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Home range areas of koalas in an urban area of north-east New South Wales

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Abstract. Conserving wildlife within urban areas requires knowledge of habitat requirements and population processes, and the management of threatening factors. The koala (*Phascolarctos cinereus*) is one species that is adversely affected by urban development. Sick and injured koalas in the Lismore urban area are regularly taken into care. We radio-tracked koalas released from care in order to estimate home-range areas and to determine their fate. Koalas were tracked for periods of 90–742 days; 7 of 10 survived for a period of at least one year. Home ranges defined by the minimum convex polygon (MCP100%) were large (mean $\pm$ s.e. = 37.4 $\pm$ 8.2 ha). Analysis using the 95% Fixed Kernel revealed home-range areas of 8.0 $\pm$ 1.7 ha. Analysis of the habitat composition of each MCP home range showed that they included 4.3 $\pm$ 0.9 ha of primary habitat (dominated by their primary food trees). These home ranges contained 27.6 $\pm$ 6.8 ha of non-habitat (cleared or developed land). Koalas crossed roads within their home ranges at least 5–53 times; one crossed the Bruxner Highway near a roundabout at least 32 times over his 2-year tracking period. Future management should include strategic food tree planting that enhances habitat connectivity and minimises the risk of car strike or dog attack.

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Introduction

Habitat loss and fragmentation are the leading causes of loss of biodiversity worldwide (Wilcove *et al*. 1998; Fahrig 2003). These threatening factors are particularly acute in urban areas where usually only a small fraction of the original habitat remains (McKinney 2002; Garden *et al*. 2006) and where built structures such as roads prevent or reduce movement through the landscape (Delaney *et al*. 2010). Species struggle for survival when confronted with inadequate areas of habitat, inadequate habitat connectivity and road barriers (e.g. Crooks *et al*. 2001; Delaney *et al*. 2010). Overcoming the challenges posed by these factors will be more difficult for large vertebrates than for small ones due to their greater vulnerability when crossing roads (e.g. Rytwinski and Fahrig 2012) and their needs for larger areas (Kelt and Van Vuren 2001).

Studies on the effects of habitat fragmentation have focussed more often on population responses (e.g. Kitchener *et al*. 1980; Laurance 1990; Bolger *et al*. 1997) rather than on the behavioural response of individuals (e.g. Selonen and Hanski 2003; Castellón and Sieving 2006; Rizkalla and Swihart 2007). These are complementary approaches but there is a great need for further studies that describe the behavioural response of species. This can provide particular insights, such as how individuals move through habitat or the surrounding matrix, or how they utilise remnant habitats. This may directly influence management actions such as the need to restore connectivity over roads (e.g. Bond and Jones 2008).

The koala (*Phascolarctos cinereus*) provides an excellent case study in Australia of a large mammal that commonly occurs in urban areas and for which population processes may be disrupted by inadequate access to sufficient areas of habitat and increased mortality caused by roads. It is now listed by the Australian Government as a vulnerable species in New South Wales, the Australian Capital Territory and Queensland. An outcome of this listing is that specific local management actions are required to arrest the decline. Many koala populations in these States occur outside the protected area network and many are located around urban centres such that they are severely affected by road mortality and a continuing decline in habitat availability (e.g. Reed *et al*. 1990; Dique *et al*. 2003). The conservation of this species is dependent on being able to adequately cater for its needs within these urban environments, in addition to being able to reduce the incidence of disease, road-kill and dog attack (McAlpine *et al*. 2006; Rhodes *et al*. 2011). Dique *et al*. (2003) estimated that ~280 koalas were killed on roads per year in south-east Queensland. Despite this, there is little documentation of how individual koalas respond to highly fragmented habitat and roads.

Impacts on koalas from habitat fragmentation are compounded by disease (Canfield 1990; Griffith and Higgins 2012; Simmons *et al*. 2012). Within the Lismore area of north-east New South Wales, sick and injured koalas are taken into care by the Friends of the Koala, a koala welfare organisation that has been operating for >20 years (www.friendsofthekoala.

org). Rehabilitated koalas are ear-tagged and released back near where they were captured. Some individuals have been resighted over time but the fate of most individuals is unknown. The aim of the present study was to describe the use of remnant habitat by koalas within the Lismore urban matrix, and to determine the fate of these rehabilitated individuals over periods of 1–2 years.

