Home ranges and mortality of a roadside Koala *Phascolarctos cinereus* population at Bonville, New South Wales

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ABSTRACT

Vehicles and Koalas *Phascolarctos cinereus* collide frequently where the Pacific Highway crosses a 3.5 km stretch of forest in Bongil Bongil National Park. Despite the number of road-kills, resident Koalas survive in a 200-500m wide area of forest that lies between the highway and a parallel powerline easement, and seldom cross either boundary. Home ranges of radio-collared animals (which included some overlap) were 22.7 (± 5.1 s.e.) hectares for males and 9.7 (± 1.1 s.e.) hectares for females and extended to the very edge of the highway. Most road deaths, which peaked in September and October, therefore result from young, dispersing animals attempting to cross the highway. Moreover, the locations of fatalities coincide with the intersection of side-tracks and the highway suggesting that some animals are dispersing along the tracks until they meet the highway. Realignment of the highway will reduce habitat for Koalas and is likely to affect some resident animals. After construction of the upgrade is complete, which will include over- and underpasses and associated exclusion fencing to cater for dispersing animals, we predict that Koalas will re-establish home ranges to the edge of the realigned highway.

Key words: barrier, dispersal, highway, home range, koala, mortality.

Introduction

Effects of roads on fauna

Habitat loss and fragmentation are primary threats to native fauna in the eastern forests of New South Wales (Sullivan *et al*. 2004; Rhodes *et al.* 2006). Some of this damage arises from the need to service coastal towns and cities with a network of roads. The effect of roads on the natural environment has been the focus of many studies, including assessments on the influence of edges, road size and traffic volume, and whether they form barriers to the dispersal of flora and fauna. Road construction may damage wildlife habitats and replace them with a zone of intense human activity (Bennett 1991). Furthermore, urbanisation and road construction fragment the natural environment, often leaving habitat patches disjointed (Dickman 1987), and flora and fauna restricted to 'islands' of remaining habitat. At least three components of roads act as a barrier to the movements of terrestrial animals from these habitat patches: the bare road surface, the altered roadside habitat, and the general disturbance caused by traffic using a road (Bennett 1991).

Biotic fragmentation caused by road construction may reduce genetic diversity (Wilkins 1982) and recolonisation, and increase the risk of local extinction due to altered population dynamics (Yanes *et al.* 1995). Road mortality of fauna is well documented in the United States of America (Coulson 1985) and is also a problem for Australian fauna, having severe impacts on native mammals (Taylor and Goldingay 2004).

Study area and background

Bongil Bongil National Park (NP), includes much of the former Pine Creek State Forest, which was a large expanse (5890 ha) of coastal hardwood native forest (3918 ha) and plantation timber (1972 ha), dominated by Blackbutt *Eucalyptus pilularis,* Flooded Gum *E. grandis,* Tallowwood *E. microcorys*, Grey Gum *E. propinqua*, Sydney Blue Gum *E. saligna,* Narrow-leaved White Mahogany, *E. acmenoides* and Red Mahogany, *E. resinifera* (Fisher and Murray 2000). The forest is known to have a large population of koalas *Phascolarctos cinereus* (e.g. Smith and Andrews 1997; Smith 2004).

Pp 127 - 136 in *Too close for comfort: contentious issues in human-wildlife encounters,* edited by Daniel Lunney, Adam Munn and Will Meikle. 2008. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

This koala radio-tracking project was initiated as part of the Pacific Highway Upgrading Program on behalf of the New South Wales Roads and Traffic Authority (RTA). The "Bonville Deviation" project includes the upgrading and deviation of the Pacific Highway through a portion of Bongil Bongil NP, approximately 18 km south of Coffs Harbour (Fig. 1). The proposed route through Bongil Bongil NP was selected in 1997, with significant modifications made after community consultation in 2000, with the aim of minimising environmental impacts (in particular habitat severance and fragmentation and edge effects) by following the existing highway corridor relatively closely (Fig. 1). Approximately 65 ha of cleared area (minimum and maximum width of approximately 60 m and 250 m) was required for the road upgrade, including an allowance for a service road. The vegetation to the east of the highway contains large areas of plantation *E. grandis* with a lantana understorey, while a broader mix of tree species occurs to the west. A range of mitigation measures aimed at reducing the long-term impact of the road on fauna has been included in the road design. These include slow points and signage on the local service road and Koala fencing, two fauna underpasses and one vegetated fauna overpass over the deviation (Fig. 1).

