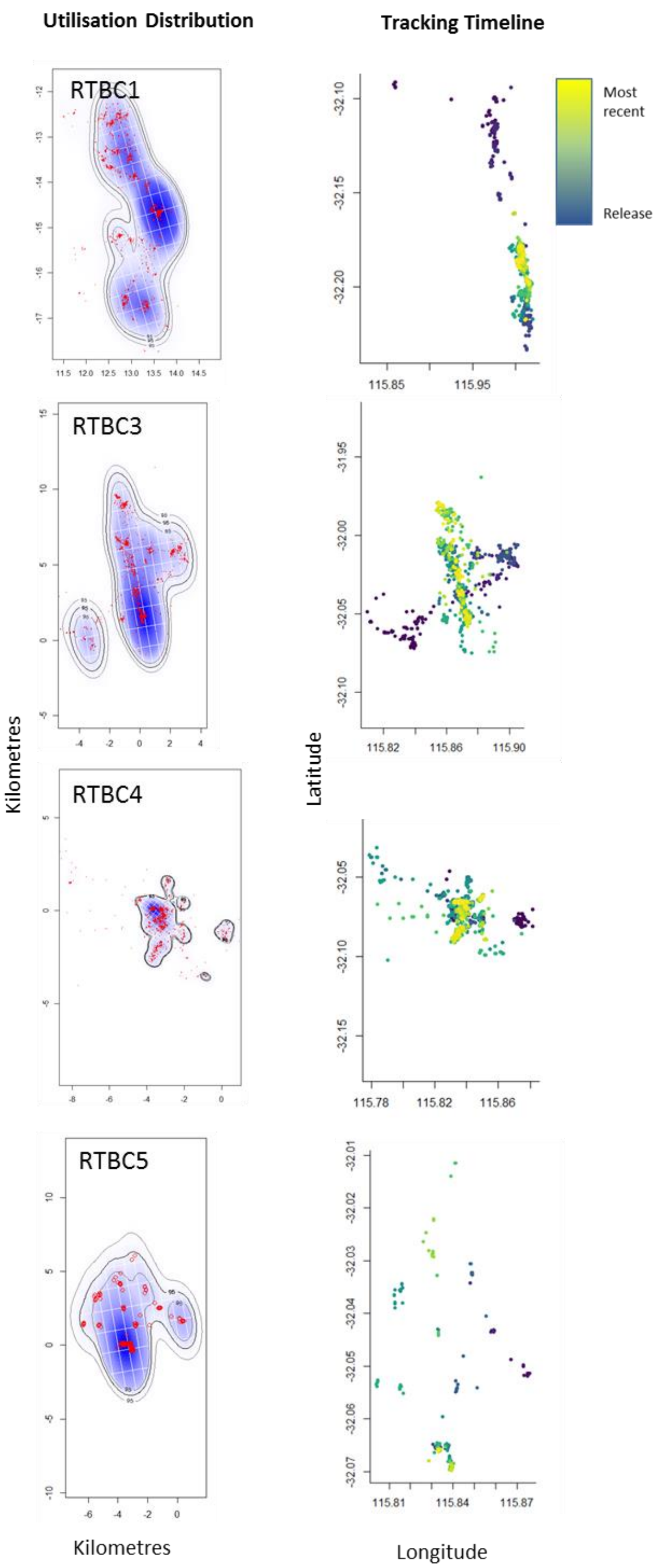

Fig. 7 – Spatial utilisation distributions for four forest red-tailed black cockatoos GPS tracked on the Swan Coastal Plain. Utilisation distributions calculated using AKDEc show the concentration of activity (blue shading) relative to location points (red). Contrasting these with the tracking timeline shows that routine movements were established and maintained from the middle of the tracking period.

Identification of key roost and foraging areas and daily activity periods.

Revisitation statistics derived from the day and night data revealed that key day foraging or roosting sites were located relatively close to key night roosts (Fig. 8). These key sites, identified as the top 20% of revisited sites in the cluster analysis, are interpreted as areas of high quality habitat. Overall, the spatial distribution of foraging locations relative to the modelled home-range boundaries showed that flocks forage throughout their home-range (Fig. 8). Three of the four flocks show moderate and repeated foraging activity at many sites across the home-range area, supporting the earlier contention that despite high revisitation of high quality habitat, birds move slowly through the landscape while foraging.

Average distances between the top 20% of day foraging and roosting sites (0.46 to 1.04 km) and between night roosts (0.54 to 5.18 km) were surprisingly small for each bird (Table 3). Similarly, the average distance that birds moved between key night roost and day foraging sites ranged between 0.47 – 5.12 km. Distances for RTBC1 are likely inflated as the clustering algorithm also identified two high use night roosts (Site 2 and 3, Fig 8) visited in the period immediately prior to the 19th September before the flock became range resident.

Individual pairwise distances for the top 20% of all sites, and among all birds, also confirmed spatial partitioning of foraging and roosting resources with comparatively large distances between, rather than within flocks, for both day and night sites (Table 4). The birds also showed clear activity periods for morning foraging, day roosting, afternoon foraging and night roosting. Longest residence times were associated with morning foraging and night roosting. Afternoon foraging activity, associated with shorter residence times, was indicative of birds foraging opportunistically as they moved to the night roost (Fig. 9).

Table 3 - Average pairwise distances (km ± range) between the top 20% of day foraging or night roosts identified using cluster analysis. These sites represent high quality habitat. These data should be interpreted considering overall utilisation distribution and the number of times a bird has crossed the linear extent of the home-range (HR). There was insufficient data for 2265 to calculate revisitation statistics. Home-range areas were calculated using GPS data for resident areas (km^2) only.

ID	Tag	No. of sample days	Between day foraging or roosting sites	Between night roosts	Between day foraging/roosting sites and night roosts	HR (95% CI)	No. of HR crossings during sample period
RTBC1	2177	73	1.04 (0.14-1.65)	5.18 (0.06-10.34)	5.12 (0.06-10.34)	8.41 (6.85-10.12)	102
RTBC3	2178	31	1.03 (0.25-1.90)	2.62 (0.56-3.88)	1.69 (0.13-4.35)	44.66 (37.03-52.99)	120
RTBC4	2176	70	0.46 (0.08-0.72)	0.54 (0.03-0.78)	0.47 (0.03-0.88)	8.33 (7.45-9.25)	329
RTBC5	2264	8	0.46 (0.08-0.72)	n.a	n.a	45.58 (25.72-76.05)	14