Methods

Study area

This study was conducted in Lismore (28°49′S, 153°17′E), in north-east New South Wales. The temperature reaches a mean maximum in January of 29.7°C and a mean minimum in July of 6.5°C. Mean annual rainfall is 1330 mm. The Lismore Local Government Area comprises an area of 126 700 ha, of which ~10% is National Park or State Forest (Harris and Goldingay 2003). The suburbs of Lismore contain dense residential development with patches of forest occurring around parks, gullies and along escarpment areas. The periurban area contains broad areas of open pasture.

Capture and radio-tracking of koalas

Koalas were captured as part of the ongoing koala rehabilitation activities of the Friends of the Koala. Koalas are routinely taken into care as a consequence of being injured from a car strike or dog attack, or due to showing overt symptoms of disease. These animals are usually examined by a vet who makes a determination of the koala's likelihood of recovery with treatment. Many animals that have advanced cases of disease are euthanased. Between September 2008 and January 2011, 12 koalas (7 females and 5 males) that had been in care (on average 30 days for females, 40 days for males) had radio-collars attached. Radio-collars (Sirtrack, Havelock North, New Zealand) contained an elastic insert to allow for animal growth and to possibly break down over time. The battery life of collars was ~2 years. Collars were attached loosely to enable koalas that became hooked by their collar within a tree to remove the collar. Indeed, 5 of the 12 koalas slipped their collars during the tracking period.

Collared koalas were released within a patch of trees near where they were first captured or within ~300 m if the original site was a road or there was a dog present. Tracking was conducted on foot using a hand-held 3-element Yagi antenna (Sirtrack) and R1000 receiver (Communication Specialist Inc., Orange, CA, USA). A GPS was used to record the location of a koala and the date, time, tree, street address and notes on the koala's behaviour were recorded. Every effort was made to visually locate a collared koala but sometimes it was not possible due to the koala being present on private property where access was not approved. In such cases the location was approximated by triangulation. In some other cases the koala could not be located so no data were recorded. Koalas were tracked every day for the first two weeks, then three times per week for another two weeks and then once per week thereafter. Diurnal tracking was necessary for the safety of the volunteers who assisted with this and because koalas often occurred on private properties. This might lead to underestimation of koala movements but the reasonably long periods over which koalas were tracked (>6 months) reduces this likelihood.

Home range estimation

Home ranges were estimated using the Biotas 2.0 (Ecological Software Solutions) spatial analysis program. Minimum Convex Polygon (MCP; 100%, 95% contours), Fixed Kernel (FK; 95%, 50%), and Harmonic Mean distance minimum (HM; 95%, 90%, 50%) were used to estimate the home-range areas (see also Goldingay *et al*. 2010). The fixed kernel used the least-squares cross-validation method. An asymptote analysis was run for MCP100% with 10 random subsamples in increments of 10 locations. The number of road-crossing events was tallied for each individual. An event was scored when a koala was required to cross a road to move between consecutive locations. This is a minimum estimate because a majority of consecutive locations were not on consecutive days.

We examined the habitat composition of each home range (defined by the MCP) by overlaying a habitat map produced by Lismore City Council (2011). This map recognises koala primary habitat, secondary (A or B) habitat and other vegetation, as well as areas of cleared or developed land. Primary habitat is defined (Lismore City Council 2011) as vegetation in which 'primary food tree species' comprise ≥50% of the overstorey. Secondary A is vegetation in which 'primary food tree species' comprise subdominant components of the overstorey and may grow in association with 'secondary food tree species'. Secondary B is vegetation containing 'secondary food tree species' but where 'primary food tree species' are absent. None of the koala home ranges contained this habitat type. The primary food tree species are listed as: *Eucalyptus microcorys*, *E. tereticornis*, *E. robusta* and *E. bancroftii*. Secondary food tree species are listed as: *E. punctata*, *E. propinqua*, *E. eugenoides*, *E. globoidea* and *E. seeana.*

Results

Tracking outcomes

Two females slipped their collars within six weeks of release and another female was found dead (cause unknown) after approximately four weeks. These koalas provided insufficient data for analysis, leaving nine individuals as the basis of the tracking study but 10 when discussing survival. A further two koalas slipped their collars after 405 days (female) and 513 days (male). Five males were tracked for a mean (±s.e.) of 589 ± 74 days and four females were tracked for 360 ± 95 days (Table 1). These nine koalas occupied seven different locations. Tracking over these periods produced an average of 90.4 locations for males and 54.3 locations for females. These means are not significantly different ($t_2 = 1.99$, d.f. = 7, $P = 0.09$). The shortest tracking periods were for two individuals that were recaptured and subsequently euthanased by a vet due to ill health (Bonnie) or due to dog attack (Oscar). Thus, 4 of 5 males and 3 of 5 females survived for at least one year. Not all of these individuals needed treatment before their release from care. Of those that were treated for dog attack, car injury and disease, 2 of 3 males and 2 of 4 females survived for at least one year.

