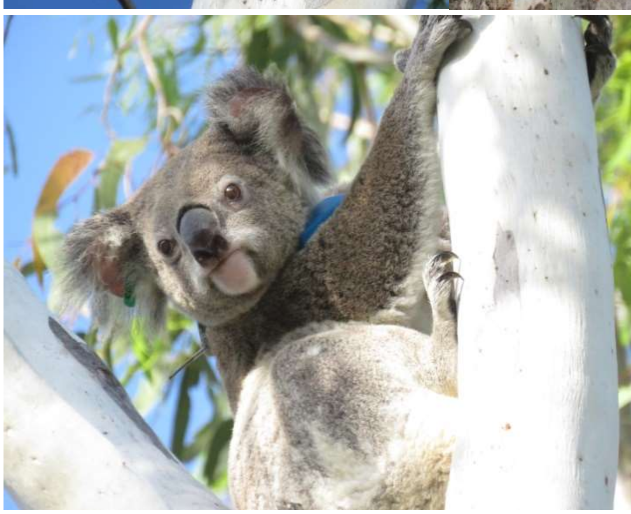
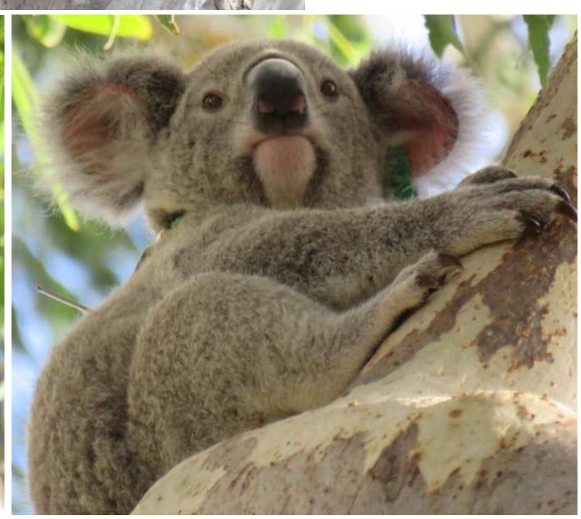
Toondah Harbour koala tracking project



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Summary

The Toondah Harbour PDA contains a locally significant population of urban koalas. In addition to the eight koalas that were telemetrically monitored, repeated sightings of non-monitored koalas (many with unique identifying features) indicated that there were at least 10 resident koalas using habitat in the area encompassing the Toondah Harbour PDA. The koalas were relatively healthy, with a high fecundity. The offspring of these koalas will further contribute to the viability of the local population.

This study highlighted the importance of single trees and complexity of habitat to urban koalas living in highly fragmented landscapes. Koalas used over 30 species of food and shelter trees and readily used trees in plantings that were less than 10 years old. Street trees provided a valuable food resource and linkages to other habitat in the landscape. Koalas constantly crossed suburban streets - at present, the Toondah Harbour precinct's residential streets, with low speed and low traffic volume, pose less of a threat to the movement of koalas. The adjacent main road, with a higher volume of traffic is a known hot spot for koalas hit by vehicles, and a dispersing sub-adult koala was hit by a car but did not sustain significant injuries. The potential for domestic dog and koala interactions was high in the densely treed dog off-leash area in GJ Walter Park, yet no incidents were recorded.

This project demonstrated that a community-based project (funded through grants and donations) can engage a local community to increase the awareness of koalas and successfully gather robust scientific data to better understand the population dynamics and health and identify important habitat of an urban koala population.

Koala Action Group members in GJ Walter Park monitoring a Toondah Harbour koala.

Introduction

The koala is a species vulnerable to extinction, with key threats from habitat loss, habitat alterations and climate change, anthropogenic threats and disease driving local and regional population decline. Koalas are distributed widely through the landscape, often in low densities. Koalas have specific habitat requirements and in many ways their presence is indicative of the quality and quantity of the landscape/bushland. However, koalas are often found in habitat that may be of good quality, but in limited quantity – that is, koalas can be found in relatively high density in areas of highly fragmented and patchy remnant and non-remnant vegetation. Typically, this includes coastal areas with highly suitable soils rich in nutrients with high moisture content, where urban development dominates the landscape.

Urban habitats such as parks, reserves, tree-lined footpaths, private residences and community facilities (e.g. schools) provide feeding, resting, breeding and ranging opportunities for koalas. The coastal areas of South East Queensland (SEQ) support large populations of urban koalas, however these environments generally result in higher exposure of animals to anthropogenic threats. Habitat loss through urbanisation is driving the significant decline of koala populations in many regions. Impacts from disease and from anthropogenic-related causes of mortality from dog attacks, vehicle strikes, and tree clearing have resulted in declines of around 80% in some SEQ populations (de Villiers 2015; Rhodes et al. 2016).

While the key threats to koalas are well known, until population monitoring studies are conducted, there is little means to quantify the exact threats to local koala populations, and in turn, the best means of managing and conserving these populations. In addition to disease and the typical anthropogenic impacts, predation from natural sources such as carpet pythons and wild dogs also results in premature mortality of koalas. Recent work on a major infrastructure project to the north of Brisbane has demonstrated that the blanket management of the typical suite of anthropogenic threats in urban and peri-urban areas (i.e. vehicle strike and domestic dog trauma) may be of limited benefit to the conservation of populations (Hanger et al. 2017). Detailed population studies are necessary to understand sources of premature mortality and adaptively manage the population in response to spatial and temporal variations in threats (Beyer et al. 2018).

Tens of thousands of public-generated reports of sick and injured koalas have been produced from SEQ over the last 10 years. Members of the public in urbanised coastal regions witness first-hand the impacts of urbanisation and disease on koala populations. There are a number of koala-focussed groups in SEQ engaged in the conservation and welfare of this species. The Koala Action Group Qld Inc (KAG) is a longstanding group operating for over 30 years in the Redlands (Redland City), southeast of Brisbane. Mainland Redland City forms approximately 2/3 of the area known as the Koala Coast, which also includes the south-eastern part of Brisbane City and the eastern portion of Logan City. The Koala Coast contains a regionally significant, but declining population of koalas, occurring across a diverse landscape of bushland, rural and urban landscapes (de Villiers 2015).

The Koala Coast continues to experience significant development pressures, particularly in the urbanised parts of the Redlands. The Koala Action Group commissioned a study to better understand the population dynamics of a local colony of coastal koalas under threat from a proposed large-scale development. To determine the status of the local koala population, information was collected on: distribution and abundance; rates of disease; fecundity; habitat use and movements; causes of premature mortality; and threatening processes. This information was required to feed into local planning and education strategies that would identify key areas to actively manage and conserve this high-profile koala population.

Methods

Study area

Toondah Harbour PDA

The Toondah Harbour study site is located along the foreshore of Toondah Harbour (Moreton Bay), a bay area of Cleveland in the local government jurisdiction of Redland City in SEQ (Figure 1). The area has mixed uses, with retail, commercial, residential/high density residential housing developments, and water taxi and ferry terminals to service the bay islands. The bayside location is currently experiencing intensive development pressures, with existing residential properties being cleared for high density apartments. The Toondah Harbour Priority Development Area (PDA) is designated over much of the study site. The PDA is a state and local government endorsed planning measure to redevelop the site to facilitate economic development and increase public open space. The revitalisation of Toondah Harbour is proposed to include new ferry terminals, boat launching facilities, bus interchange, car parks, boardwalks and cycleway, a waterfront plaza, foreshore parks and water play area, and open space and wildlife corridors. The PDA is also proposed to add up to ten thousand people and several thousand vehicles to the area with the addition of 3600 dwellings in the form of apartments and a high activity entertainment precinct.

Figure 1. Toondah Harbour PDA is on the foreshore of the suburb of Cleveland, in Redland City, a coastal local government authority to the south-east of Brisbane, Queensland. Koala habitat within and adjacent to the PDA is included in three council parks, tree-lined streets, residential properties and community facilities.

Koala habitat

Koala habitat in the area is included in three council parks, tree-lined streets, residential properties, and education facility (trade college) and council offices. As such, there are numerous endemic and non-endemic native species and exotic vegetation in the area, particularly plantings in private properties. The dominant forested vegetation community is endangered Regional Ecosystem 12.5.2, described as *Corymbia intermedia, Eucalyptus tereticornis open forest on remnant Tertiary surfaces usually near the coast and consisting of deep red soils. Other species can include Melaleuca quinquenervia, Lophostemon suaveolens*, *Angophora leiocarpa*, *E. acmenoides* or *E. portuensis*, *E. siderophloia* or *E. crebra*, and *C. tessellaris*. This vegetation community has been extensively cleared for horticulture, sugar cane and urban development.

Koala habitat linkages

The landscape within and adjacent to the Toondah Harbour PDA supports koala food and habitat trees and provide koalas with many linkages to other areas. Koalas move widely throughout the landscape using trees in streets, backyards and parks. However, three primary areas to the north, south and west contain a majority of koala habitat in parkland and along a creek corridor.