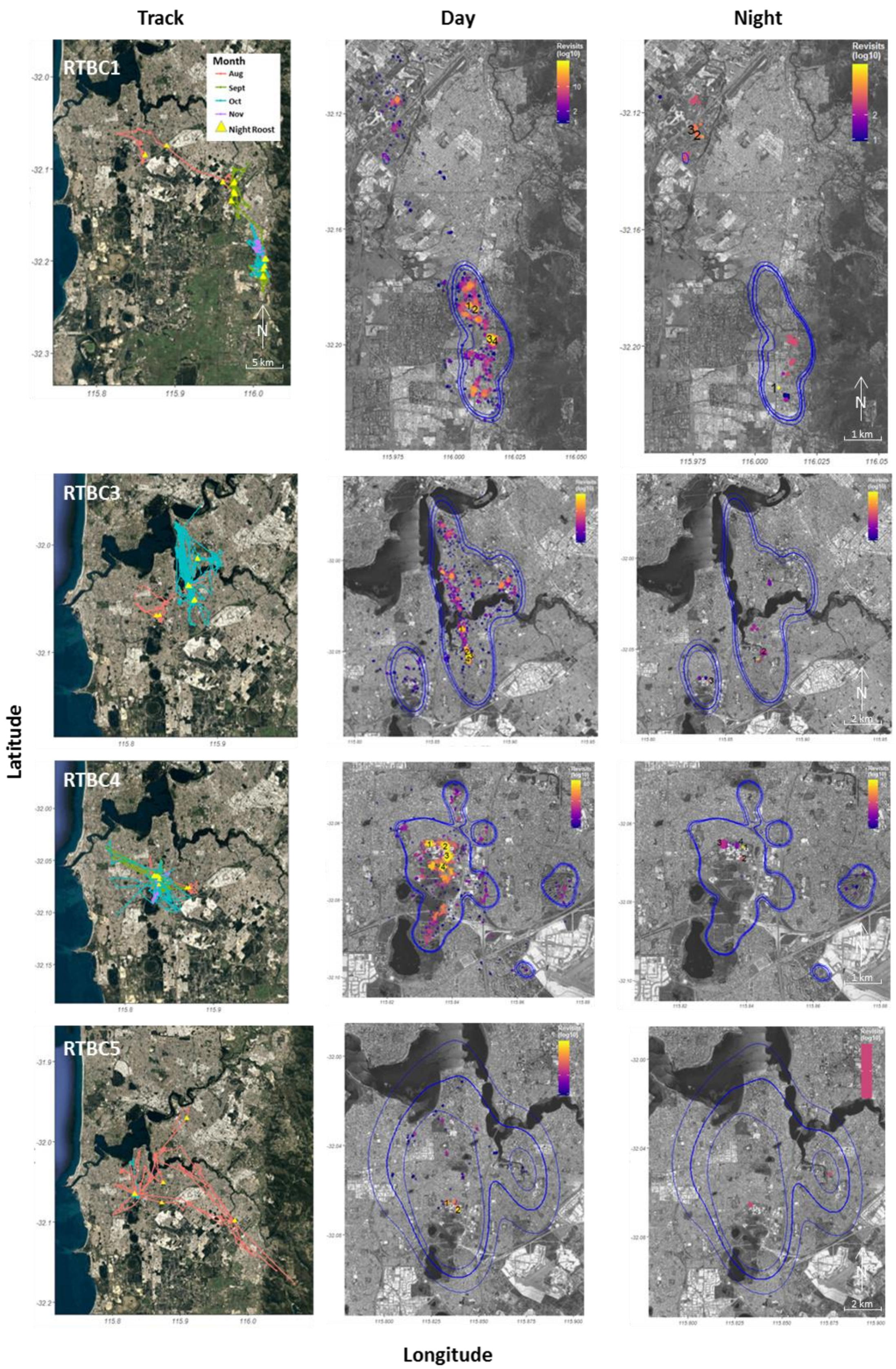

Fig. 8 – Key day foraging/roosting and night roosting sites identified using 'recurse' analysis relative to the overall tracking timeline and home-range contours for four forest red-tailed black cockatoos. Areas with high revisitation are indicated with warmer colours. Sites identified in the top 20% based on revisitation statistics are labelled 1 – 4 (the number order does not indicate preference). See Appendix 2 for larger versions.

Table 4 - Pairwise distance (km) between day foraging /roosting sites in the lower triangle, compared with pairwise distances between night roosts identified using cluster analysis for forest red-tailed black cockatoos (N=4). Distances were generated using the centroid of the top 20% of sites identified using 'recurse' analysis, and should be interpreted as representing movement between high quality habitat. Within flock comparisons are shaded grey, and show in almost all instances that distances between sites are small. An exception to this is Flock RTBC1 which has a pairwise distance of 10km between one site and all other main night roosts. This site was established following a ranging movement and corresponds to Site 1 in Fig 8. There was insufficient data to calculate night roost pairwise differences for RTBC5 or perform the analysis for RTBC6.

			NIGHT														
	ID(Tag)		RTBC4 (2176)				RTBC1 (2177)				RTBC3 (2178)				RTBC5 (2264)		
		Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
DAY	RTBC4	1		0.66	0.76	0.03	15.30	15.12	15.34	23.58	4.33	3.94	0.65	.	.	.	.
	(2176)	2	0.08		0.31	0.67	14.66	14.48	14.70	23.02	3.80	3.37	0.10	.	.	.	.
		3	0.58	0.65		0.78	14.55	14.37	14.58	22.82	3.98	3.52	0.22	.	.	.	.
		4	0.66	0.72	0.08		15.32	15.14	15.35	23.60	4.33	3.94	0.66	.	.	.	.
	RTBC1	1	21.91	21.84	22.48	22.56		0.20	0.06	10.14	12.81	12.67	14.65	.	.	.	.
	(2177)	2	22.05	21.98	22.62	22.70	0.14		0.26	10.34	12.61	12.48	14.48	.	.	.	.
		3	20.75	20.68	21.32	21.40	1.28	1.39		10.09	12.86	12.71	14.69	.	.	.	.
		4	20.47	20.39	21.04	21.12	1.52	1.64	0.29		22.15	21.88	22.98	.	.	.	.
	RTBC3	1	4.45	4.49	4.56	4.58	22.57	22.70	21.33	21.06		0.56	3.88	.	.	.	.
	(2178)	2	3.76	3.78	4.02	4.06	21.39	21.51	20.15	19.88	1.32		3.44	.	.	.	.
		3	3.78	3.79	4.09	4.14	20.98	21.11	19.74	19.48	1.70	0.41		.	.	.	.
		4	3.58	3.59	3.91	3.96	20.86	20.99	19.63	19.36	1.90	0.58	0.25		.	.	.
	RTBC5	1	0.00	0.08	0.58	0.66	21.91	22.05	20.75	20.47	4.45	3.76	3.78	3.58		.	.
	(2264)	2	0.08	0.00	0.65	0.72	21.84	21.98	20.68	20.39	4.49	3.78	3.79	3.59	0.08		.
		3	0.58	0.65	0.00	0.08	22.48	22.62	21.32	21.04	4.56	4.02	4.09	3.91	0.58	0.65	
		4	0.66	0.72	0.08	0.00	22.56	22.70	21.40	21.12	4.58	4.06	4.14	3.96	0.66	0.72	0.08