Koala biology and ecology

Koalas are fundamentally solitary animals occupying home ranges that may overlap with the home ranges of other individuals (Martin and Handasyde 1999). Availability of palatable food trees largely dictates the distribution and home range of Koalas, since few of their requirements are non-food related (White 1999). Preferred plant species are not exclusively eucalypts, as previously considered (e.g. Hume 1990). For example, the Koalas in Bongil Bongil NP have been reported as feeding from ten eucalypts and nine non-eucalypts, with 70 % of scats containing *Allocasuarina torulosa* (State Forests of New South Wales 1997; from Moore and Foley 2000). Surveys carried out in recent years estimated the Koala population in Bongil Bongil NP at a minimum of 350 to 450 animals (Smith and Andrews 1997; Smith 2004). The distribution of Koalas, however, is not uniform throughout the forest and appears to depend on the quality of the habitat and tree species present, and most probably depends on forest structure and diversity, soil type, topographic position and disturbance history (Smith and Andrews 1997; Smith 2004).

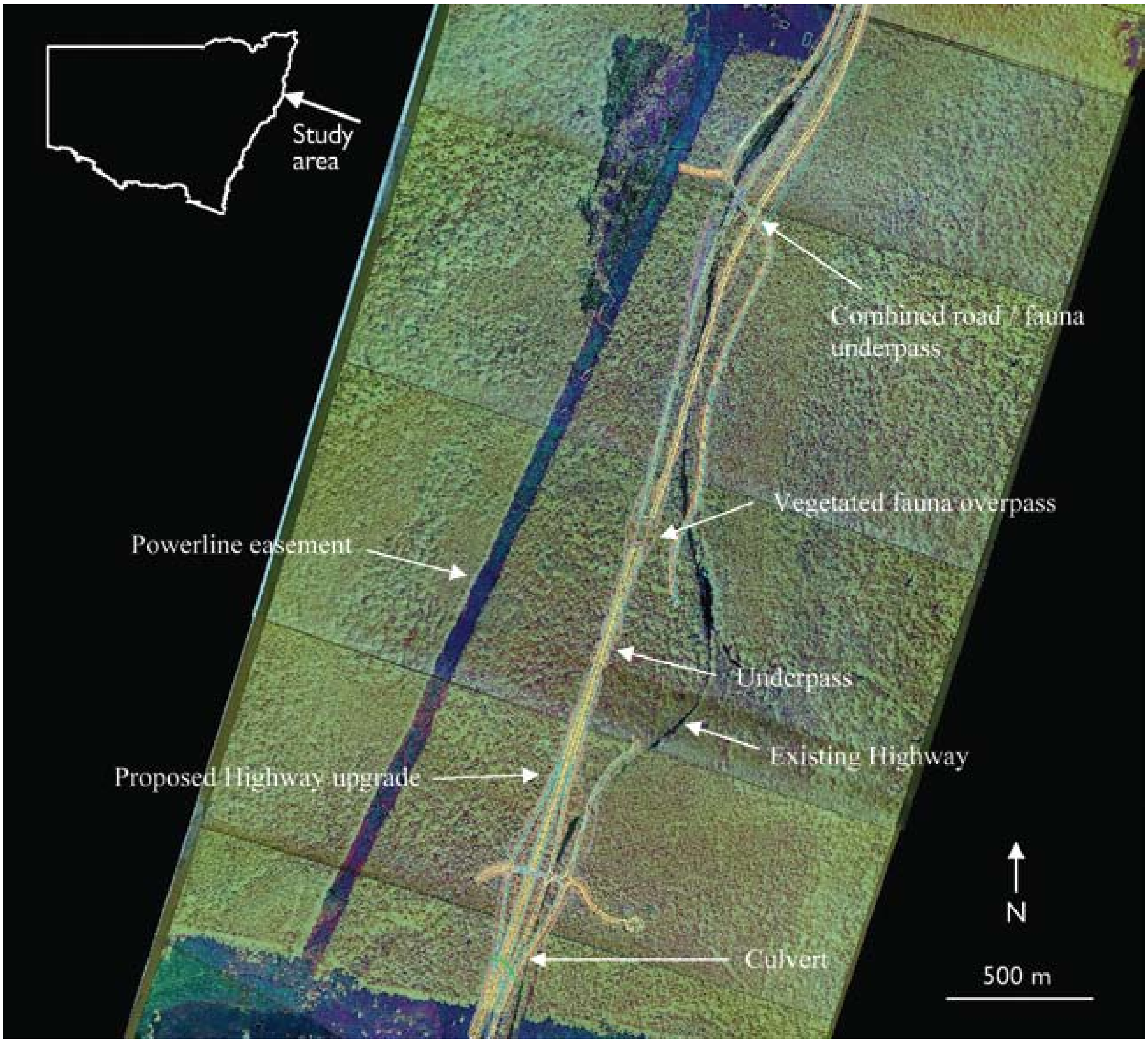

Figure 1. Aerial image illustrating the study area and the planned "Bonville deviation" upgrade of the Pacific Highway.

Generally the Koala breeding season occurs between October and May (Martin and Handasyde 1999), although the actual period may differ with latitude and the availability of food resources. Immediately prior to and during breeding time, Koala activity increases markedly owing to the dispersal of the young males and females (Dique *et al.* 2003a).

Study objectives

This paper describes the first of three objectives in a study of the effects of road construction on Koalas living adjacent to the Bonville Deviation. The first objective was to assess and analyse the numbers of Koalas killed on the existing road and to determine base-line data on the movements and home ranges of any resident animals. The second objective was to examine the effects of the construction itself, which requires the clearing of approximately 65 ha of forest, on any resident Koalas; while the third objective will be to evaluate the efficacy of specially designed over- and underpasses and associated exclusion fencing