Koala surveys

Community engagement

The distribution and abundance of koalas in and around the Toondah Harbour Precinct was well known at the commencement of the project from numerous sightings and reports, spanning many decades, of sick and injured koalas admitted to SEQ wildlife hospitals. The KAG has also compiled numerous records of sightings during KAG's annual phone-in survey, encouraging members of the public to report all koalas sighted in their neighbourhood over one weekend in October. The KAG conducted a preliminary survey in the proposed study area and local surrounds (within approximately 1km of the bounds of the PDA) over a half day in August 2016 and searched public lands (reserves and parkland) and street trees with over 50 volunteers from KAG and the community. A total of 19 koalas were identified, consisting of 13 adult (11 females, 2 males) 1 sub-adult (unknown sex) and 5 dependent juveniles (unknown sex) (Appendix 1).

These preliminary surveys were key to the engagement of the local community, increasing the public's awareness of koalas in the area and the upcoming koala monitoring program.

Koala capture and veterinary assessment

Endeavour Veterinary Ecology (EVE), an environmental consultancy, was engaged by the Koala Action Group to provide expertise in the form of project management, koala capture, tagging and telemetry, veterinary services and data management and analysis.

Koala capture

KAG and EVE personnel conducted searches in, and immediately adjacent to, the Toondah Harbour PDA to locate koalas to recruit to the monitoring program. The majority of koala habitat in the area is in public open space and tree lined streets, so private residences/back yards were not searched unless residents contacted the KAG to report a koala on their property. The capture of eight koalas was carried out over three days (late November 2016, early December 2016 and early January 2017) by a very experienced team that have conducted thousands of captures of koalas. Due to the nature of the environment, some koalas found during searches were unsuitable for capture, for example, located in trees in close proximity to powerlines, over hard surfaces such as roads and footpaths and fences that could cause significant injury to animals if they were to jump or fall during capture.

Koalas were captured by traditional flagging methods where a climber in the tree encouraged the koala to descend by waving a telescopic pole with a round ‘halo’ of canvas above the koala’s head. Koalas were captured at the base of the tree and placed in a cage with fresh browse for transport to EVE’s veterinary clinic for health assessment and the customised fitting of monitoring devices.

Veterinary assessment

Veterinary examinations were comprehensive and standardised to ensure thorough and consistent data collection. The examination included: a general physical exam; ultrasonography; cytological examination of bone marrow, urine, abdominal fluid and blood; and other tests, as required. Koalas that were ill were treated at the EVE veterinary clinic or the Australia Zoo Wildlife Hospital, Beerwah. Koalas were microchipped, ear tagged and fitted with radio-telemetry transmitters and a bio-telemetry collar before release. These uniquely numbered, coloured swivel ear tags (Leader Products, Australia) were attached in the left ear for males, and right ear for females which assisted in the identification of koalas during and after the completion of the project. The combination of tracking devices on the koalas (collar and/or VHF anklet transmitter [attached to left/right leg]) further assisted with the definitive identification of koalas when multiple animals were located in the same tree. Koalas were caught for a health assessment at approximately 6-month intervals and more frequently to ensure the correct fit of monitoring devices (collars and anklets) on growing animals, replace dropped monitoring devices or to treat animals showing signs of illness or injury.

Koala monitoring and data collection

Telemetry

An innovative bio-telemetry monitoring system, The K-Tracker (LX Group) collar, was used to monitor koalas, in conjunction with a back-up VHF transmitter anklet (Sirtrack, New Zealand; Plate 1). These GPS collars have been custom-designed for koalas to be very low profile and incorporate a break point to release the collar in case of hang up on branches (hence the back-up anklet). This safety feature means that collars can also be dropped during intraspecific interactions (fights, matings, etc.) or falls where impact can break the link. The K-Tracker system allowed for daily monitoring of koalas, using remote (desk-top) access to both GPS and activity data streams. A web-based user interface allows querying of each koala’s movements as coordinates/data in a spreadsheet, or graphically via maps (Appendix 2). Time sequences for location data on maps are graded with colour indicating older locations as purple points through to recent locations represented as yellow points on the maps. The K-Tracker system has other interactive features to display spatial and temporal movement data of the koalas.

Plate 1. Koala *Scout* with telemetry devices: a bio-telemetry collar (combining the LX K-Tracker and VHF transmitter) and a backup anklet (with VHF transmitter).

Data collection

The K-Tracker GPS collar collected 12-hourly movements, providing a GPS location at 10am and 10pm. Koalas wearing these collars were field-tracked at a minimum of once every two weeks, but in reality, koalas were located more frequently in the field. Trackers used a 3-element Yagi antenna and Telonics receiver to locate animals. Koalas were also located in the field for welfare checks when remote monitoring indicated that the koala's last location may constitute an immediate threat to the animal. Data collected during field monitoring allowed an assessment of:

- Land tenure usage (park, private property, road reserve, etc.) and movement patterns, with each location marked with a GPS unit and/or description/address of the koala;
- Tree use, including the height, diameter at breast height (DBH) of the tree, and tree species;
- Health status, to determine if the koala is in good health with no overt signs of illness or injury, using binoculars to assess individuals;
- Reproductive status, observing the presence or absence of joeys in females and the timing of independence in joeys; and
- The correct fit and functioning of the tracking devices (collar/anklet) to ensure the welfare of monitored animals.

All data were entered in the field on a custom-designed database that could be synchronised with a central server to ensure real-time access to current field events and veterinary assessment data to ensure any alerts or concerns for individual koalas were evident and actioned. Koalas were monitored for varying lengths of time until the last koala was uncollared and removed from the program in January 2018. Koalas were monitored during the koala breeding season and non-breeding season.

Community participation in data collection

In addition to formal tracking events, records were also kept of sightings of the koalas by members of the public and local residents who had a keen interest in the project. Koalas requiring assistance or needing rescue were also reported by the local community to the council-operated volunteer wildlife ambulance (Redlands Afterhours Wildlife Ambulance), who in turn reported the sighting or incident to KAG or EVE personnel for actioning/recording.

Data analysis

Home range analysis was performed in the statistical software package R. The adehabitatHR program was used to calculate the 95% Kernel Density Estimates (95%KDE) for each koala. This home range estimation was used in preference to the Minimum Convex Polygon (MCP) method to better reflect the area in which a koala spent the majority (95%) of its time. The MCP method calculates the total area that an animal might use, drawing a polygon to incorporate all points recorded for an animal, some of which may be brief exploratory movements and not part of their usual home range.

Results

Eight koalas from the Toondah Harbour PDA and surrounds were recruited to the project, comprising a mixture of adult (n=6), and recently dependent sub-adult (n=2) male and female animals (Table 1). Koalas varied in age from 1 year to 6 years old. The group was generally in good health, with only two koalas detected with disease at first capture (koalas *Mia* with reproductive disease and cystitis, and *Saxon* with unilateral conjunctivitis; Plate 2). The reproduction rate of females was high, with 80%, or all except one female (*Mia*) with pouch young during the project. All young observed during the monitoring period were raised to independence by project end, or shortly thereafter, as koalas still could be easily located and identified after monitoring devices were removed.

Koalas were monitored for an average of 44 weeks (range 34-52 weeks) or 10.5 months from the end of one breeding season to the next. The project resulted in 524 in-field tracking events, 435 of the eight collared koalas, and 89 opportunistic sightings of other non-monitored koalas in the area. Some of these un-monitored koalas were readily identified (ear tag from previous hospital admission for illness or injury, or other distinguishing features) and were unofficially 'tracked' and interactions with the monitored koalas noted and recorded (Plate 3). The LX tags provided approximately 1600 GPS locations of collared koalas (Appendix 2). There were 24 vet exams and tag checks of koalas during the project, including health rechecks, the assessment of the fit of monitoring devices (collars and anklets) in growing animals and the replacement of dropped collars and anklets.

Plate 2. Koala *Saxon* showed signs of chlamydial disease at first capture. He was admitted to the EVE veterinary clinic where he was treated for unilateral conjunctivitis before release at his point of capture.