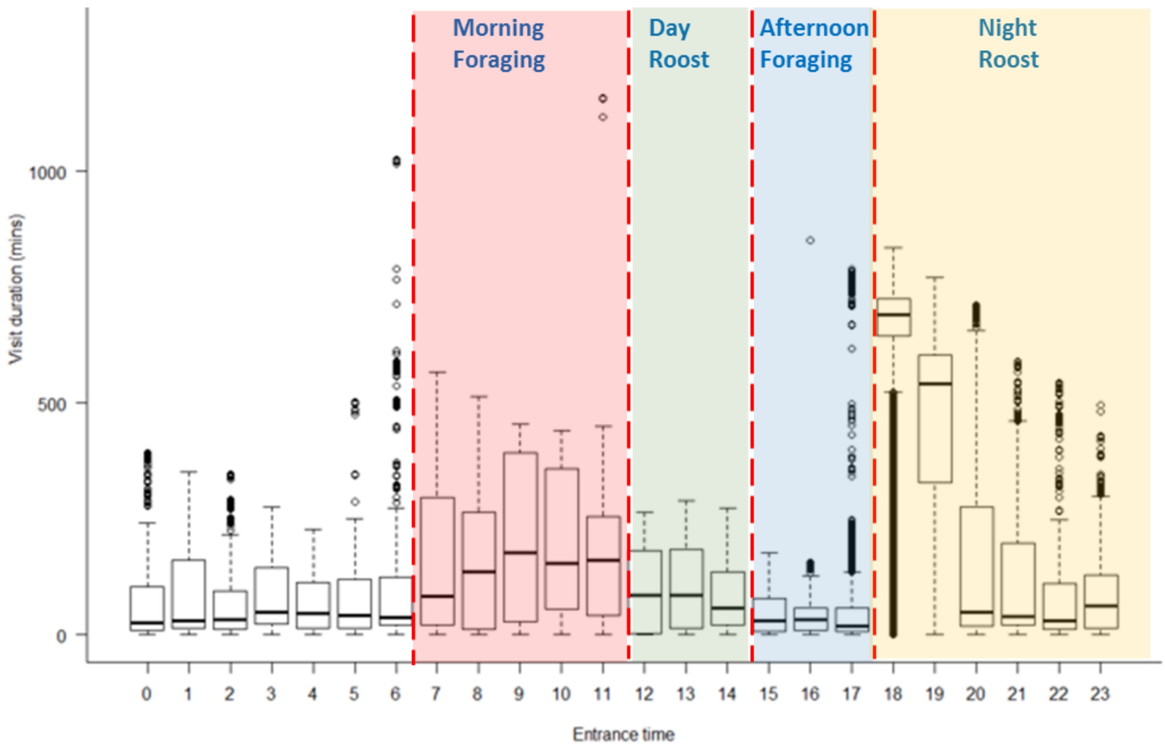

Fig. 9 – Temporal pattern of residence time based on hour of the day for one forest red-tailed black cockatoo (RTBC4) using revisitation statistics. This analysis considered day and night data together using a circle radius of 500m with a 60-minute threshold (see Methods – Data Analysis). The longest residence times were during morning foraging and night roosting. This pattern was typical for all GPS tagged birds in this study. 250 mins equals four hours.

Dominant vegetation characteristics of key day forage/roost and night roost sites

There were 14 key day sites and 10 key night roost sites identified using 'recurse' and clustering analysis (Table 5). Site visits (6th and 10th June 2019) showed that overall, both foraging and roosting areas were dominated by marri *(Corymbia calophylla)* and other tall tree species such as jarrah *(Eucalyptus marginata)* and spotted gum *(Corymbia maculata)*. In all cases, trees were mature and ranged in height from 10 – 20m. Many of the sites had recent feed residue present. Sites on the Murdoch campus had birds present, or nearby, based on calls and fly-through observations. Sixty-seven percent of day sites had water present. In nearly all cases, these were water troughs, but two metropolitan sites had natural waterbodies. At least one of these may by seasonally dry. Only 40% of night roosts had an available water source, and again these were water troughs. Most peri-urban areas that did not have water immediately present had water troughs nearby as most sites were horse studs, or livestock paddocks.

Other forage species present included lemon scented gum (*Corymbia citriodora*), blackbutt (*Eucalyptus patens*), illyarrie (*Eucalyptus erythrocorys*) and she-oak (*Casuarina spp.*), along with various non-natives including tipuana (*Tipuana tipu*), liquid amber (*Liquidambar spp.*) and jacaranda (*Jacaranda spp.*). Tipuana is not generally listed as a food species, but RTBC were seen feeding on this at the Murdoch University campus. Very few cape lilac *(Melia azedarach)* were seen at the sites though they would have been present, at least in some of the suburbs visited. Residential properties identified as either day or night sites had retained large trees or linear stands of trees along the nature strip, driveways or within gardens. One residential site was adjacent to Brolga Park, which is also a high use night roost with natural water and a significant number of mature native and non-native forage species.

Day and night sites that were not privately owned were classified by Landgate as part of the Urban Forest Mesh Block network with canopy covers ranging from 17 – 59% (https://maps.slip.wa.gov.au/landgate/locate/). Several sites on the Murdoch University campus were classified as Native Vegetation Extent – Remnant Vegetation (https://maps.slip.wa.gov.au/landgate/locate/).

Table 5 – Location and vegetation characteristics of key day foraging/roosting sites and night roosts identified using 'recurse' and cluster analysis. Sites were visited on the 6th or 10th June 2019 to identify the dominant vegetation type and the presence of water.

Site	Flock ID (Tag ID)	Roost No.	Long	Lat	Location	Land Type	Land Tenure[1]	% Canopy Cover[1]	Veg. Complex[2]	Veg. Complex Description[2]	Dominant Veg. Characteristics	Water present
Day	RTBC1 (2177)	1	116.006	-32.186	Wungong	Peri-urban	Private - residential - retained roadside trees	.	Guildford	Open Forest to tall open forest and woodland	Marri, spotted gum	Water troughs
		2	116.009	-32.188	Wungong	Peri-urban	Private - residential - retained roadside trees	.	Guildford	Open Forest to tall open forest and woodland	Marri	No
		3	116.015	-32.198	Oscar Bruns Reserve	Peri-urban	Urban Forest Mesh Block - 2016 (DOP-112)	55	Forestfield	Open forest and fringing woodland	Marri, mixed Eucalypt spp., other known forage	No
		4	116.016	-32.198	Byford	Peri-urban	Private - residential - retained roadside trees	.	Forestfield	Open forest and fringing woodland	Spotted gum	Water troughs
	RTBC3 (2178)	1	115.868	-32.037	Rossmoyne Park	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	20	Bassendean - Central and South	Woodland to low woodland and sedgelands	Marri, Jarrah, mixed Eucalypt spp., Illyarrie	Water trough, 2x artificial hollow
		2	115.871	-32.049	Bull Creek Park	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	51	Bassendean - Central and South	Woodland to low woodland and sedgelands	Marri, mixed Eucalypt spp., other known forage	Natural
		3	115.874	-32.052	Willeton	Urban	Private - residential - retained lge trees. Adjacent to Brolga Park	.	Bassendean - Central and South	Woodland to low woodland and sedgelands	Mixed Eucalypt spp., other known forage	No
		4	115.873	-32.054	Willeton Park	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	17	Bassendean - Central and South	Woodland to low woodland and sedgelands	Mixed Eucalypt spp., other known forage	No
	RTBC4 (2176)	1	115.833	-32.065	Murdoch Uni Carpark P4	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	22	Karrakatta - Central and South	Open forest and woodland	Marri, spotted gum, mixed Eucalypt spp.	No
		2	115.837	-32.072	Cheledonia Reserve	Urban	Geomorphic Wetland (DBCA-019)	20-25	Karrakatta - Central and South	Open forest and woodland	Marri, mixed Eucalypt spp., other known forage	Water troughs and natural
		3	115.838	-32.068	Murdoch Uni Carpark P9	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	22	Bassendean - Central and South	Woodland to low woodland and sedgelands	Marri, spotted gum, illyarie, she-oak	Water troughs
		4	115.837	-32.071	Murdoch Uni remnant veg	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	20-25	Karrakatta - Central and South	Open forest and woodland	Marri	Water troughs
	RTBC5 (2264)	1	115.833	-32.066	Murdoch Uni Carpark P4	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	20	Karrakatta - Central and South	Open forest and woodland	Marri, spotted gum, mixed Eucalypt spp.	No
		2	115.839	-32.069	Murdoch Uni Carpark P9	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	22	Bassendean - Central and South	Woodland to low woodland and sedgelands	Marri, spotted gum, illyarie, she-oak	Water troughs
Night	RTBC1 (2177)	1	116.010	-32.214	Byford - Peri-urban	Peri-urban	Private - residential - discrete stand of large trees	.	Forestfield	Open forest and fringing woodland	Marri	No
		2	115.977	-32.127	Camillo - Champion Lakes	Peri-urban	Private - residential - retained linear stands of trees	.	Southern River	Open woodland	Marri, spotted gum, mixed Eucalypt spp.	Water troughs
		3	115.975	-32.126	Camillo - Champion Lakes	Peri-urban	Private - residential - retained linear stands of trees	.	Southern River	Open woodland	Marri, spotted gum, mixed Eucalypt spp.	Water troughs
	RTBC3 (2178)	1	115.872	-32.055	Trevor Gribble Park	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	29	Bassendean - Central and South	Woodland to low woodland and sedgelands	Mixed Eucalypt spp., other known forage	No
		2	115.875	-32.051	Brolga Park	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	59	Bassendean - Central and South	Woodland to low woodland and sedgelands	Mixed Eucalypt spp., other known forage	Natural
		3	115.838	-32.067	Murdoch Uni	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	21	Bassendean - Central and South	Woodland to low woodland and sedgelands	Marri, Jarrah, mixed Eucalypt spp.	No
	RTBC4 (2176)	1	115.839	-32.066	Murdoch Uni Carpark P1/P2	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	22	Bassendean - Central and South	Woodland to low woodland and sedgelands	Mixed Eucalypt spp., other known forage	No
		2	115.838	-32.069	Murdoch Uni Carpark P9	Urban	Urban Forest Mesh Block - 2016 (DOP-112)	22	Bassendean - Central and South	Woodland to low woodland and sedgelands	Marri, spotted gum, illyarrie, she-oak	Water troughs
		3	115.832	-32.065	Murdoch Uni	Urban	Native Vegetation Extent (DPIRD-005) - remnant vegetation	.	Karrakatta - Central and South	Open forest and woodland	Marri, mixed Eucalypt spp., other known forage	No
		4	115.832	-32.064	Murdoch Uni	Urban	Native Vegetation Extent (DPIRD-005) - remnant vegetation	.	Karrakatta - Central and South	Open forest and woodland	Marri, mixed Eucalypt spp., other known forage	No