which will be constructed to facilitate crossing the road. Each stage was expected to last two years. However, after two years of Objective 1, construction was delayed and it was decided to remove radio-collars from all collared animals, with the aim to re-collar as many animals as possible one year before the construction of the upgrade was to commence. An attempt to capture animals in June 2006 prior to construction commencing in November 2006 was unsuccessful; however, four animals were captured and collared in September 2006.

Objective 1: Aims

Our first aim was to examine road kill data in the Bonville area between 1992 and 2006 to determine average monthly mortality and to examine if any correlations with the road network structure existed in an attempt to pinpoint temporal and spatial 'hotpots' within the study area. Our next aim was to capture and radio-track a number of Koalas living adjacent to the Pacific Highway, to ascertain the effects of the road and a nearby parallel powerline easement on home-range size and shape. The research was aimed at recognising and distinguishing the particular vulnerabilities of 'resident' and 'dispersing' Koalas to a road with heavy traffic loading. The powerline easement runs almost parallel to the Highway, carries no traffic and provides a good control for edge effect comparisons (Fig. 1).

Methods

Road kills

We collected all available information regarding position, date and gender of road deaths of Koalas in the broader Bonville area between 1992 and 2006. Information was gathered from both the NSW Wildlife Information, Rescue and Education Service Incorporated (WIRES) and the Department of Environment and Climate Change (DECC), as well as the current study. For seasonal analyses, we used all data collected and determined the average number of road deaths each month over the 14 years of data. We used ANOVA to determine whether there was a significant difference in road deaths between months of the year. We then compared all pairs of months using Tukey-Kramer Honestly Significant Difference (HSD) tests. We visually examined the spatial road kill data at a comparatively fine scale, utilising the Koala road deaths reported exclusively in our study area, which included a 3500 m strip of the Pacific Highway at Bonville (Fig. 1).