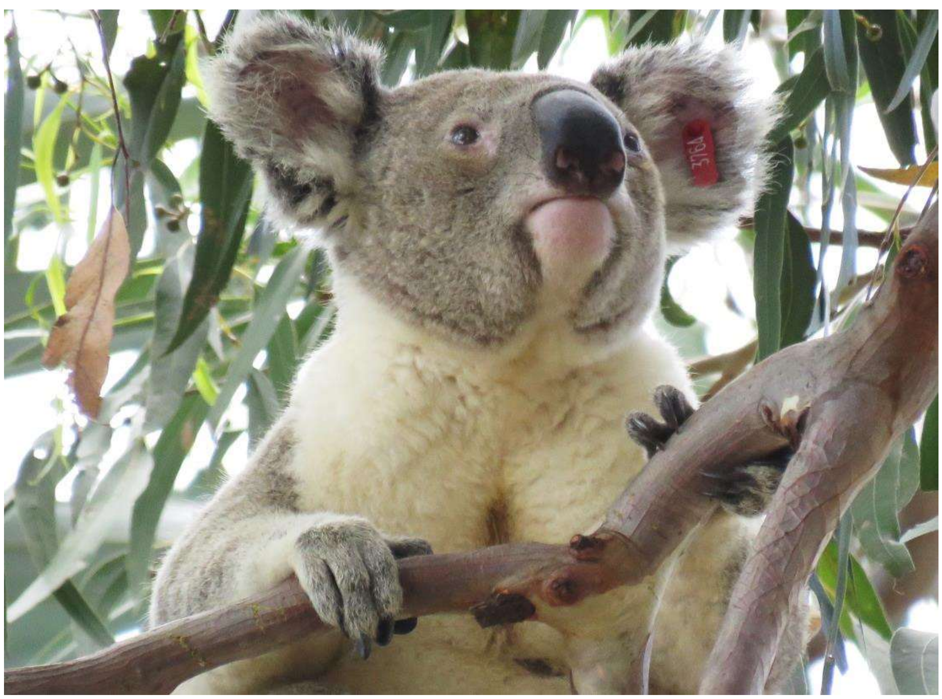


Plate 3. Koala *Paddy* was a resident of the northern Toondah Harbour PDA. He was not one of the project koalas but was readily identified by his numbered left red ear tag, after treatment and release from the Australia Zoo Wildlife Hospital in February 2016. His interactions with the collared koalas and independent sightings were recorded during the project.

Table 1. Summary statistics of koalas monitored for the Toondah Harbour koala tracking project.

Koala	Sex	Age (first capture; years)[1]	Weight (first capture; kg)	Health status (first capture)	Pregnancy / joey[1]	Weeks monitored	Fate
Hollie	Female	2	4.77	Healthy	9-10 mth joey at initial capture; large pouch young at end of project.	29/11/16 - 3/8/2017 35 weeks	Holly had two joeys during monitoring period. 'Violet' was raised to independence and Hollie had a large pouch young at the end of the project. Hollie was uncollared and anklet removed and released at point of capture. Addendum 13/6/18 – nearly a year after being removed from the monitoring program, Hollie was found on the ground with hindlimb paralysis. She also had a mass in her throat. Her condition was likely related to lymphoma (vet exam conducted at a wildlife hospital). Hollie was euthanased and her 100g joey was fostered, but died overnight.
Tyler	Male	3.5	8.01	Healthy	N/A	29/11/16 – 18/10/17 46 weeks	Tyler lost his collar near the completion of the project, having previously slipped his anklet monitoring device, however he was still able to be found during the tracking of the other koalas. Addendum 2019 – Tyler can still be observed in the Toondah Harbour area, identified by his ear tag and broken top tooth. He appears healthy with no overt signs of illness or injury.
Ethan	Male	1.2	3.0	Healthy	N/A	29/11/16 - 23/7/17 34 weeks	Ethan's fate is unknown. Numerous extensive searches were conducted within his well-defined home range and in a 5km radius from his last known location in the event he had started to disperse away from his natal home range, but could not be located.

							Addendum, end of 2018. Ethan's whereabouts remain unknown.
Airlie	Female	6.0	5.85	Healthy	No young at first capture, but 1-2 mth present at mid-year exam	5/12/16 – 29/11/17 51 weeks	At time of uncollaring and release Airlie had an approximate 5 month pouch young. (This young was successfully raised to independence as Airlie could be readily sighted in her home range.) Addendum 21/5/18 – Airlie was reported by a member of the public sitting in the road opposite a favourite food and shelter tree. Airlie was in poor condition and had been observed sitting lower in trees in the two months prior to being found on the ground. She was admitted to a wildlife hospital where she was euthanased due to disease (cystitis and fungal dermatitis). Her necropsy identified a necrotic area of her caecum consistent with an old domestic dog attack).
Mia	Female	5.0	6.58	Chlamydial disease – bilateral reproductive disease and sub-clinical cystitis. Treated.	Nil	9/1/17 – 27/11/17 46 weeks	Mia dropped her collar and then later her anklet before she could be recaptured, effectively removing herself from the project.
Kacey	Female	2.5	5.41	Healthy	Newborn approx. 1 week old joey present at first capture.	9/1/17 – 9/11/17 43 weeks	Kacey was recaptured and all monitoring devices removed and released at point of capture. At completion of project, Kacey had a near independent 10-11 month old female joey. (This young was successfully raised to independence as Kacey could be readily sighted in her home range.) Addendum 14/10/18 – Kacey was observed in her usual home range, identified by her coloured ear tag. She was in good health with a large 9-10 month old joey. Addendum June 2019 – Kacey is often sighted and has a medium sized joey, her third since the commencement of the project.

Scout	Female	3.0	6.28	Healthy	Recently independent joey 'Saxon' captured in the same tree with Scout. Early term pregnancy at first exam.	9/1/17 - 9/11/17 43 weeks	Scout was recaptured, LX collar and anklet removed and released at point of capture. At project completion, Scout had a large approximately 9-10 month old joey. This young was successfully raised to independence and could be readily spotted in Scout's home range. Addendum 13/2/18 – Scout was found moribund on the ground and died a short time later. Scout showed signs of significant trauma and bleeding to the musculature of the thigh and acute haemorrhage from laceration of the femoral vein, likely the result of a lightning strike in the tree during a severe storm two nights prior to being found. She was otherwise in good health with an approx. 1 mth old joey in the pouch, which was unviable for hand raising and was euthanased.
Saxon	Male	1.1	2.73	Chlamydial disease – unilateral conjunctivitis (right eye). Treated.	N/A	9/1/17 - 8/1/18 52 weeks	Saxon remained monitored for a few months longer than the other koalas to ensure he would establish a stable home range after dispersing away from the Toondah Harbour precinct. Nearing the time of his planned uncollaring, Saxon was observed with overt signs of disease (cystitis) and was captured and admitted to a wildlife hospital for treatment. He was released without monitoring devices two months later. Addendum 1/5/19 – Saxon was spotted showing signs of disease (cystitis) and was readmitted to AZWH for treatment. He responded poorly to treatment and was euthanased on welfare grounds.

Note:

1. Age based on the tooth wear characteristics described by Gordon 1991. Joey age was estimated based on the growth characteristics described in Hanger et al. 2017.

Habitat use and ranging behaviours

The monitored koalas used a variety of habitat types in the landscape, consisting of parks, street trees, private properties and the grounds of an education facility (Table 2). Locations of koalas throughout the koala breeding (second half of the year) and non-breeding (first half of the year) seasons and across multiple seasons highlighted the koalas' detailed habitat use and ranging behaviours.

Tree use

Koalas used over 30 tree species for food and shelter in the Toondah Harbour precinct (Figure 2). Due to the urbanised nature of the environment, there was a mixed ensemble of native and exotic species (particularly in private properties) that the koalas utilised (Appendix 3). A portion of these trees were unable to be readily identified in the field and are listed as 'unknown'. The most frequently used tree species was the blue gum *Eucalyptus tereticornis*, one of the most common eucalypt species in the area and a recognised favourite koala food tree. Koalas were observed in *E. tereticornis* on 70% of occasions. One large blue gum on private property (Plate 4) was extremely popular with the monitored koalas and was used on numerous occasions by *Tyler* (5% of in-field observations), *Ethan* (69%), *Kacey* (37%), *Scout* (13%) and *Airlie* (55%), along with four other non-monitored koalas.