Home-range estimates

Estimates of home-range areas by the MCP100% ranged from 5.5 ha up to 88.1 ha (Table 1). There was no significant difference ($t_2 = 0.75$, d.f. = 7, $P = 0.48$) between the mean values (ln-transformed) of males and females (Table 1). Data for all males except Oscar reached an asymptote (at 40–70 locations) for MCP100%, as did the data for two females (Table 1). The MCP95% averaged 25.6 ha, which was substantially smaller than the average MCP100% at 37.4 ha. The HM95% produced values that varied enormously, from 6.1 ha up to 156.5 ha. There was no significant difference ($t_2 = 0.11$, d.f. = 7, $P = 0.92$) between the mean values (ln-transformed) of males and females (Table 1). The HM50%, which can be viewed as defining the core areas of the home range, averaged 4.0 ha across the nine koalas. The FK95% ranged from 3.0 ha up to 18.4 ha (Table 1). For these estimates, the mean values of females (ln-transformed) were significantly larger ($t_2 = 2.76$, d.f. = 7, $P = 0.03$) than those of males (Table 1). The FK50% ranged from 0.1 ha up to 2.0 ha.

Composition of home ranges

Calculating the area of different categories of habitat within each home range showed that relatively small areas (overall mean of 4 ha) of primary habitat were included (Table 2). Comparison of the values for males and females (ln(x+1)-transformed) showed there was no significant difference between them ($t_2 = 1.46$, d.f. = 7, $P = 0.19$). Each home range contained an average of 3 ha of secondary habitat, which contained the primary food trees. Of particular note was that each home range contained an average of 28 ha of non-habitat. This habitat type included buildings, roads, parks, open pasture, golf course fairways and a car park.

Table 1. Tracking details and home-range estimates for koalas at Lismore

Home-range areas (ha) were estimated by three methods and for different percentage boundaries. MCP, minimum convex polygon; HM, harmonic mean; FK, fixed kernel

Koala	Sex	Age	Weight (kg)	Start date	Tracking period (days)	No. of 30-day periods	No. of locations	MCP 100%	MCP 95%	HM 95%	HM 90%	HM 50%	FK 95%	FK 50%
Matthew	M	6	6.6	13 Sept 2008	674	22.5	107	44.2	23.7	62.1	35.3	1.7	3.0	0.1
Ashley	M	4	6.2	6 Nov 2008	678	22.6	113	26.4	16.4	29.7	23.5	5.2	5.6	0.1
Oscar[A]	M	3	4.8	13 Feb 2010	336	11.2	49	28.8[A]	26.0	43.1	39.2	6.4	7.5	0.4
Pinnochio	M	7	6.6	4 Aug 2009	742	24.7	97	52.7	22.0	50.9	36.6	4.8	3.4	0.1
Pineapple	M	2	3.7	23 Feb 2010	513	17.1	86	31.0	22.0	34.1	22.2	2.6	5.2	0.4
Carrie	F	3	4.9	17 Jul 2009	405	13.5	61	88.1	72.7	156.5	96.6	4.7	10.3	0.7
Ruby	F	2	3.4	11 Feb 2010	609	20.3	91	5.5	4.1	6.1	4.4	1.0	5.3	0.8
Indigo[A]	F	6	6.8	25 Jan 2011	228	7.6	27	11.7[A]	11.2	34.7	24.5	3.5	18.4	2.0
Bonnie[A]	F	2	3.7	26 May 2009	198	6.6	38	48.1[A]	32.5	131.4	78.8	6.2	12.9	0.6
Means														
Female (4)					360.0	12.0	54.3	38.4	30.1	82.2	51.1	3.9	11.7	1.0
Male (5)					588.6	19.6	90.4	36.6	22.0	44.0	31.4	4.1	4.9	0.2
Overall					567.2	16.2	74.3	37.4	25.6	61.0	40.1	4.0	8.0	0.6

[A]Individuals that did not reach an MCP asymptote.