[1.] Land tenure and percentage canopy cover are derived from data layers accessed through the SLIP Locate V5 software accessed through DataWA (https://maps.slip.wa.gov.au/landgate/locate/). Layers references are given in brackets.

[2.] Vegetation complex and description are derived from the Vegetation Complexes - Swan Coastal Plain (DBCA-046) layer available through DataWA (https://catalogue.data.wa.gov.au/dataset/vegetation-complexes-swan-coastal-plain).

Application of home-range sizes and roost use to the Edward Street roost site

Assuming equal probability of movement in any direction, and the fact that flocks may use a network of nearby roosts within a resident area, we applied home-range buffers (Fig. 10) to the Edward Street roost site (GOSKENR001). The buffers were either 8.3 km^2 (1.62km radius) or 46 km^2 (3.83 km radius) based on the minimum and maximum home-range sizes from this study.

With the exception of the GOSKENR002 roost, which was within 500m, most other known GCC roosts were outside these home-range boundaries. Only two sites were within 6 km. The average straight-line distance to other sites was 7km (range: 4 km – 9.5 km). Average distances between key roosts in this study were 500 m to 5.2 km, so it seems unlikely that these other roosts would form part of a roost network for a flock based at Edward Street.

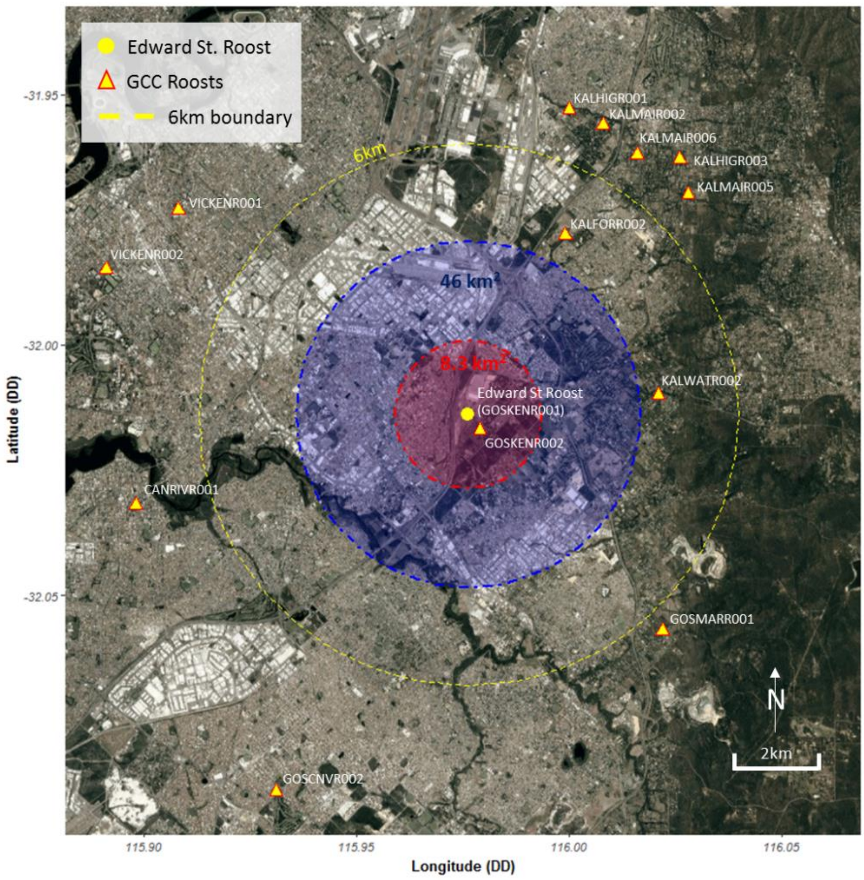

Fig. 10 – Minimum (8.3 km^2) and maximum (46 km^2) home-range areas captured using AKDEc estimation overlaying the location of the Edward Street Roost (GOSKENR001) relative to other known roosts recorded in the Birdlife Western Australia Great Cocky count (Peck et al. 2018). With the exception of GOSKENR002 which was only 434 metres from the Edward Street Roost, other known roosts were an average of 7km (Range: 4km – 9.5km) from the centre of the Edward Street Roost site. Only two of these were within a 6km boundary of the site.

Use of movement corridors

The ability to identify movement corridors was dependent on the number of days tracked and whether the tracker bird was part of the Murdoch University flock. RTBC5 which joined a flock after seven days only had eight days of data. During the early part of its track it recorded larger movements which contributed to a relatively large home-range (45.6 km^2; Table 3), but in the latter part of its track movement was centred around the Murdoch University campus (Fig. 8) where it both foraged and roosted. These movements were too small to use in corridor identification. RTBC4 which was also based at the campus, foraged and roosted on campus and made few excursions outside the University grounds until the end of September after which it extended a significant part of its daily foraging activity south to Beeliar Regional park on the eastern side of Bibra Lake (Fig. 11). This area has a large number of forage species as well as artificial breeding hollows. This change in activity, coupled with other longer movements in many directions from the main roost sites, preceded it's ranging movement in November to the Darling Scarp (Fig. 4) and it is possible that this sudden increase in activity may have included prospecting behaviour for suitable hollows. This activity was all during daylight hours. The bird and it's flock roosted only at identified key sites on campus (Fig. 8). Despite small daily movements making corridor identification impossible, the majority of its movement was within continual 'green space', highlighting the value of retained forest remnant and large canopy trees to assist movement and meet daily resource requirements.

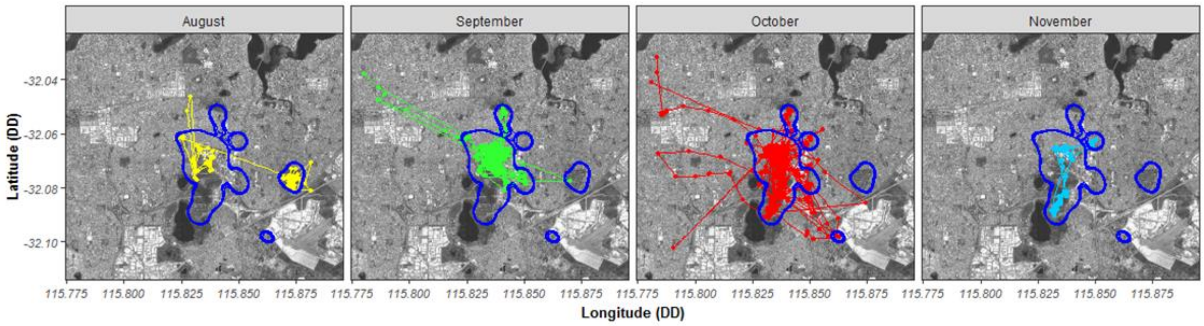

Fig. 11 – Change in monthly foraging activity for RTBC4 whose home-range (blue contours) centred on the Murdoch University campus. Note the sudden increase in foraging activity in October, which preceded a ranging movement to the Darling Scarp after the 4th November 2015.