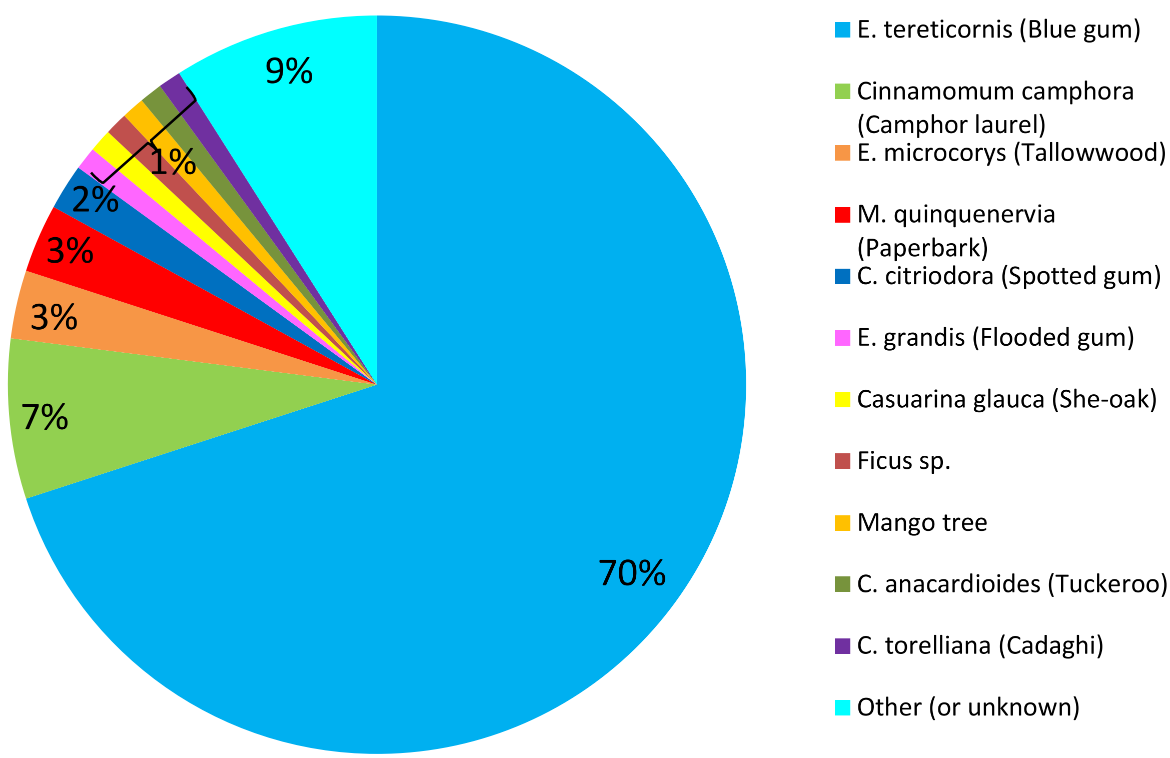


Figure 2. Tree species used by koalas for shelter and resting based on daytime in-field tracking observations.

The next most commonly used food tree species were the tallowwood (*E. microcorys*), paperbark (*Melaleuca quinquenervia*), spotted gum (*Corymbia citriodora*), and flooded gum (*E. grandis*), with koalas found in these trees between 1-3% of occasions. The introduced pest tree species Camphor Laurel (*Cinnamomum camphora*) was the second most commonly used roost tree for koalas, with 7% of koalas found in this species - 40% of those records in the summer months of November to January when koala sought refuge from the heat in dense-canopied trees that offered maximum shade. Koalas were observed in food tree species (Eucalypt and Melaleuca) on 73% of occasions, on average, with a range of 46% (*Saxon*) to 100% (*Ethan* and *Hollie*).

Plate 4. A large blue gum *(E. tereticornis)* retained in the grounds of a townhouse complex was almost always occupied by at least one, and as many as four koalas.

Table 2. Habitat use and ranging behaviour of the Toondah Harbour koalas.

Koala	No. in-field records	No. GPS tag locations	Primary habitat/land use type	Home range (95% KSD, ha)	Comments
Hollie	49	300	Reserve	1.1	• Hollie ranged exclusively within Nandeebie Park and had the smallest home range of the monitored females. • Her home range did not overlap with any of the other koalas. • Two other adult koalas (one male, one female) were spotted in this area during the monitoring period, the male showing signs of disease (unilateral conjunctivitis).
Tyler	67	286	Private property, street trees, reserve	12.6	• Tyler had a large home range that overlapped with all of the other monitored koalas, except Hollie. • He routinely crossed suburban and higher volume local roads, using private property, parks and the grounds of a local trade college. • He was reported by the public a number of times for misadventure, on one occasion falling onto the roof of a parked car during a fight with another male in a street tree. • Another male koala *Paddy* (easily identified by a red ear tag from a prior admission to a wildlife hospital for conjunctivitis) was occasionally observed in the northern part of Tyler's home range.
Ethan	51	71	Private property, street trees	0.5	• Ethan had the smallest home range of the eight koalas, typical of a newly dependent juvenile koala establishing a home range. • Based on comparisons of his home range with the other koalas, and their reproductive status at the start of the project, he is the potential offspring of Kacey or Airlie. • He spent a considerable amount of time in one large *E. tereticornis* on private property (69% of in-field observations) and the street trees surrounding this tree. • Ethan is likely to have dispersed from his natal home range or experienced some form of misadventure, as eight months in to the project his signal was lost on his telemetry tag. He had been tracked the previous day to a *E. tereticornis* in Wharf Street and should have been within the range for a signal on his collar to be detected, even if he had started to disperse from the area.

Koala	No. in-field records	No. GPS tag locations	Primary habitat/land use type	Home range (95% KSD, ha)	Comments
Airlie	60	303	Private property, street trees	4.5	• Airlie had the largest home range of the female koalas that were monitored. • She regularly crossed suburban streets and used many street trees in the area. • Airlie was located for a short period in the trade college, with Tyler and Mia also located in the grounds.
Mia	46	89	Education facility (Trade college)	4.2	• Mia dropped her GPS collar after two months of monitoring and was not able to be immediately recaptured for collar replacement due to restricted access to the trade college. She continued to be tracked on her back-up VHF anklet. • At least one untagged koala was spotted in her home range during the project • Mia made a significant move during the breeding season, away from the trade college grounds and was observed in a tree with Tyler, approximately 300m to the north of her typical home range.
Kacey	48	195	Private property, street trees, reserve	2.4	• Kacey ranged in the north western corner of the Toondah Harbour precinct and was often located in a large blue gum frequented by the other koalas. • She regularly crossed roads as part of her usual ranging behaviour. • While her home range wasn't as extensive as the other koalas in the area, she shared habitat with all of the monitored koalas, except Hollie.
Scout	53	136	Private property, street trees, reserve	3.3	• Scout utilised much of the habitat in GJ Walter Park and adjacent private residences. • She infrequently crossed streets as part of her ranging behaviour.
Saxon	61	208	Private property, street trees, reserve	2.1	• Home range calculated prior to dispersal to the north-east and west. • Saxon had considerable exploratory/dispersal movements in the landscape, first increasing his activities within the immediate vicinity of his home range, then travelling north-east along the coastline briefly before turning westward and settling in an area to the west of the Toondah Harbour precinct.

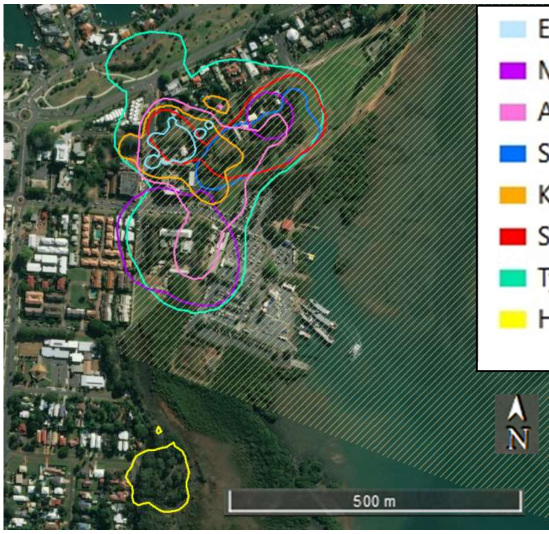
Home range and movements

Home ranges varied in size from 0.5 ha for a young sub-adult male Ethan, to 12.6 ha for *Tyler* (Table 2; Figure 3). *Tyler* was likely the dominant resident male in the area and was the largest male koala (radio-monitored or not) observed during the project. He ranged widely through the urban landscape, frequently crossing roads. His home range encompassed the home ranges of all the monitored koalas, except Hollie, who resided to the south in Nandeebie Park (Figure 3). *Tyler* regularly crossed the road to access Linear Park and used immature eucalypts that had been planted approximately 8-10 years previously to restore areas of habitat in the park.

Breeding season movements

There was noticeable variation in seasonal the movements of koalas, typically related to the koala breeding season or mating opportunities. Koala *Airlie* ventured south to the vicinity of *Tyler*. She was found sharing a tree with *Tyler* and stayed in and around the grounds of the trade college for two weeks. She was captured two and a half months later with a 1-2 month old joey in the pouch. Koala *Mia*, who spent the large majority of time in the trade college grounds, was tracked to a property on the northern boundary of GJ Walter park, sitting in the same tree as *Tyler*. While the distance was only approximately 300 m, it was an atypical location for *Mia* and resulted in two distinct ranging areas when her home range was calculated. Like *Airlie*, *Mia* may have been seeking mating opportunities with *Tyler*. *Mia* was never observed with a pouch young, and although still able to come into oestrus, her reproductive disease had likely rendered her infertile.

The two sub-adult koalas *Ethan* and *Saxon* were of an age (1.5 years) to disperse from their natal home range at the start of the koala breeding season in July and both appeared to have dispersed. *Ethan* could no longer be found in his usual home range after exhaustive searches of the area when a signal could no longer be detected on his GPS collar, and was never sighted during routine tracking of the remaining monitored koalas. He is highly unlikely to still be in the area. *Saxon's* GPS collar recorded his detailed movements and use of habitat around the Toondah Harbour precinct over two months (Figure 4). *Saxon* spent approximately one month to the north east of the Toondah Harbour precinct, before dispersing due west, through Linear Park and along Shore Street North before settling in an area around a creekline corridor after two months of dispersal activity.