Table 2. Habitat composition of each home range and road crossing

Primary habitat, primary feed trees comprise ≥50% of the overstorey; Secondary habitat, primary feed trees are subdominant and/or secondary food tree species present; Other, other vegetation (excluding grassland); Unknown, was not identified; Non-habitat, cleared land or buildings or roads. Road crossing, no. of consecutive locations that traverse a road

Koala	MCP 100%	Primary	Secondary	Other	Unknown	Non-habitat	Road crossing	No. of crossings per 30 days
Matthew	44.2	4.0	7.3	9.7	0	23.2	7	0.31
Ashley	26.4	9.3	0	0.7	0.2	16.2	53	2.35
Oscar	28.8	2.8	2.0	0.1	0	24.0	12	1.07
Pinnochio	52.7	4.4	3.7	0	0	44.5	37	1.50
Pineapple	31.0	5.6	0	2.5	1.4	21.5	24	1.40
Carrie	88.1	6.8	8.9	5.6	1.0	65.8	30	2.22
Ruby	5.5	2.1	0.7	0	0	2.8	10	0.49
Indigo	11.7	3.0	0.1	2.0	1.3	5.3	6	0.79
Bonnie	48.1	0.9	1.2	0.6	0	45.5	5	0.76
Means								
Female (4)	38.3	3.2	2.7	2.1	0.6	29.9	12.8	1.1
Male (5)	36.6	5.2	2.6	2.6	0.3	25.9	26.6	1.3
Overall	37.4	4.3	2.7	2.4	0.4	27.6	20.4	1.2