Home ranges and radio-tracking

Locating the Koalas required searches beside the 3.5 km section of the proposed road upgrade which passes through Bongil Bongil NP. An area extending to 500 metres east and west of the Pacific Highway was searched in 2000 by a team of nine searchers, generally walking in pairs along forest paths where mobility and visibility were easiest and where faecal pellets were more easily seen. During September 2000 we captured animals for telemetry and examined them to determine their suitability for inclusion in the research program. We made a visual assessment of the health of each animal (clinical signs of disease, weight, muscle-bulge on the scapula, body and pelage condition) at the point of capture; most animals were also transported to the local Veterinary Hospital for an independent assessment. Overall health and age of the animals were prime determinants in assessing their ability to carry a collar and therefore their long-term inclusion in the research program. Approximate estimates of age were made based on wear on the upper premolars (Gordon 1991), body weight and head-length. All animals were given individually numbered ear-tags, and those deemed fit were fitted with a collar and radio-tracked by an observer on foot with a Yagi antenna and a hand-held receiver (Regal 2000, Titley Electronics, Ballina). Those animals not selected for telemetry were released at the point of capture, sometimes after a period of up to six weeks in veterinary care. All of those chosen to be collared were found within the search area defined above and were fitted with radio transmitters mounted on a vinyl collar (Titley Electronics, Ballina). Animals were recaptured and recollared in September 2001. At that time we opportunistically captured and collared an additional animal, although our focus was on recapture rather than finding new animals for telemetry. All surviving collared animals in the study area were recaptured in 2002 and their collars removed. Then during September 2006 we trapped and fitted radio-collars to four Koalas for monitoring changes or impacts on these animals during clearing and construction of the highway upgrade (Stage 2).

We used two methods to capture animals (Fig. 2). Most were captured using active climbing, where Koalas were waved down with a flag attached to a long pole and caught by hand by catchers on the ground (Fig. 2). In trees of up to 40 metres in height, this is an operation requiring considerable skill and experience. The 'fence and trap' (Hasegawa and Carrick 1995) method was also used. In 2000 we used a fence made of thin metal and a heavy, wooden box trap. After 2000 we used a lighter version as adapted by S. Phillips (pers. comm. 2001) that included a light, strong, collapsible plastic fence (Corflute) around the tree (or copse of trees) holding the Koala. A collapsible fox cage-trap (90 x 45 x 45 cm) was inserted through the

Figure 2. Images demonstrating methods used for Koala capture: a) and b) tree climbing and flagging; and c) fence trapping.

fence so that Koalas descending the tree would follow the fence until entering the only apparent escape route, the cage trap. Each trap was checked at 2-3 hourly intervals during the night. This capture method is ineffective in heavily sloping terrain, where trees are very close together (within 2-3m) or where the understorey or shrubs cause obstructions and are too dense to be removed. Each radio-collared individual was tracked every day for the first two weeks, weekly for a further three to six weeks, and then weekly or fortnightly depending on the range of movements and social behaviour of the individual. Locations of each telemetry fix were determined by GPS or by map and compass reconnoitring.

Radio-telemetry and mapping were used to monitor the animals' movements in relation to the proposed road and to determine how they utilise available habitats. Home ranges of individual Koalas were calculated using the kernel (KNL) algorithm, within Arcview 3.2 spatial analysis package (Hooge and Eichenlaub 1997). The KNL model is a mathematically robust estimation technique (Harris *et al.* 1990; Seaman and Powell 1996) where there are sufficient (>50) number of fixes (Seaman *et al.* 1999), but home range estimates are only a general measure of an animal's area of activity (Boulanger and White 1990).

Results

Road kills

We recorded 123 Koala road deaths between January 1992 and October 2006 in the Bonville area, of which 44 occurred within the study area. The average age of road-kill was approximately 4 years, but we could obtain age estimations for only 16 Koalas because of damage to the skulls or the absence of the skulls for analysis. There were temporal (monthly) differences in the number of road deaths (ANOVA, $F = 4.33$, $p < 0.0001$) (Fig. 3). Post hoc (Tukey-Kramer) HSD tests revealed that September and October had significantly more road kills than January, February, March, April, May, June and December. The differences in number of Koala road-kills were not significant between all other months. The road-kills recorded within our study area were spatially concentrated around junctions of the Pacific Highway with unsealed roads from within Bongil Bongil NP (Fig. 4).