Corridor use was more readily identifiable once birds had settled to a home-range and established daily foraging patterns. For example, RTBC3 established a clear north-south movement corridor (Fig. 12a). When comparing areas of high revisitation (Fig. 12b) and

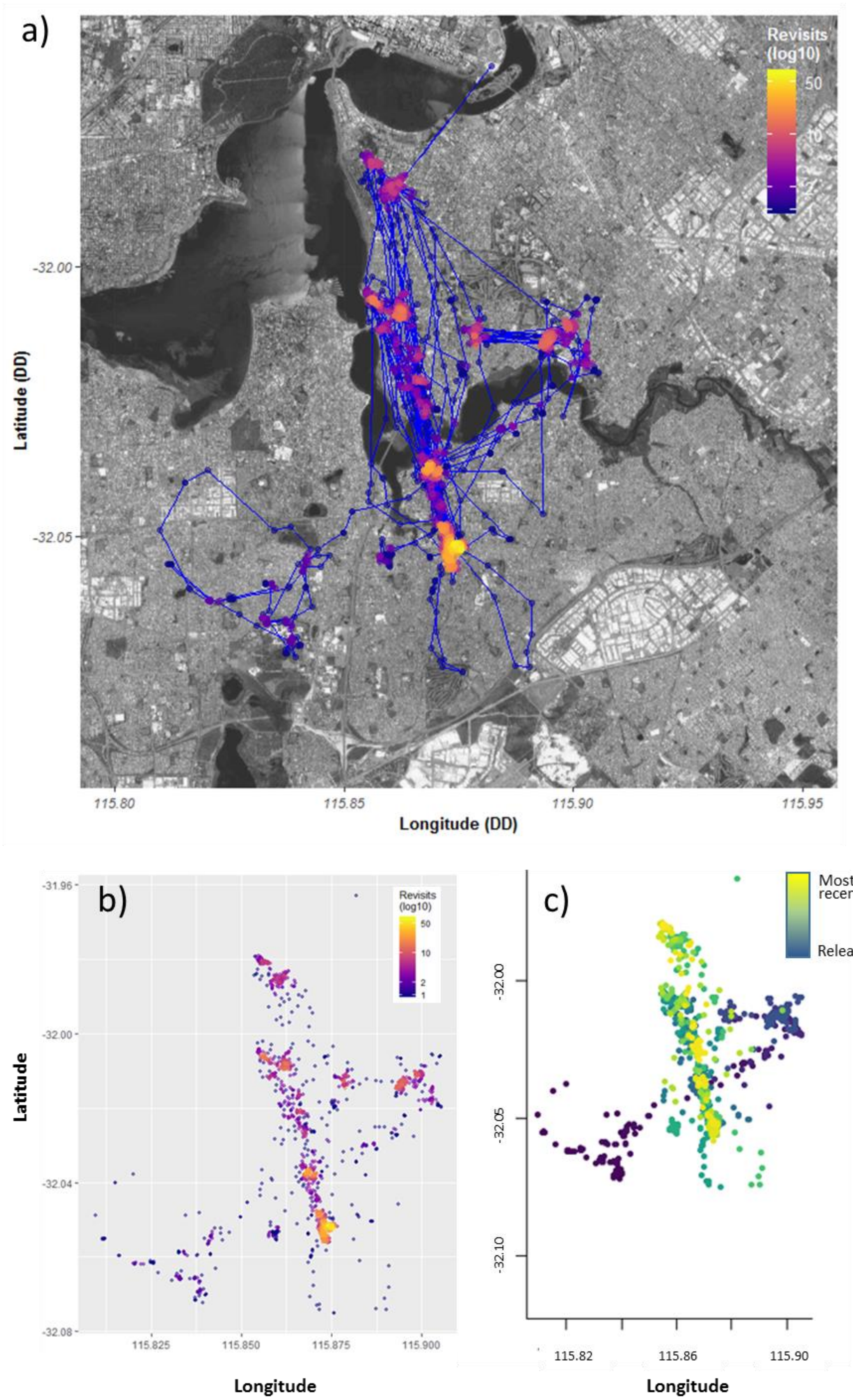

Fig. 12 – a) Evidence of a clear north – south movement corridor for RTBC3; b) Areas of high revisitation are clearly associated with the mid to latter part of the tracking timeline (c).

the tracking timeline (Fig. 12c), in combination with whether high use areas were day or night associated (Fig. 8), it is clear for this bird and its flock that virtually all movements are day foraging trips from the main roost area at the southern end of the home-range (Fig. 8). This accounts for the high number of home-range traverses during the 31-day tracking period (Table 3).

Similar to RTBC4, RTBC1 and RTBC3 both showed spatial and temporal shifts in the movement corridors used over time within their home-range boundaries (Fig 13a and b). Viewing the raw movement tracks in the absence of revisitation or temporal partitioning shows clear movement corridors based solely on track density (Fig. 13c). Across all flocks, movements were overwhelmingly related to day foraging activity.

Discussion – Application of research outcomes to the future maintenance of the Edward Street roost site

Home-range and distance to forage sites

Average daily flight distances and movement speeds in RTBCs are relatively small. By comparison Carnaby's cockatoos may move twice the distance on the SCP during daily foraging activity (Shephard and Warren 2018). Projecting home-range polygons (Fig. 10) over the Edward Street roost site demonstrates that a resident flock has relatively limited access to native food resources. According to the Bancroft et al. (2017) report, assuming a radius of 5 km around the roost, only 9.7% of the surrounding area is made up of native vegetation. This describes an area of 78.5 km^2, 1.7 times larger than the largest home-range modelled in this study. Additionally, the average canopy cover for the surrounding area ranges from zero - 15 % based on the 2016 Urban Forest Mesh Blocks (DOP-112) spatial dataset (https://maps.slip.wa.gov.au/landgate/locate/). Some of this may have reduced further with recent clearing across the overall MKSEA P3 site and more broadly in the region. This contrasts strongly with the 17 – 59% canopy cover reported for key sites identified in this study (Table 5). Much of the native vegetation adjacent to the development area has a canopy of less than 5%. Irrespective, the Edward Street roost has functioned consistently since 2017, so the apparent deficit in native vegetation and impact of existing clearing must be compensated for at least in part by retained vegetation in surrounding private land or roadside vegetation.