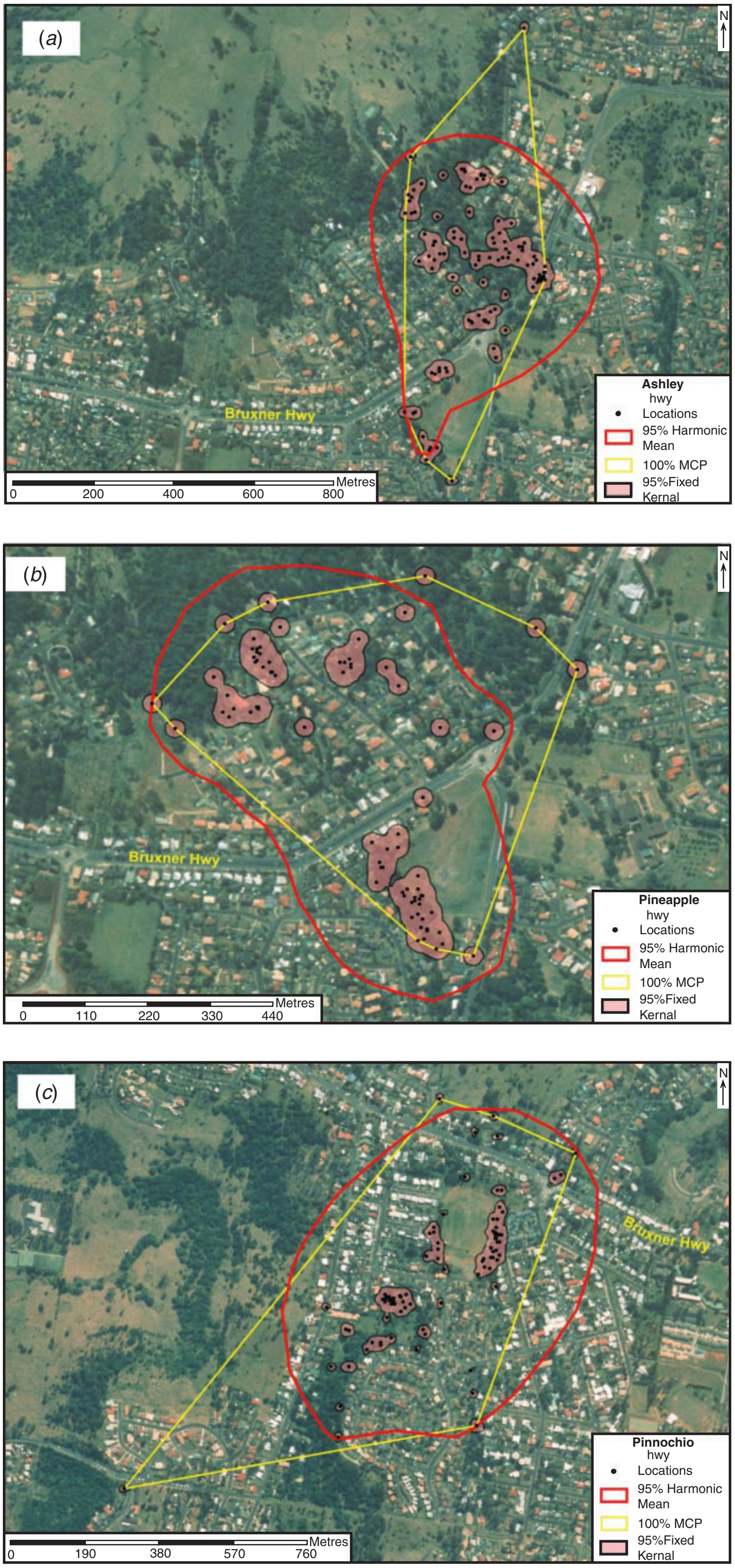

Fig. 1. Home ranges of three koalas that used trees on both sides of the Bruxner Highway: (*a*) Ashley, (*b*) Pineapple, (*c*) Pinocchio.

Road crossing

All individuals crossed roads, the average per individual being 20.4 times (Table 2). Three individuals crossed 30 or more times. Three individuals crossed the Bruxner Highway (Ballina Road) (Fig. 1); Ashley crossed 32 times, Pinnochio 4 times and Pineapple 3 times. Although males crossed roads twice as often as females, there was no significance difference between the mean (ln-transformed) values ($t_2 = 1.39$, d.f. = 7, $P = 0.21$).

Discussion

Home-range estimates

We estimated the home-range areas of our koalas using a range of estimation methods. This is desirable because it facilitates comparison among studies (Harris *et al*. 1990; Goldingay and Kavanagh 1993). Home-range areas have been reported for locations broadly across the geographic range of the koala (Table 3). The 95% Fixed Kernel method was common to four studies. Home-range areas of males estimated with this method were at least twice the size of those of females. This trend was reversed in the present study but this may reflect variation in the locations where males and females were located.

The HM95% method appears to have overestimated home-range areas in the present study, which may call into question estimates with this method in brigalow woodland in central Queensland (Ellis *et al*. 2002). However, the magnitude of those estimates suggests much larger areas than observed elsewhere (Table 3). The small home-range areas (1–2 ha) on French Island estimated with HM90% (Mitchell 1990) are in stark contrast to all other estimates (Table 3). Those areas may have been underestimated because the values reported are for the breeding season only (October–March) and so do not include all areas used across most of the year.

We estimated MCP home ranges at 37 ha, with little difference between sexes. This compares with MCP estimates of 7–14 ha in Brisbane and 17–52 ha in north-western New South Wales (Table 3). This estimator is often criticised because it may incorporate many areas where animals are never seen. In the present study non-habitat areas accounted for 74% of the area. This is an enormous amount but the configuration of the primary habitat appears to have required that individuals inadvertently incorporate such amounts of non-habitat so they could access a sufficient number of feed trees (see Fig. 1). Conducting a compositional analysis such as this is valuable to identify those habitats of key importance, the amounts apparently required and those habitats of lower or no value (see Goldingay and Kavanagh 1993; Sharpe and Goldingay 2007).

Roads

Roads pose a significant management issue for koalas around Lismore. All of our koalas had roads within their home ranges. Three individuals managed multiple crossings of the Bruxner Highway (Ballina Road), which may indicate some familiarity with traversing roads. One of these koalas (Ashley) came into care after being hit by a car and was hit again, though not injured, one year after his collar was removed. Another of our koalas (Ruby) was killed on Ballina Road 18 months after collar removal. In the period 2011–12, only 10 of 52 koalas hit by vehicles in the broader Northern Rivers area survived (Friends of the Koala, unpubl. data). This raises the question of how land managers can minimise the frequency of vehicle strike on koalas (Dique *et al*. 2003; Lassau *et al*. 2008).

Koala crossing signs that aimed to reduce vehicle speed were ineffective in south-east Queensland (Dique *et al*. 2003). In contrast, the installation of floppy-top fencing along major roads in New South Wales appears to be reasonably successful in reducing koala road-kill (Taylor and Goldingay 2003; Lassau *et al*. 2008; Hayes and Goldingay 2009). Fencing may have limited application in Lismore where driveways occur at regular intervals. Furthermore, movement across roads is required to enable population processes to continue (Lee *et al*. 2010). Current research has documented relatively little use of road underpasses and overpasses by koalas (see AMBS 2011), suggesting that further investigation of crossing structure design is needed. Tree planting that provides greater concentrations of food trees and that may reduce the need to cross major roads may be appropriate.