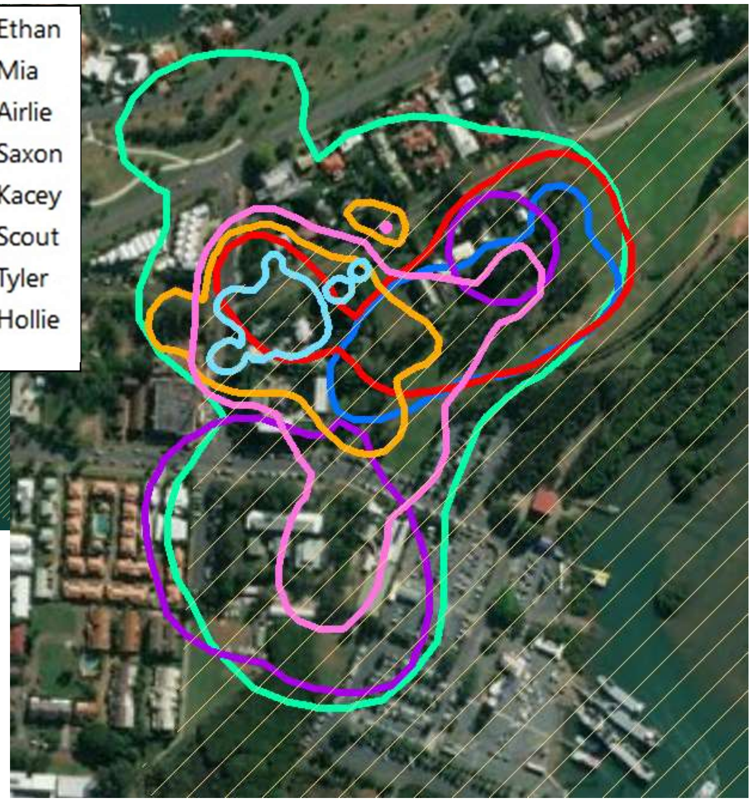


Figure 3. Home ranges of koalas monitored around the Toondah Harbour precinct. (Orange stippled area is the Toondah Harbour PDA.)

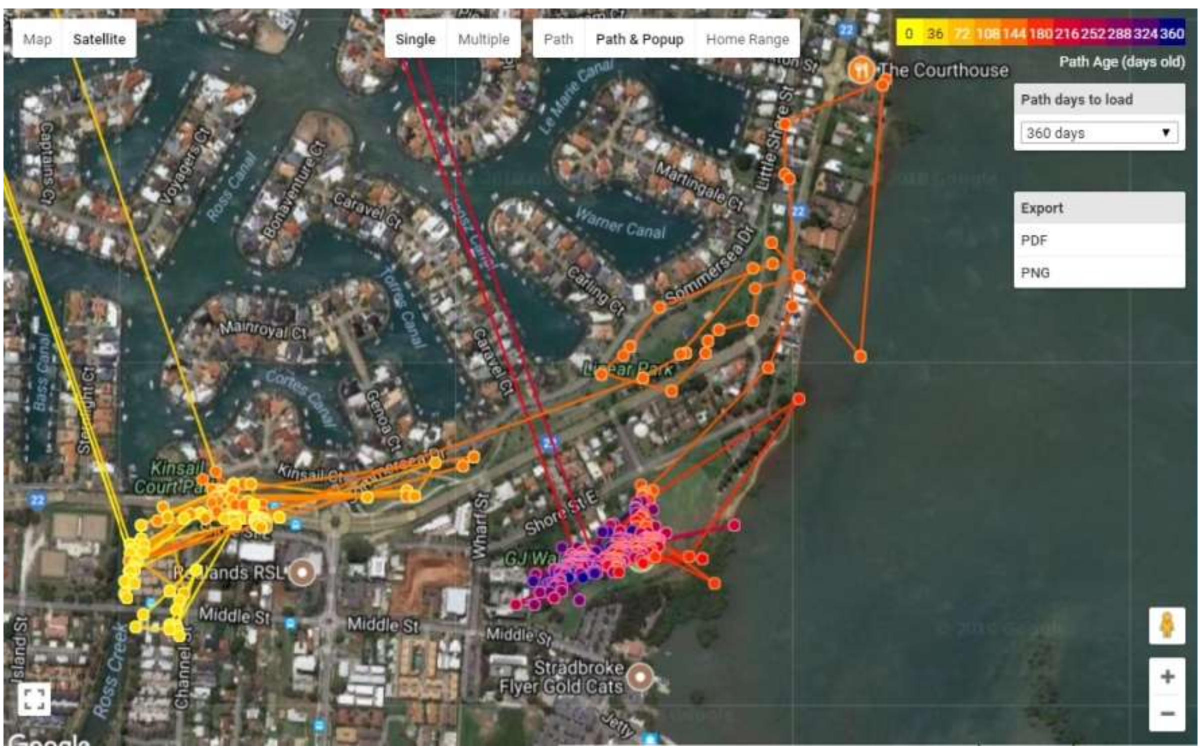


Figure 4. Dispersal map of *Saxon* showing his original locations around GJ Walter Park (purple and red denoting older locations) and his more recent dispersal movements (orange and yellow movement paths). (Note: 1. The location in the bay is positioned over a mangrove that *Saxon* appeared to have used at low tide – he was noted that day with mud on his coat and legs from traversing the mud flats; 2. the red and yellow lines projecting off the map to the north of the study site reflect Saxon's GPS collar locations at the EVE clinic at Toorbul.)

Threats

Vehicle strike

All koalas, except *Hollie*, routinely crossed roads and were at risk of vehicle-related trauma causing injury or death. *Tyler* and *Saxon*, in particular, regularly crossed a local road to the north of Toondah Harbour with a high traffic volume (Shore Street West/North Street/Shore St North) using trees in Linear Park and plantings along the road reserves, facing increased risk of vehicle strike. *Saxon* was the only koala with two known interactions with vehicles. The first incident occurred during daylight hours when he crossed the road and drivers had to slow down or stop their vehicles to avoid him. A month later, *Saxon* was reported as hit by a vehicle crossing the road at night between two patches of habitat (Linear Park and road reserve planting) while still dispersing. He was admitted to a wildlife hospital for a veterinary assessment which indicated no injuries except for superficial grazes (Plate 5). He was released after 24 hours of observation.

Plate 5. Koala *Saxon* was at high risk of vehicle-related trauma as he crossed main roads during dispersal movements. He was hit by a vehicle crossing a road at night between two patches of habitat while still dispersing. Veterinary assessment indicated no injuries except for superficial grazes, for example, around his left eye. *Saxon* was admitted to the AZWH for 24 hours of observation before release.

Domestic dogs

There were no reported instances of domestic dog and koala interactions during the project. However, koala *Airlie*'s necropsy, in addition to identifying disease as the primary cause of her illness six months after monitoring ceased, identified a necrotic area of her caecum consistent with trauma from a prior domestic dog attack. Koalas were exposed to dogs in residential backyards and GJ Walter Park, which doubled as a dog off-leash area, and was extensively used by dog owners.

Disease and other illness

Chlamydia-related disease was apparent in two of the eight, or 25% of the tagged koalas (*Mia* with reproductive disease and *Saxon* with conjunctivitis) at the commencement of the project. After treatment, the group remained healthy for the remainder of the project and there were no deaths of monitored koalas during the year-long study. However, monitoring of these koalas via welfare-focussed public reporting, incidental sightings and active searches (by KAG) after the completion of the project showed that a few of these koalas succumbed to a variety of illness and injury in the subsequent years (Table 1). Discounting *Ethan* (whose whereabouts were unknown at the completion of the project), 3 of the 7 koalas, or 43% have died – *Hollie* from disease (lymphoma), *Airlie* from disease (*Chlamydia*-related) and *Scout* from trauma (lightning strike). All three koalas had produced at least one young since project commencement, with *Hollie* and *Scout* with their third pouch young at the time of death.

Habitat loss and fragmentation

Ongoing habitat loss and fragmentation in the area was obvious during and after the project. Properties were being cleared for large apartment blocks, requiring the removal of all vegetation on and often adjacent to the development. A group of street trees (two were retained) was cleared to facilitate the development of an apartment block. Pressure to remove large street trees by some local residents to eliminate the 'mess' that they created was articulated quite clearly to field personnel; however the large majority of local people were very supportive of the protection of koalas and their habitat.

Discussion

The Toondah Harbour PDA contains a locally significant population of urban koalas. In addition to the eight koalas that were monitored, repeated sightings of non-monitored koalas (many with unique identifying features) indicated that there were at least 10 resident koalas using habitat in the area encompassing the Toondah Harbour PDA, and a local population of around 13 koalas, if the koalas in the park to the immediate south were included. This is a relatively high density of koalas, at approximately 0.7 koalas/ha; however other research projects in the Redlands and other coastal regions with high quality habitat have demonstrated similar high densities of koalas (e.g. de Villiers 2015, Hanger et al. 2017).