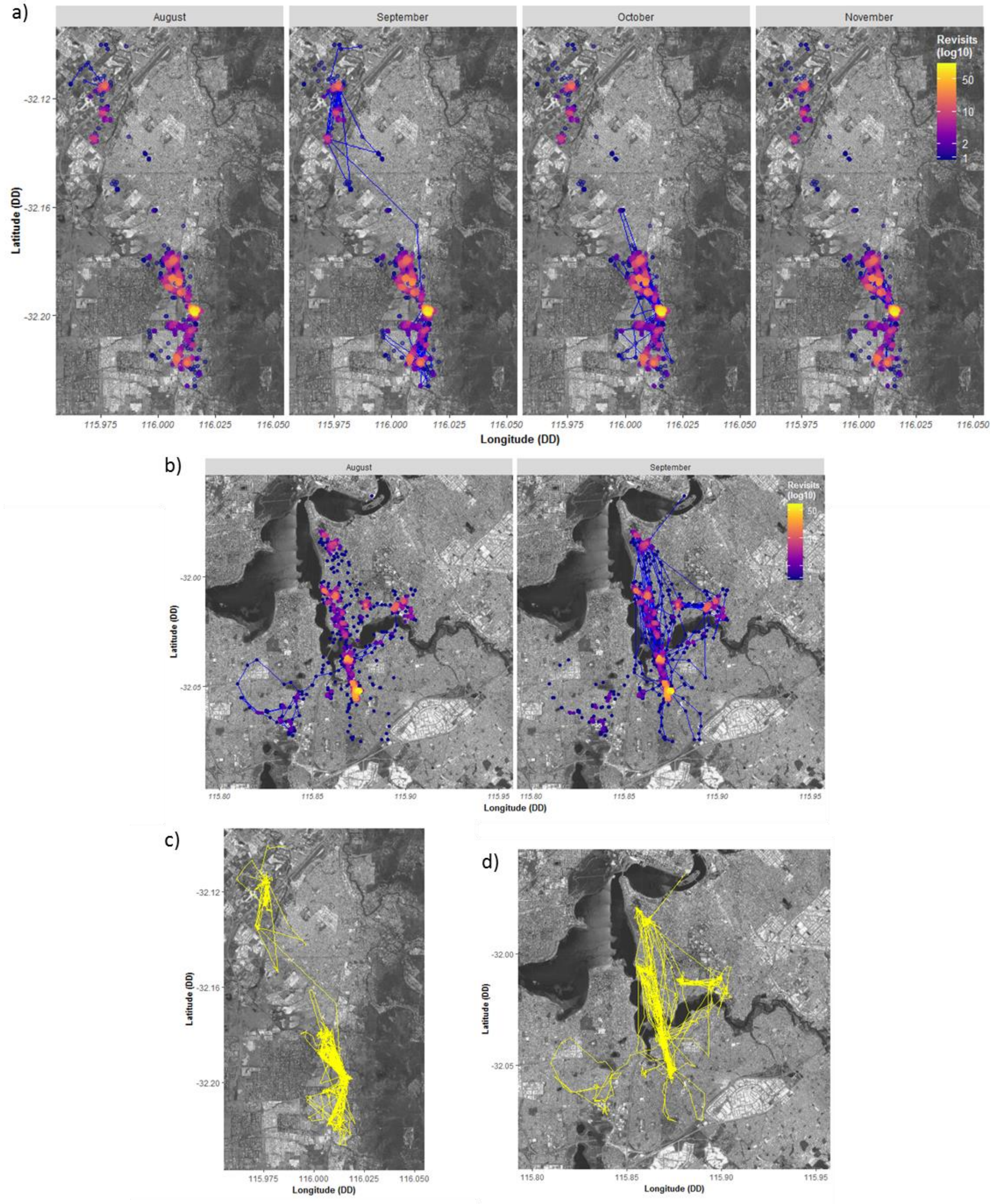

Fig. 13 – Temporal and spatial shifts in the movement tracks for: a) RTBC1 and b) RTBC3. Track densities for c) RTBC1 and d) RTBC3, clearly demonstrate the concentration of foraging activity to and from night roosts.

Roost characteristics

Suitable roost and foraging tree species are not necessarily the same. The success of the Murdoch University roost complex (Fig. 8), despite only moderate canopy cover of 20–25 %, is a function of the fact that there are many species of roost and forage trees in the same area, with a very high proportion of mature marri and jarrah. The portion of the campus supporting all key foraging and roosting sites is less than 1 km^2. This fits easily within the home-range footprint of RTBC4, the main bird to use this area.

The Edward Street roost is composed mainly of red river gum, a roost tree, but not a forage species. Key roosts identified in this study showed that the average distance to foraging sites was only 0.46 km to 1.04 km. As 4.49 ha of existing mature marri was removed across the overall MKSEA P3 site in November 2017 (Linc Property 2018), it is a priority to replace forage species in the local environment (< 2km from the roost). In the short term, the lack of nearby forage may see decreased roosting activity, but replacement will assist in ensuring integrity of the roost over the long-term.

Movement corridors

Long residence times identified by 'recurse' (Fig. 9) in conjunction with short step lengths between consecutive GPS points suggested that birds either rested, roosted or foraged within a limited area for a large part of the day, or moved through the landscape relatively slowly most of the time. This can only be facilitated where there are suitable movement corridors (for example, Fig. 14). The tracking data used in this study show a clear relationship between occupancy and vegetation, irrespective of whether the vegetation was in remnant stands, metropolitan parks, fringing roadside vegetation, or large trees retained on private residential properties. Flight speeds were higher, and transit times faster, where birds crossed cleared, or non-vegetated, areas.

As daily movement from the Edward Street roost will be required for foraging, careful planning is required to ensure replanting contributes to and promotes the establishment of corridors and maintains a permeable landscape matrix. The retention of remnant vegetation patches, or creation of patches with a suitable water supply, could provide potential corridors.

Fig. 14 - Day foraging sites for RTBC3. The central cluster is key Day Roost–2 in Table 5. Distances to the other sites are 360m and 100m respectively. These sites form part of the north-south vegetation corridor in Fig. 13.

Road sensitive planting

Vehicle strike is a significant threat to black cockatoos on the SCP, with the Perth Zoo Veterinary Department receiving over 240 injured birds per year, many of which are RTBCs.

Planting programs will need to recognise that RTBCs are slow to take off, when flushed from roadside vegetation, and vehicle speed limits will need to be set appropriately on site. Similarly, planned planting at the Woodlupine Brook Reserve will need to be sensitive to the fact that the reserve is separated from the Edward Street roost by the Roe Highway and utilise appropriate re-vegetation setbacks to allow for slow and long flight take-offs .

Fig. 15 – a) Vehicle strike has emerged as a significant threat to black cockatoos on the Swan Coastal Plain. The Perth Zoo Veterinary Department received over 240 injured birds per year, a high proportion of which are forest red-tailed black cockatoos. This bird was not so fortunate; b) GPS and satellite trackers retrieved from RTBC6 which was struck and killed by a vehicle while crossing Tonkin Highway; c) The use of 'black cockatoo' road signs has been very effective in reducing deaths in some vehicle strike hotspots.

Absence from the roost

The long-term satellite data showed that birds tracked for long enough moved away from the SCP to the foothills or into the Darling Scarp during spring. This timing corresponds with a zero roost count at the Edward Street roost made by Emerge Consultants on the 20th November 2018, while counts in the months previously recorded moderate to high numbers of birds (9 – 334; Glenn Coffey – Linc Property, pers. comm.). Three of these four tagged birds released in August 2015 (RTBC1, RTBC3 and RTBC4) remained in the scarp until the end of their tracking period in April 2016. The fourth bird released in 2016 travelled to the scarp but returned earlier than the birds from the previous release arriving back on the SCP in December 2017. Emerge Consultants recorded 113 birds at the Edward Street roost on 8th February 2019 (Glenn Coffey – Linc Property, pers. comm.). It seems that movement away from the plain in Spring was consistent among years, but that the time spent in the Darling Scarp may vary between flocks, and some seasonal fluctuation in numbers at the Edward Street roost, and other roosts throughout the SCP, should be expected.

Roost management considerations on the Swan Coastal Plain

There are four key findings from this study that have important implications for roost management on the Swan Coastal Plain: 1) 40% of key roosts and 67% of key foraging sites had water present, and in almost all cases this was in the form of an artificial trough; 2) on the SCP, during resident phases, flock movement distances and speeds were less than expected with long residence times; 3) key roost and foraging sites were spatially close together and contained within relatively small home-ranges (max. radius of 3.8 km); and, 4) tracking in this study showed that flocks move to the foothills or onto the Darling Scarp in spring, and so absence from a roost is seasonal, and not necessarily indicative of an inactive roost.