Disease management

The high incidence of disease among koalas in north-east New South Wales (Canfield 1990; Simmons *et al*. 2012) means that disease management (e.g. Griffith and Higgins 2012) needs to be

Table 3. Home-range area (ha) estimates for the koala at different locations
HM, harmonic mean; FK, fixed kernel; MCP, minimum convex polygon; M, male; F, female

Location	HM95%		HM90%		95%FK		MCP		References
(sample size: M, F)	M	F	M	F	M	F	M	F	
Victoria									
French Island (20, 18)			2	1					Mitchell (1990)
New South Wales									
North-western[A] (6, 4)					45	11	52	17	Kavanagh *et al*. (2007)
Coffs Harbour (6, 7)					23	10			Lassau *et al*. (2008)
Lismore (5, 4)	44	82	31	51	5	12	37	38	This study
Queensland									
Central (8, 9)	136	101							Ellis *et al*. (2002)
South-east (8, 16)					34	15			White (1999)
Brisbane (16, 27)					16	8	14	7	Thompson (2006)

[A]Only includes animals in unlogged area and those tracked across the whole tracking period.

a central component of actions to conserve koalas. Our study revealed that 4 of 7 rehabilitated koalas survived for at least one year following return to their habitat. A further three that did not receive treatment also survived for at least one year. This suggests that this type of management has potential to contribute to the conservation of the local population but a larger sample size, longer study period and the inclusion of untreated controls are needed to better resolve this (e.g. Lunney *et al*. 2004).

Management implications

There are two key findings from this study. First, that relatively small areas of habitat (7 ha) containing primary feed trees were included within koala MCP home ranges. Our estimate of the FK95% home-range area was 8 ha, which confirms that the most intensively used areas were relatively small compared with the areas in which they were embedded. This area may approximate the size needed to satisfy koala feeding requirements in Lismore. The fact that the MCP home ranges contained an average of 28 ha of non-habitat highlights the extent to which habitat is fragmented. The obvious management implication from this is that, where possible, tree plantings of primary feed trees are needed to fill the non-habitat gaps or to create larger patches of koala habitat. This requires a more detailed strategic approach than can be elucidated here but the objective should be to create larger patches of feed trees wherever possible. Indeed, McAlpine *et al*. (2006) found that habitat patch size and proportion of food tree species in a patch had a positive influence on the occurrence of koalas, whilst the distance between forest patches and road density had a negative influence.

The second key finding is that most koalas had to cross roads, often repeatedly, to access feed trees and, presumably, mates. Therefore, connectivity across roads should be provided where habitat patches are separated by roads. Three individuals crossed the Bruxner Highway; one individual did so at least 32 times. This road has daily traffic of ~30 000 vehicles. The road feature that may have allowed this koala to cross unharmed was the presence of a roundabout near Kadina High School which slows traffic to ~40 km h^{-1}. Several near misses of this koala by vehicles were described to us during the tracking period. Preece (2007) found that road segments with roundabouts in Brisbane had significantly less koala mortality than expected compared with secondary roads and implicated reduced vehicle speed. Roundabouts or other traffic-slowing devices (e.g. Jones 2000) could be considered for key locations where koala movements occur over roads. Our findings are consistent with other research that suggests that habitat augmentation, safe road crossing and minimising dog attacks, as well as disease management (see Griffith and Higgins 2012), are key management actions that must be enacted together to ensure the conservation of koala populations (see Lunney *et al*. 2002; Rhodes *et al*. 2011).

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References

AMBS (Australian Museum Business Services) (2011). Investigation of the impact of roads on koalas. Prepared by Australian Museum Business Services, Sydney, for the NSW Roads and Traffic Authority.

Bolger, D. T., Alberts, A. C., Sauvajot, R. M., Potenza, P., McCalvin, C., Tran, D., Mazzoni, S., and Soulé, M. E. (1997). Response of rodents to habitat fragmentation in coastal southern California. *Ecological Applications* **7**, 552–563. doi:10.1890/1051-0761(1997)007[0552:RORTHF]2.0.CO;2

Bond, A. R., and Jones, D. N. (2008). Temporal trends in use of fauna friendly underpasses and overpasses. *Wildlife Research* **35**, 103–112. doi:10.1071/WR07027

Canfield, P. (1990). Disease studies on New South Wales koalas. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 249–254. (Surrey Beatty: Sydney.)

Castellón, T. D., and Sieving, K. E. (2006). An experimental test of matrix permeability and corridor use by an endemic understorey bird. *Conservation Biology* **20**, 135–145. doi:10.1111/j.1523-1739.2006.00332.x

Crooks, K. R., Suarez, A. V., Bolger, D. T., and Soulé, M. E. (2001). Extinction and colonization of birds on habitat islands. *Conservation Biology* **15**, 159–172.