Number of individuals sighted and caught

We captured 25 Koalas (including 3 back young) during 2000 and 2001, of which fourteen (seven females and seven males) were fitted with radio-tracking collars. The main trapping effort was a 13 day period in September 2000 in which 40 sightings were recorded and 23 animals captured. All but six were captured on the western side of the highway. An additional young female was killed on the highway in the study area during this period. A one week period in 2001 was devoted to changing the collars but included two opportunistic captures including an old female tagged the previous year (but who was not collared) and an adult male (Wilbur) who was collared and tracked for 12 months. Also in September 2001 one koala (Gaze) was de-collared and released from

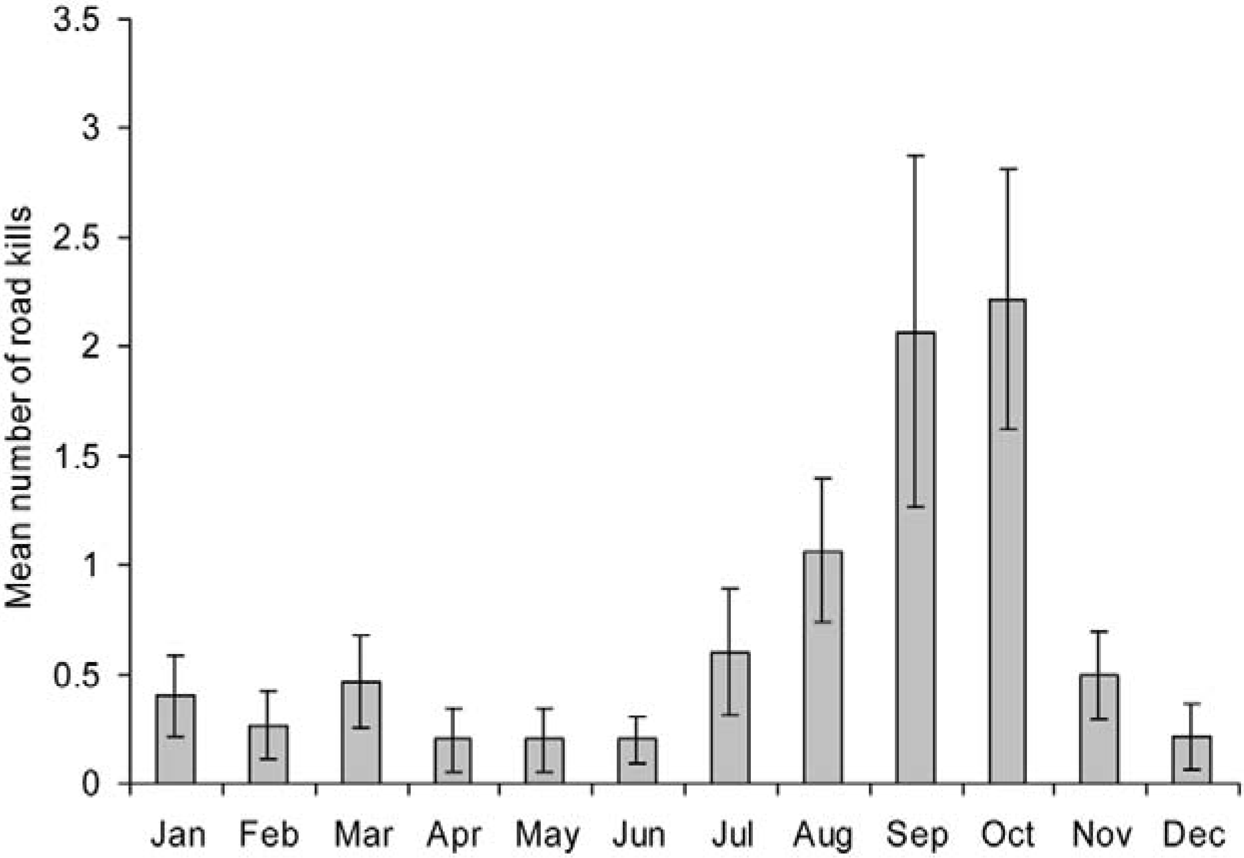

Figure 3. Mean number of Koala road kills in the Bonville region each month between January 1992 and October 2006.