Due to increasing urban expansion and habitat conversion on the SCP, strategic and pre-emptive planning prior to the approvals stage, or as part of the preparation of referral documentation for the Federal Department of Environment and Energy, should be undertaken to ensure both short and long-term management, or rehabilitation of impacted roosts. Roost site management, which adheres to the roost and foraging requirements listed in the four points above, site re-vegetation early in the development timeline with appropriate forage and roost species, and consideration to the maintenance or creation of vegetation corridors in the broader local landscape, through additional planting to meet offset conditions, will contribute positively to the management of short-term and long-term impacts of development on roost sites.

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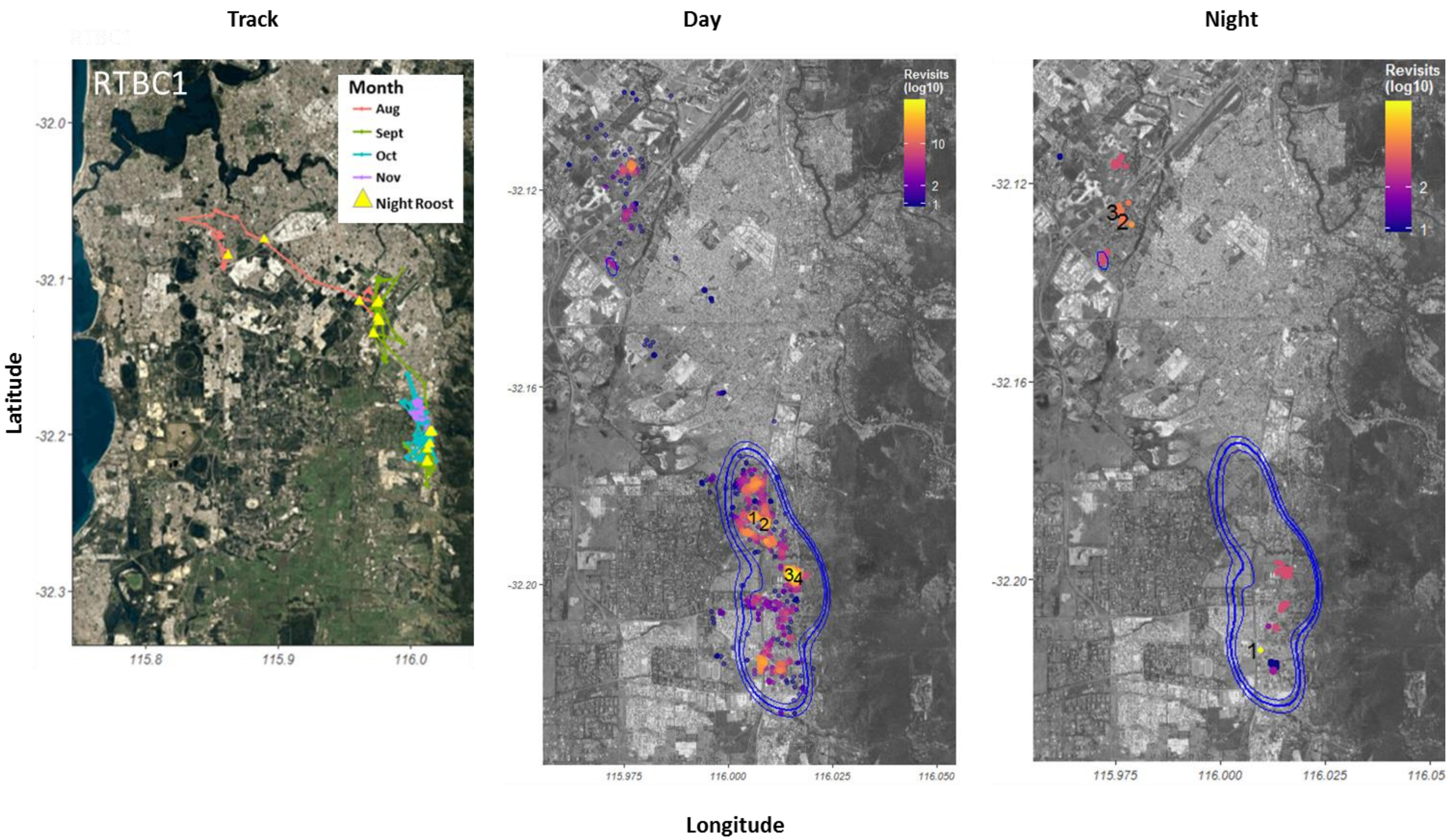
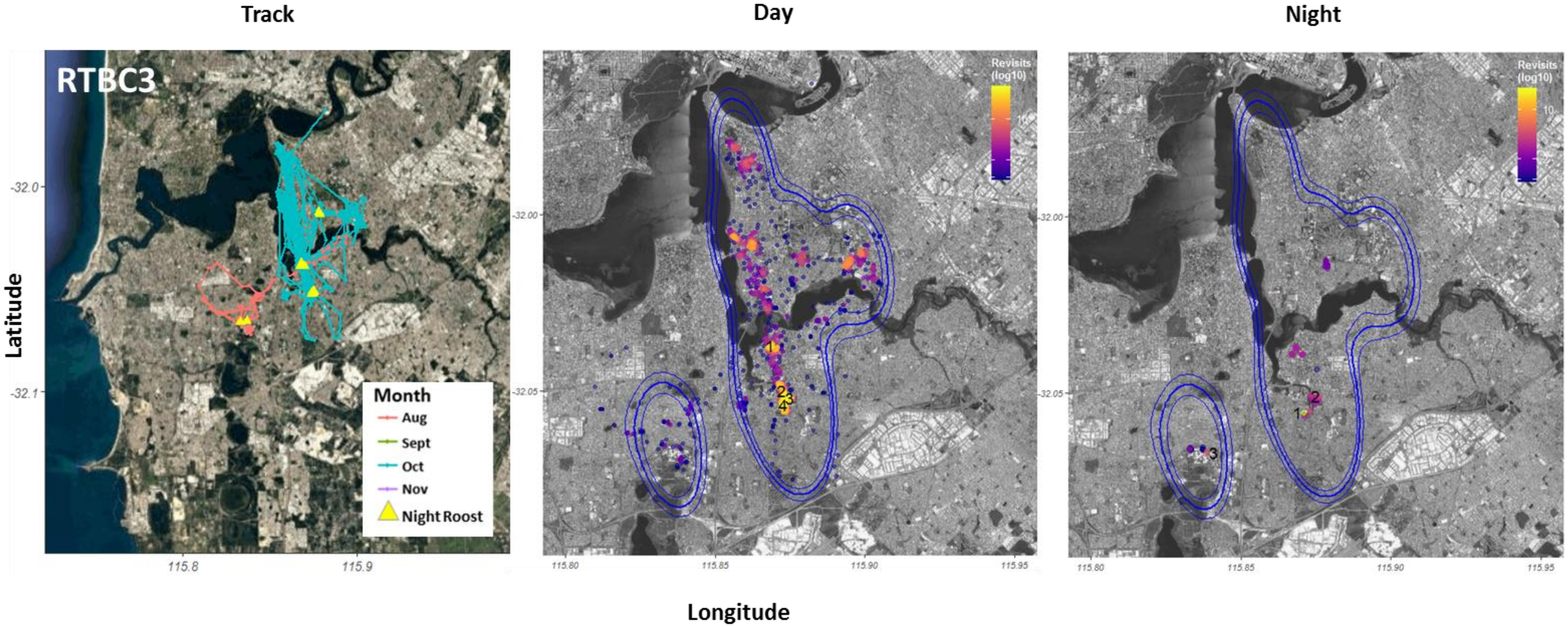
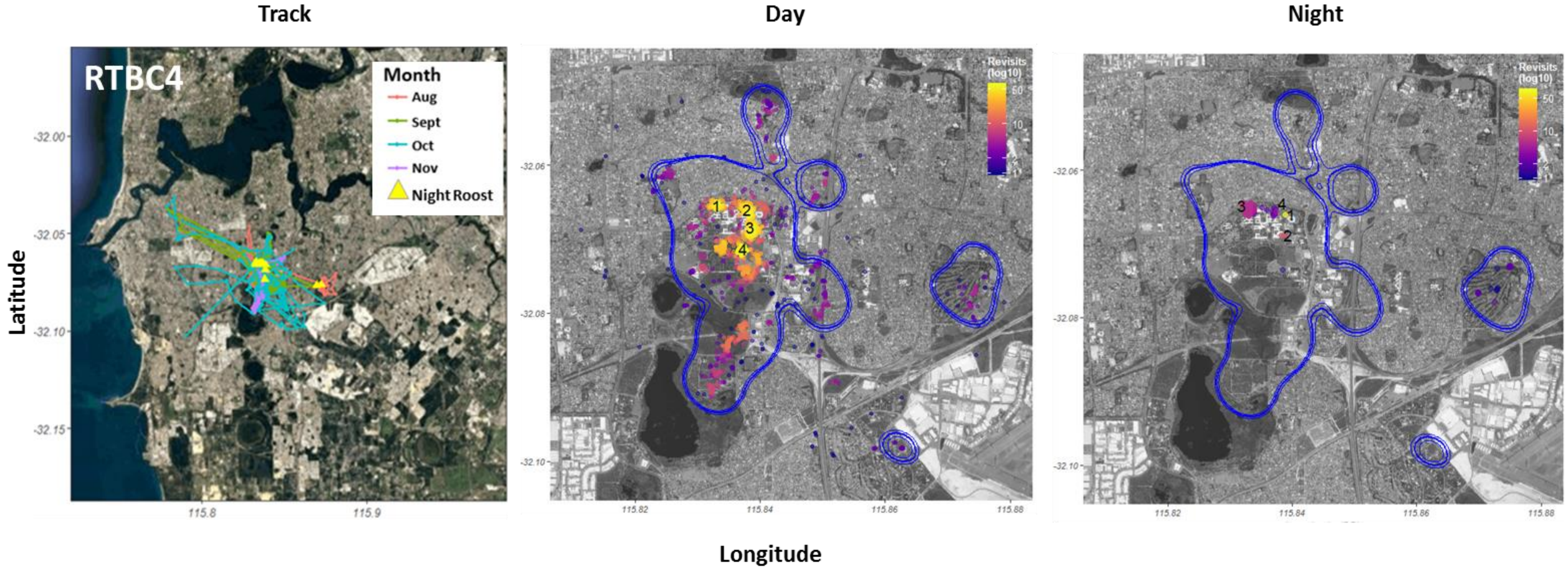
Appendix 1 – Point counts of the number of birds present at the Edward Street roost (GOSKENR001; data supplied by Linc Property).