The Toondah Harbour koalas were relatively healthy with a high fecundity. However, ongoing loss of breeding females from the population, particularly from disease can quickly reduce population viability (Beyer et al, 2018). Managing chlamydial disease and reducing female infertility in a population can relatively quickly recover a declining population and significantly improve population viability. Home range sizes were typical of urban koalas in high quality habitat (males were generally at least double the size of the home ranges of females), and sub-adult animals showed typical dispersal behaviour in the early months of the breeding season.

The resident koalas successfully utilised a variety of habitat in the local area, spending considerable amounts of time in private property and parks. While the area is highly fragmented, the resident koalas successfully utilised a variety of food and non-food tree species during their daily ranging activities. Koalas were found in food trees approximately three out of every four tracking events. The habitat used was highly correlated with the vegetation assemblages in the immediate area. *Saxon*, living in the park with many casuarinas was often found in these trees. His home range included a creekline with riparian species and he spent more than half of his time sheltering in non-eucalypt species. On the contrary, *Hollie's* entire home range encompassed parkland with remnant eucalypt woodland and was dominated by koala food tree species. She was found in eucalypts at every tracking event.

This study highlights the significance of single trees and complexity of habitat to a local koala population living in a highly fragmented landscape. Individual trees were shown to be extremely important to urban koalas living in fragmented habitats. A large *E. tereticornis* retained by the body corporate of a townhouse complex was rarely unoccupied by koalas, and it was common to see up to four koalas using this tree at the same time. Ten individual koalas have been recorded using this single tree during and after the project, and it is a significant food and shelter tree for the Toondah Harbour koalas.

Koalas in urban areas with high quality habitat tend to require fewer food trees as a resource and seem to be able to persist in a landscape with a lower ratio of food to shelter trees. However, they still require a complex habitat structure and need variation in canopy and understory species to cope with extremes in weather. Koalas sought shelter/shade along the creekline and in densely canopied Camphor laurel species in the summer months, in particular to assist with thermoregulation.

Koalas used relatively recent plantings of trees along road reserves and in parks, demonstrating that habitat restoration practices add valuable habitat in these urbanised areas. KAG tree plantings that were established around 15 years ago are being heavily used by the local koalas, with direct (actual sightings) and indirect (heavily scratched trunks and pellets on ground) signs of frequent use by koalas. While there is often limited or no room to retain eucalypts and other significant vegetation on blocks undergoing development due to the scale of the developments, street scaping and the addition of koala habitat in adjacent parkland would ensure the persistence of the local koala population. The wide road reserves in the local area could support further eucalypt plantings and street scaping with koala food trees should be considered to offset the loss of trees being cleared from private properties. 'Beautifying' of the streets with the removal of large *E. tereticornis* and replacement with exotic trees would be extremely detrimental to the persistence of the local koalas and reduce habitat and the stepping stones used by koalas to move between habitat patches in this already fragmented landscape.

While a lack of koala food trees may keep koalas out of most yards, and avoids conflict with domestic dogs, encouraging koalas to use street trees and cross streets adds to the threat of vehicle-related injury to animals. At present, the Toondah Harbour precinct's residential streets, with low speed and low traffic volume, generally pose less of a threat to the movement of koalas. All the monitored koalas safely navigated multiple residential street crossings during night time movements. The higher volume, higher speed road to the north had many historical and recent reports of vehicle accidents, resulting in injury (e.g. Saxon) and death of koalas. Dispersing koalas are highly threatened by dogs and cars while traversing unfamiliar environments, and heightened movements on the ground during the day and night leads to more opportunity for misadventure. Mitigation strategies such as education campaigns in the form of mobile vehicle activated signs should be actively considered and installed at key crossing black spots for koalas, and locations revised to actively mitigate emerging black spots. The proposed Toondah Harbour development will significantly increase the night time traffic and volume of vehicles in the area, as proposed plans include entertainment precincts and restaurants.

Domestic dog-related trauma resulting in injury and death is a common cause of premature mortality of urban koalas (de Villiers 2015). However, no monitored koalas were injured or killed by domestic dogs during the project, however koala *Airlie* was known to have experienced trauma from a domestic dog attack, likely in the months after intensive monitoring at the completion of the project and before she succumbed to disease and was euthanased. This was remarkable considering that all koalas, except *Hollie*, used GJ Walter Park, which is a dog off-leash area where residents can let their dogs run throughout the park (and koala habitat). There are likely two reasons for this: 1. the Toondah Harbour precinct is dominated by units or townhouses, where dogs are kept indoors and not within property grounds; and 2. the dog off-leash area is rarely used at night time when koalas are most active. Despite koala education and awareness signs on the northern boundary of the park, many of the dog owners were unaware of koalas in the area, suggesting that it was not education of the park users that kept the dog and koala interactions to a minimum.

Development pressures in the area will continue, but strategic planning for the area needs to ensure koalas and their habitat are thoughtfully considered for this population to persist in the medium to longer term. All vegetated areas around Toondah Harbour were used by koalas (see Appendix 2, Figure 2.1) and the majority of this vegetation is important for the persistence and viability of this population. Where important trees are retained, adjacent development must ensure that these trees are not impacted by works that may result in damage to the crown or roots of the tree. Trees can be successfully retained and managed - for example, the large *E. tereticornis* frequented by numerous koalas was annually inspected by an arborist to assess the health of the tree and carry out maintenance to ensure ongoing safety for the residents and their property.

This project demonstrated that a community-based project (funded through grants and donations) can engage a local community to successfully gather robust scientific data to better understand the population dynamics and important habitat of an urban koala population. These data are being used to inform the ongoing planning and potential redevelopment of this area to ensure that koala sensitive measures are in place to mitigate threats, improve permeability of the landscape and ensure the persistence and conservation of the Toondah Harbour and other urban koala populations.

Acknowledgements

Thank you to Lynn Roberts, Sue Whitelaw and numerous other KAG and community members who volunteered time and used their photographic skills to assist with monitoring of the koalas. Thank you to the local community who reported concerns about the koalas' behaviour and health, and the Redlands City Council wildlife ambulance volunteers who responded to the calls after hours. Also thank you to the Cleveland Waters body corporate and the Grand View Hotel owners who allowed the installation of monitoring equipment on their properties.

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Koala *Hollie* with large 10 month old joey, nicknamed *Violet*.

Appendices

Appendix 1. **Toondah Harbour community survey, August 2016.**

Locations of 14 koalas spotted during a preliminary survey of public areas in the Toondah Harbour PDA and surrounding environment. Survey participants were made up of KAG and community members with varying level of koala spotting experience, from novice to well-developed skills. Colour coded pins on the map indicate: adult female = pink pin; adult female with dependent young = pink pin with star; sub-adult of unknown sex = green pin; adult male = blue pin.

Appendix 2. Maps of koala locations

Location of koalas over time as determined from GPS collar locations.

Figure 2.1. GPS locations of all koalas in the Toondah Harbour project.

Note: *Saxon's* GPS location offshore appears to be accurate as he was located after the upload with mud on the lower half of his body suggesting he was resting in the mangrove at that location and had crossed the mud flats at low tide (Figure 2.5).