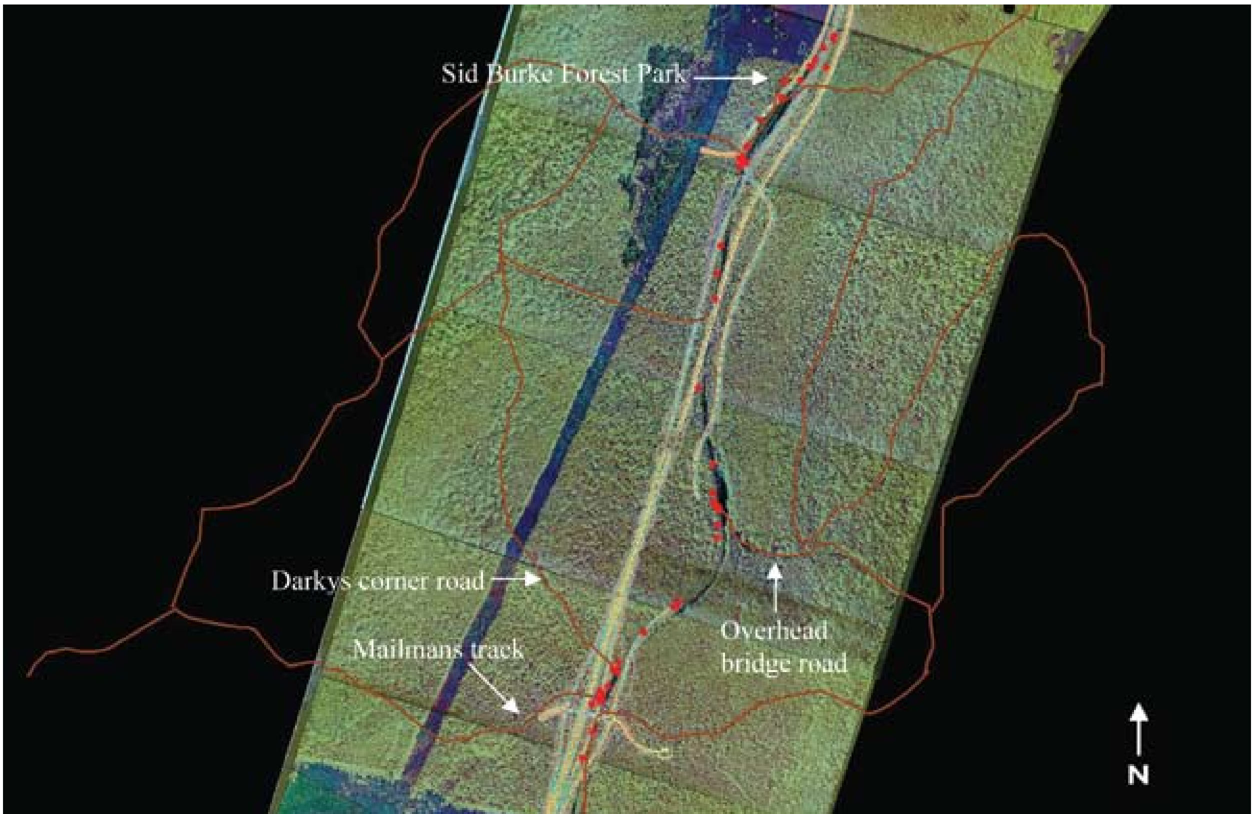

Figure 4. Koala road kills in the study area between January 1992 and October 2006.

the study because he had left the study area. On 21st October 2001 a young female koala (Jelena) was found sitting on the highway within the study area, brought to WIRES, assessed as unhurt and fit to carry a collar, and released 200 m from the highway, but was killed by a vehicle that night.

In September 2002, all the remaining collars were removed. An additional, juvenile cub of Susie (Table 1) and an adult female with back young were captured opportunistically and tagged during the 2002 trapping. In June 2006 a 5 day search period, involving seven searchers (including five of the original nine), resulted in only one sighting and no captures, while in September 2006 another 5 day search period by six searchers (including four of the original nine), resulted in six sightings and four captures.

Home ranges and mortality

Three females and one male of the seven adult Koalas captured but not collared in the initial search period were rejected from the telemetry study because they showed signs of chlamydial infection (2 of these were taken into care); another male was considered to be too old, while another two females were considered too young to carry a collar. These seven were ear-tagged and released at their point of capture.