Source	Date	GOSKENR001
Great Cocky Count 2017	09/04/2017	51
Great Cocky Count 2018	08/04/2018	334
Emerge Consultants	10/04/2018	335
Emerge Consultants	08/05/2018	49
Emerge Consultants	15/05/2018	92
Emerge Consultants	22/05/2018	68
Emerge Consultants	12/06/2018	40
Emerge Consultants	10/07/2018	9
Emerge Consultants	20/11/2018	0
Emerge Consultants	15/01/2019	4
Emerge Consultants	08/02/2019	113
Emerge Consultants	19/03/2019	56
Emerge Consultants	28/03/2019	5
Emerge Consultants	04/04/2019	0
Great Cocky Count 2019	07/04/2019	29
Emerge Consultants	24/05/2019	0

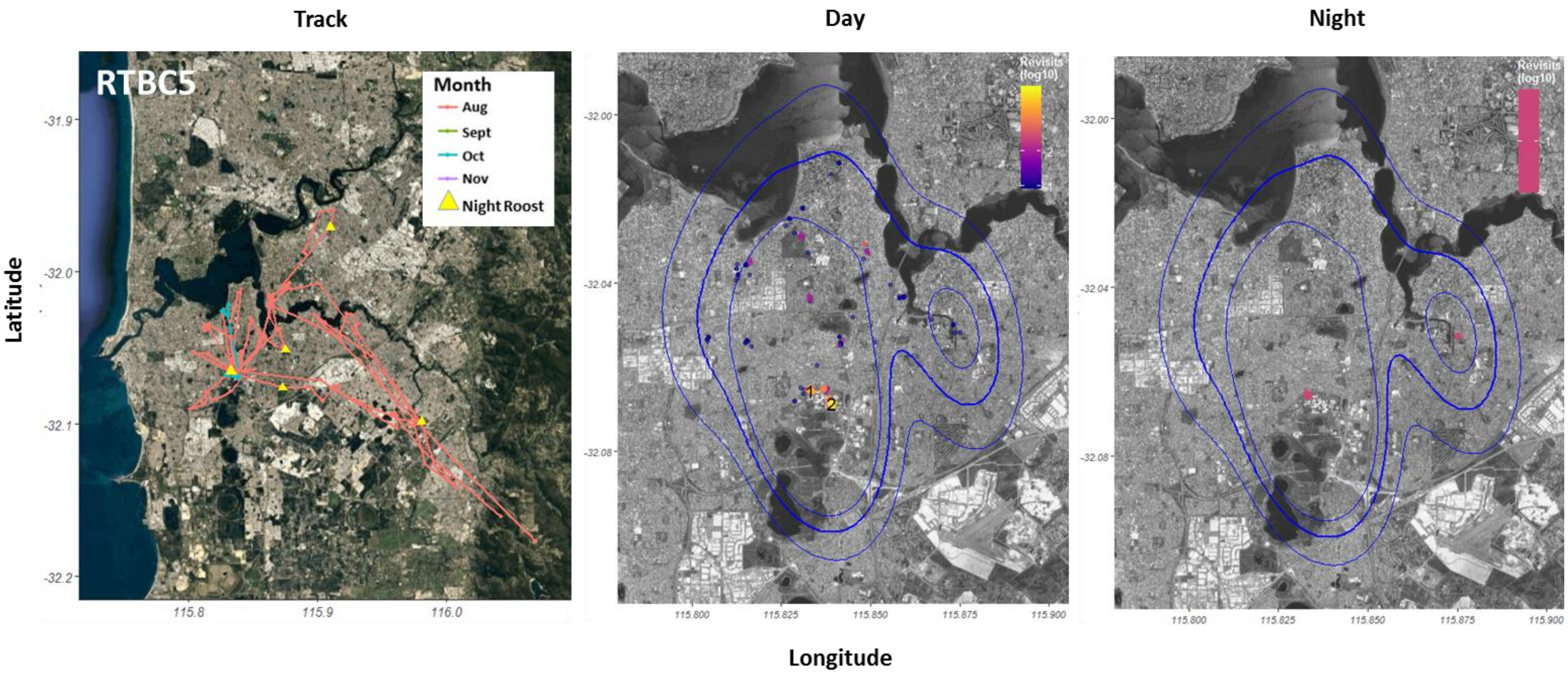
Appendix 2 - Larger versions of Figure 8 - Key Foraging and Roost sites.




Track
Day
Night
RTBC3
Month
Aug
Sept
Oct
Nov
Night Roost
Revisits (log10)
Latitude
Longitude
-32.0
-32.1
115.8
115.9
-32.00
-32.05
115.80
115.85
115.90
115.95



Track
Day
Night
RTBC4
Month
Aug
Sept
Oct
Nov
Night Roost
Revisits (log10)
Latitude
Longitude


Track
Day
Night
RTBC5
Month
Aug
Sept
Oct
Nov
Night Roost
Revisits (log10)
Latitude
Longitude
-31.9
-32.0
-32.1
-32.2
115.8
115.9
116.0
-32.00
-32.04
-32.08
115.800
115.825
115.850
115.875
115.900
1
2