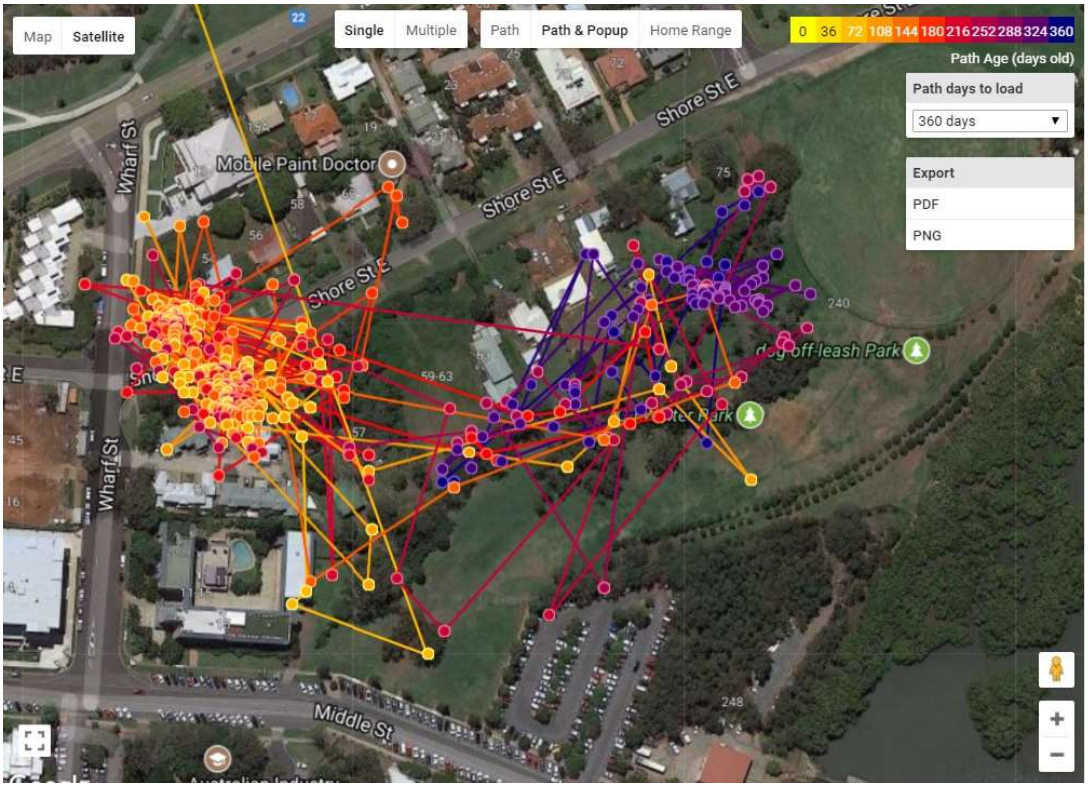

Figure 2.2. Koala *Scout's* movements from GPS tracking collar.

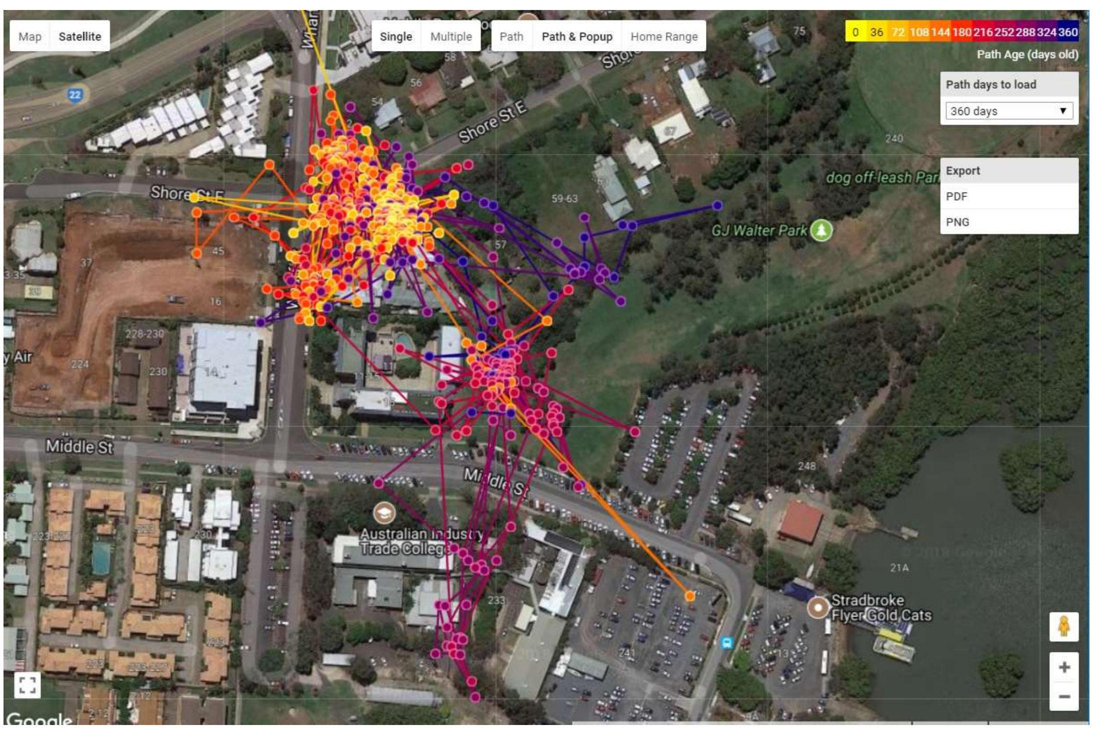

Figure 2.3. Koala *Airlie's* movements from GPS tracking collar.

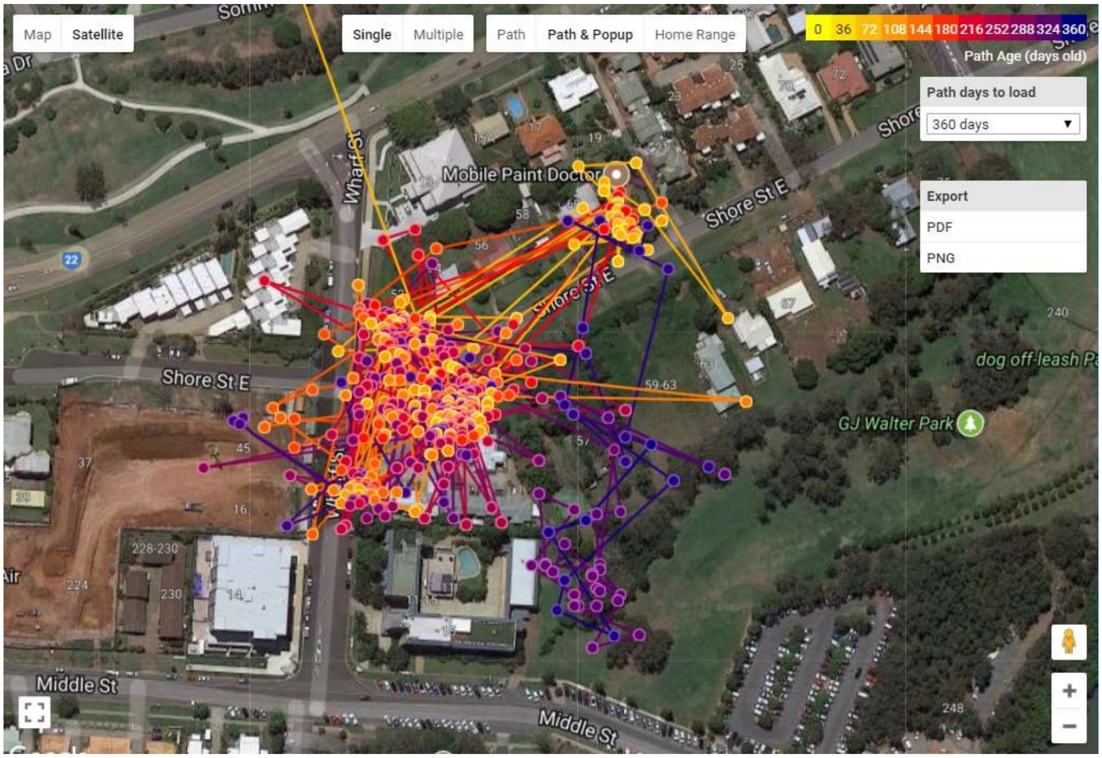

Figure 2.4. Koala *Kacey's* movements from GPS tracking collar.

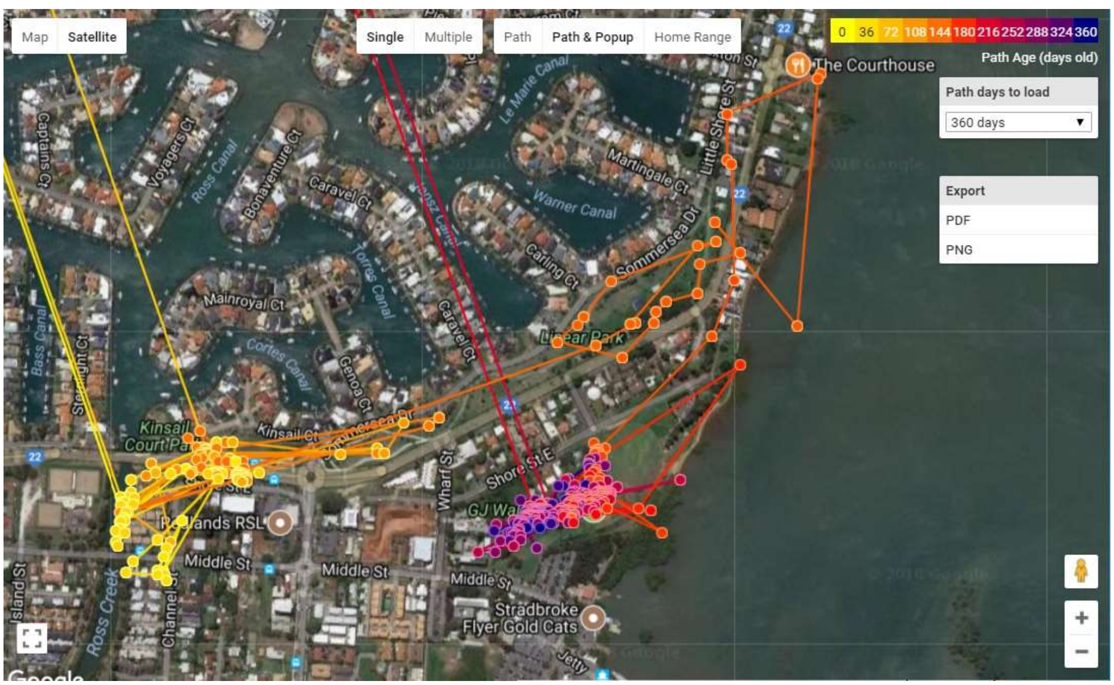

Figure 2.5. Koala *Saxon's* movements from GPS tracking collar.