Of the 14 Koalas captured and radio-collared within 500 m of the Pacific Highway: six were radio-tracked for the entire two year program (between 2000 and 2002); one escaped his collar one month before he was due to be released; one dispersed (and we removed the collar) after one year; and there were six deaths (Table 1). These deaths occurred several months to a year after capture, so were unlikely to be related to the telemetry program (see Table 1 for post-mortem results). The 14 animals carrying collars were tracked for up to 2 years in order to collect sufficient data to demonstrate a clear home range (Bali and Delaney 1996) (Table 1). The average male (n = 6) and female (n = 7) home ranges (delineated by the 95% probability polygon from a kernel estimator) were approximately 22.7 (± 5.1 s.e.) and 9.7 (± 1.1 s.e.) ha respectively. Figure 5 shows the cumulative home ranges of the five collared Koalas residing on the western side of the highway for both years of the initial survey. The home ranges lay within the area bounded by the powerline easement to the west, and the Pacific Highway to the east (Fig. 5) as did those of four others who died during the survey period. However, there were occasional forays across both boundaries. Kieran, a large male in the north of the study area, crossed both boundaries. Another animal, a young male (Gaze), was captured on film (Fig. 6) crossing eastward under the highway via the culvert marked in Fig. 1 at the southern end of the study area, as was an ear-tagged male that crossed westward under the highway and returned 3 days later. The former animal eventually moved more than 3 km eastwards and then settled. A third young male, Matt, was killed on the Pacific Highway a month after his collar was removed after two years of radio-tracking. A normally sedentary female, Shane, who for two years had a seemingly predictable home range (~6 ha) in a corner bounded by the existing highway and cleared land to the south was also killed on the road (December 2003) after a large branch had fallen over the fauna exclusion fencing adjacent to her home range allowing her access to the highway to the east. Of the nine recorded deaths of ear-tagged animals, three were from vehicle collisions. Wilbur, the male captured in 2001, was unusual in that he spent most of his time west of the powerline but made occasional short-term forays into the study area. In all, only three of the fourteen radio-collared Koalas successfully crossed over or under the highway while two crossed the powerline easement.

Table 1. The home range and fate of fourteen radio-collared Koalas in Bongil Bongil National Park 2000-2002.

Name	Sex	Initial Age estimation	Capture date	Status / cause of death	Home Range (ha) (95 % Kernel)	No. of fixes
Dawn	F	3yrs	11/09/2000	Died - chlamydial infection March 2001	13	35
Thorpe	M	4yrs	11/09/2000	Escaped - collar thrown, August 2002	19	98
Gaze	M	2yrs	12/09/2000	Dispersed - collar removed, September 2001	N/A	79
Debbie	F	7yrs	13/09/2000	Died – trauma (fall), January 2002	11	63
Betty	F	9yrs	16/09/2000	Died - old age probable, May 2001	11	54
Matt	M	2 yrs	17/09/2000	Collar removed - September 2002; road kill - October 2002	26	87
Shane	F	6 yrs	18/09/2000	Collar removed - September 2002; road kill - December 2003	6	80
Kieran	M	6 yrs	19/09/2000	Collar removed - September 2002	45	114
Shirley	F	6 yrs	19/09/2000	Presumed dead - collar found with teeth marks January 2001	7	23
Klim	M	3 yrs	20/09/2000	Died - cancer, July 2001	13	42
Susie	F	6 yrs	21/09/2000	Collar removed - September 2002	13	84
Alison	F	7 yrs	22/09/2000	Collar removed - September 2002	7	85
Aussie Joe	M	6 yrs	23/09/2000	Died - cause unknown (old age probable), March 2001	10	31
Wilbur	M	6 yrs	8/09/2001	Collar removed - September 2002	23	45