Delaney, K. S., Riley, S. P., and Fisher, R. N. (2010). A rapid, strong and convergent genetic response to urban habitat fragmentation in four divergent and widespread vertebrates. *PLoS ONE* **5**, e12767. doi:10.1371/journal.pone.0012767

Dique, D. S., Thompson, J., Preece, H. J., Penfold, G. C., de Villiers, D. L., and Leslie, R. S. (2003). Koala mortality on roads in south-east Queensland: the koala speed-zone trial. *Wildlife Research* **30**, 419–426. doi:10.1071/WR02029

Ellis, W. A. H., Melzer, A., Carrick, F. N., and Hasegawa, M. (2002). Tree use, diet and home range of the koala (*Phascolarctos cinereus*) at Blair Athol, central Queensland. *Wildlife Research* **29**, 303–311. doi:10.1071/WR00111

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics* **34**, 487–515. doi:10.1146/annurev.ecolsys.34.011802.132419

Garden, J., McAlpine, C., Petersen, A., Jones, D., and Possingham, H. (2006). Review of the ecology of Australian urban fauna: a focus on spatially explicit processes. *Austral Ecology* **31**, 126–148. doi:10.1111/j.1442-9993.2006.01578.x

Goldingay, R. L., and Kavanagh, R. P. (1993). Home-range estimates and habitat of the yellow-bellied glider (*Petaurus australis*) at Waratah Creek, New South Wales. *Wildlife Research* **20**, 387–404. doi:10.1071/WR9930387

Goldingay, R. L., Sharpe, D. J., and Dobson, M. (2010). Variation in the home range size of the squirrel glider (*Petaurus norfolcensis*). *Australian Mammalogy* **32**, 183–188. doi:10.1071/AM10006

Griffith, J. E., and Higgins, D. P. (2012). Diagnosis, treatment and outcomes for koala chlamydiosis at a rehabilitation facility (1995–2005). *Australian Veterinary Journal* **90**, 457–463. doi:10.1111/j.1751-0813.2012.00963.x

Harris, J. M., and Goldingay, R. L. (2003). A community-based survey of the koala *Phascolarctos cinereus* in the Lismore region of north-eastern New South Wales. *Australian Mammalogy* **25**, 155–167.

Harris, S., Cresswell, W. J., Forde, P. G., Trewhella, W. J., Woollard, T., and Wray, S. (1990). Home-range analysis using radio-tracking data – a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* **20**, 97–123. doi:10.1111/j.1365-2907.1990.tb00106.x

Hayes, I. F., and Goldingay, R. L. (2009). Use of fauna road-crossing structures in north-eastern New South Wales. *Australian Mammalogy* **31**, 89–95. doi:10.1071/AM09007

Jones, M. E. (2000). Road upgrade, road mortality and remedial measure: impacts on a population of eastern quolls and Tasmanian devils. *Wildlife Research* **27**, 289–296. doi:10.1071/WR98069

Kavanagh, R. P., Stanton, M. A., and Brassil, T. E. (2007). Koalas continue to occupy their previous home-ranges after selective logging in *Callitris–Eucalyptus* forest. *Wildlife Research* **34**, 94–107. doi:10.1071/WR06126

Kelt, D. A., and Van Vuren, D. H. (2001). The ecology and macroecology of mammalian home range area. *American Naturalist* **157**, 637–645. doi:10.1086/320621

Kitchener, D. J., Chapman, A., Muir, B. G., and Palmer, M. (1980). The conservation value for mammals of reserves in the Western Australian wheatbelt. *Biological Conservation* **18**, 179–207. doi:10.1016/0006-3207(80)90033-6

Lassau, S. A., Ryan, B., Close, R. L., Moon, C., Geraghty, P., Coyle, A., and Pile, J. (2008). Home ranges and mortality of a roadside koala *Phascolarctos cinereus* population at Bonville, New South Wales. In 'Too Close for Comfort: Contentious Issues in Human–Wildlife Encounters'. (Eds D. Lunney, A. Munn, and W. Meikle.) pp. 127–136. (Royal Zoological Society of New South Wales: Sydney.)