Note: the GPS location offshore appears to be accurate as Saxon was located after the upload with mud on the lower half of his body suggesting he was resting in the mangrove at that location and had crossed the mud flats at low tide.

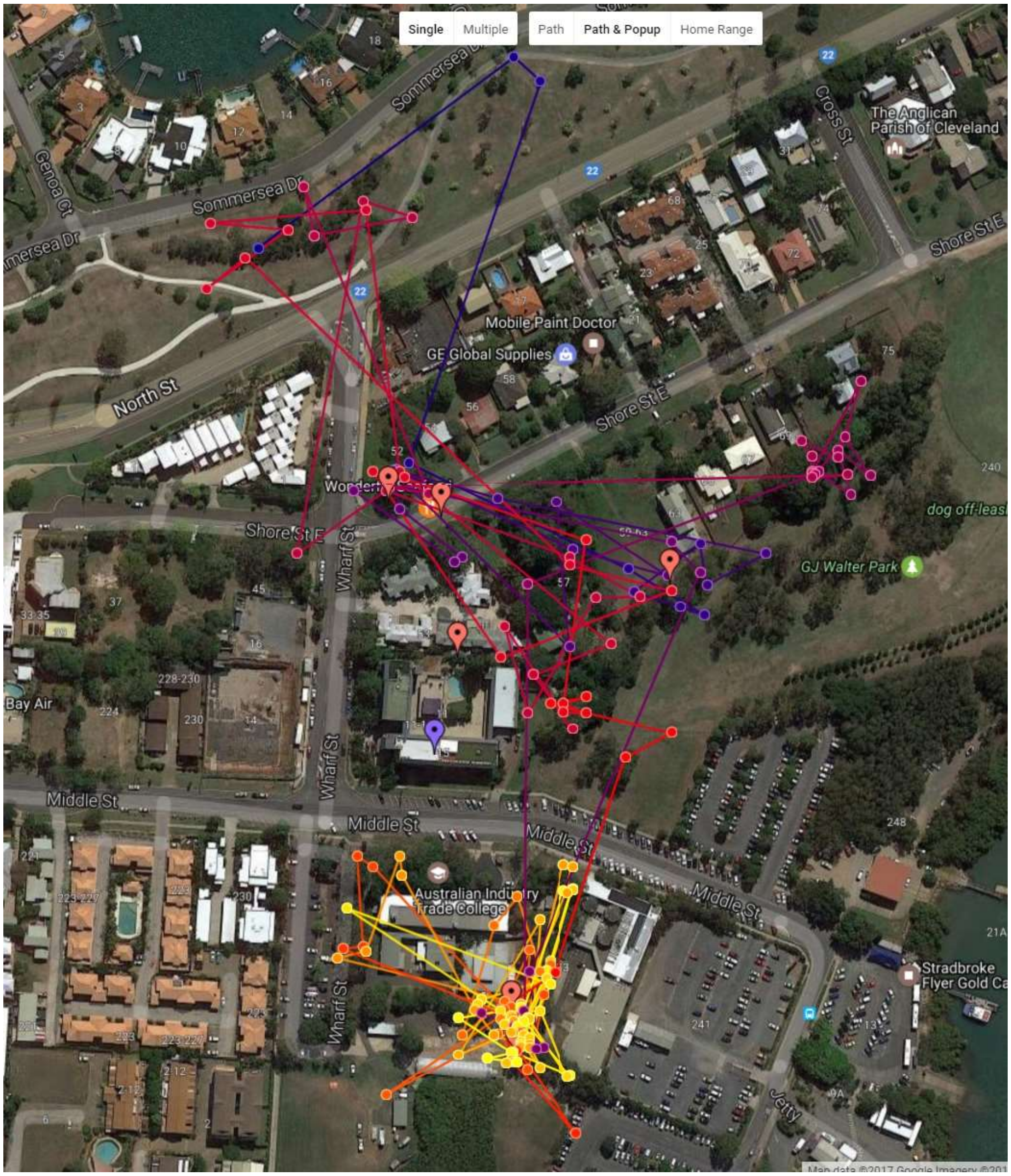

Figure 2.6. Koala *Tyler's* movements from GPS tracking collar.

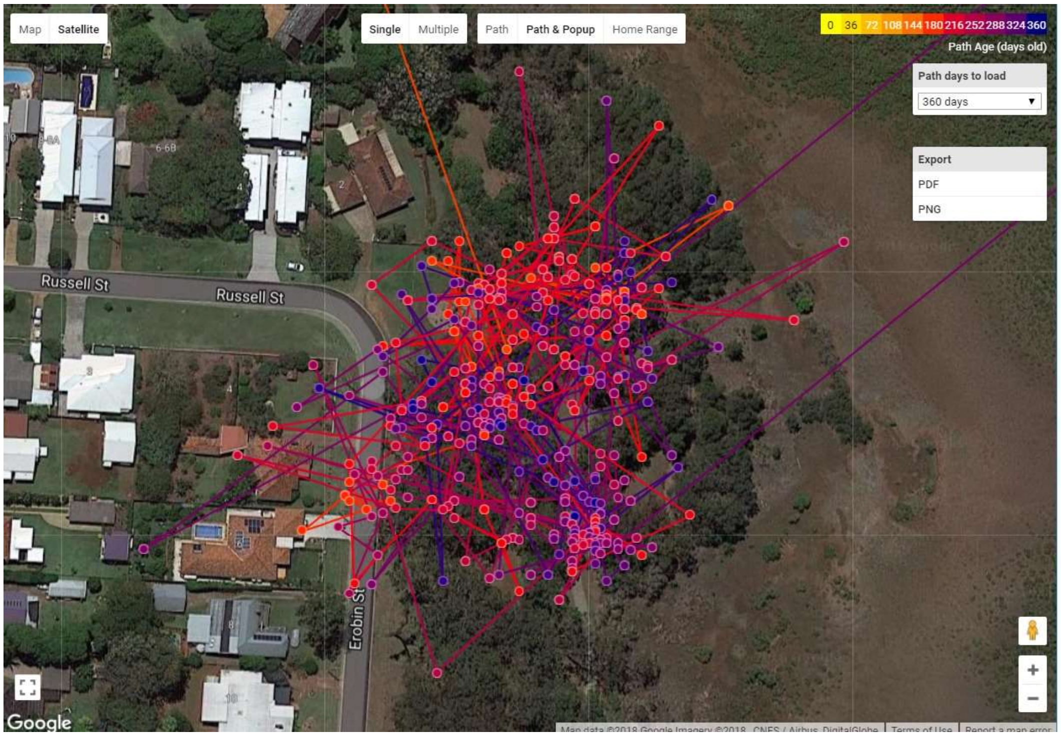

Figure 2.7. Koala *Hollie's* movements from GPS tracking collar. (Note: Hollie was never tracked in private property opposite Nandeebie Park, and it is likely that these locations are spurious GPS readings.)

Figure 2.8. Koala *Mia's* GPS tracking collar locations.

Appendix 3. Tree species list

Frequency of occurrence of koalas found in tree species around Toondah Harbour

Acacia sp.	4
C. anacardioides (Tuckeroo)	5
C. citriodora (Spotted gum)	11
C. tessellaris (Moreton Bay Ash)	2
C. torelliana (Cadaghi)	3
Callistemon sp. (Bottlebrush)	1
Casuarina glauca (She-oak)	9
Cinnamomum camphora (Camphor laurel)	31
E. fibrosa (Broad-leaved ironbark)	1
E. grandis (Flooded gum)	6
E. microcorys (Tallowwood)	20
E. moluccana (Gum-topped box)	2
E. propinqua (Grey gum)	2
E. seeana (Narrow-leafed redgum)	1
E. siderophloia (Grey ironbark)	2
E. tereticornis (Blue gum)	372
Eucalyptus sp.(unidentified)	11
Ficus sp.	9
Leopard tree	1
M. quinquenervia (Paperbark)	8
Mango tree	3
Mangrove	1
Other	44
Ulmus parvifolia (Chinese Elm)	1

Examples of 'other' species of trees include Flame tree, Jacaranda, Umbrella tree, Macaranga, Lilly Pilly, Brown Plum Pine, Golden Shower Tree, African Tulip, Broad Leaf Pepper Tree and mostly unidentified non-indigenous species planted on private property.