Laurance, W. F. (1990). Comparative responses of five arboreal mammals to tropical forest fragmentation. *Journal of Mammalogy* **71**, 641–653. doi:10.2307/1381805

Lee, K. E., Seddon, J. E., Corley, S. W., Ellis, W. A. H., Johnston, S. D., de Villiers, D. L., Preece, H. J., and Carrick, F. N. (2010). Genetic variation and structuring in the threatened koala populations of southeast Queensland. *Conservation Genetics* **11**, 2091–2103. doi:10.1007/s10592-009-9987-9

Lismore City Council (2011). Comprehensive Koala Plan of Management for South-east Lismore. Lismore City Council: Goonellabah.

Lunney, D., O'Neill, L., Matthews, A., and Sherwin, W. B. (2002). Modelling mammalian extinction and forecasting recovery: koalas at Iluka (NSW, Australia). *Biological Conservation* **106**, 101–113. doi:10.1016/S0006-3207(01)00233-6

Lunney, D., Gresser, S. M., Mahon, P. S., and Matthews, A. (2004). Post-fire survival and reproduction of rehabilitated and unburnt koalas. *Biological Conservation* **120**, 567–575. doi:10.1016/j.biocon.2004.03.029

McAlpine, C. A., Rhodes, J. R., Callaghan, J. G., Bowen, M. E., Lunney, D., Mitchell, D. L., Pullar, D. V., and Possingham, H. P. (2006). The importance of forest area and configuration relative to local habitat factors for conserving forest mammals: a case study of koalas in Queensland, Australia. *Biological Conservation* **132**, 153–165. doi:10.1016/j.biocon.2006.03.021

McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *Bioscience* **52**, 883–890. doi:10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2

Mitchell, P. (1990). Social behaviour and communication of koalas. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 151–170. (Surrey Beatty: Sydney.)

Preece, H. J. (2007). Monitoring and modelling threats to koala populations in rapidly urbanising landscapes: Koala Coast, south east Queensland, Australia. Ph.D. Thesis, University of Queensland, Brisbane.

Reed, P., Lunney, D., and Walker, P. (1990). Survey of the koala *Phascolarctos cinereus* (Goldfuss) in New South Wales (1986–1987), with an ecological interpretation of its distribution. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 55–74. (Surrey Beatty: Sydney.)

Rhodes, J. R., Ng, C. F., de Villiers, D. L., Preece, H. J., McAlpine, C. A., and Possingham, H. P. (2011). Using integrated population modelling to quantify the implications of multiple threatening processes for a rapidly declining population. *Biological Conservation* **144**, 1081–1088. doi:10.1016/j.biocon.2010.12.027

Rizkalla, C. E., and Swihart, R. K. (2007). Explaining movement decisions of forest rodents in fragmented landscapes. *Biological Conservation* **140**, 339–348. doi:10.1016/j.biocon.2007.08.019

Rytwinski, T., and Fahrig, L. (2012). Do species life history traits explain population responses to roads? A meta-analysis. *Biological Conservation* **147**, 87–98. doi:10.1016/j.biocon.2011.11.023

Selonen, V., and Hanski, I. K. (2003). Movements of the flying squirrel *Pteromys volans* in corridors and in matrix habitat. *Ecography* **26**, 641–651. doi:10.1034/j.1600-0587.2003.03548.x

Sharpe, D. J., and Goldingay, R. L. (2007). Home range of the Australian squirrel glider, *Petaurus norfolcensis* (Diprotodontia). *Journal of Mammalogy* **88**, 1515–1522. doi:10.1644/06-MAMM-A-404R1.1

Simmons, G. S., Young, P. R., Hanger, J. J., Jones, K., Clarke, D., McKeed, J. J., and Meers, J. (2012). Prevalence of koala retrovirus in geographically diverse populations in Australia. *Australian Veterinary Journal* **90**, 404–409. doi:10.1111/j.1751-0813.2012.00964.x

Taylor, B. D., and Goldingay, R. L. (2003). Cutting the carnage: a study of wildlife usage of road culverts in northeast New South Wales. *Wildlife Research* **30**, 529–537. doi:10.1071/WR01062

Thompson, J. (2006). The comparative ecology and population dynamics of koalas in the koala coast region of south-east Queensland. Ph.D. Thesis, University of Queensland, Brisbane.

White, N. A. (1999). Ecology of the koala (*Phascolarctos cinereus*) in rural south-east Queensland Australian. *Wildlife Research* **26**, 731–744. doi:10.1071/WR98002

Wilcove, D. S., Rothstein, D., Dubow, J., Phillips, A., and Losos, E. (1998). Quantifying threats to imperiled species in the United States. *Bioscience* **48**, 607–615. doi:10.2307/1313420