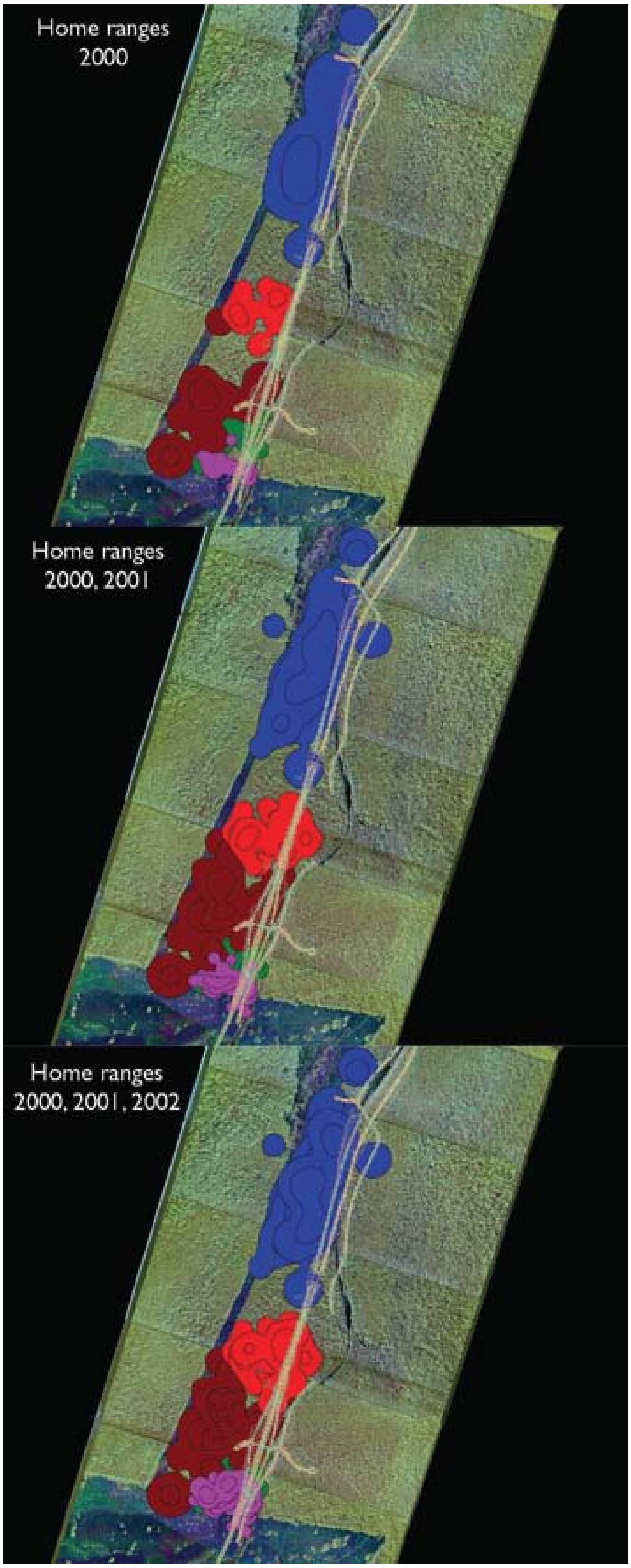

Figure 5. Estimated home ranges (using the kernel algorithm) of five Koalas radio-tracked for two years. Each colour represents one Koala: Blue = Kieran; Red = Susie; Brown = Matt; Purple = Shane; Green = Alison. The outer line of each colour represents the 95 % Kernel, whilst the inner line represents the 50 % Kernel.

Figure 6. Radio-collared male Koala crossing the Pacific Highway through a designated fauna underpass. Image captured by an automated camera with a movement sensing infra-red beam used to trigger the photograph (positioned by C. Moon).

We trapped and collared four koalas in September 2006 and radio-tracked them between September and November 2006 before road construction commenced. Three koalas appear to have established home ranges adjacent to the highway. One of these animals crossed the road twice during the approximately two months we radio-tracked him. A young female dispersed in a south-westerly direction (Fig. 7) for 8 weeks, travelling approximately 5 km until she eventually settled 3.5 km away from our study site.

Discussion

Koala mortality

This study demonstrates remarkable increases in Koala road deaths in Bonville in September and October (Figure 3). This trend reflects records of Koala sightings in the Campbelltown Local Government Area of Sydney (Ward and Close 1998; Ward 2002) and in south-east Queensland (Nattrass and Fiedler 1996), except that in the latter the increase began in late June and ceased by early January, whereas Bonville area road kills were low in June, November and December. The road kill peaks correspond to the dispersal period for Koalas (Dique *et al.* 2003a) and also to the breeding season, October to March in south east Queensland (White and Kunst 1990) and Victoria (Mitchell 1990a). The link between peaks in public sightings and road kills with the dispersal period is obvious: the more animals move, the more likely they are to be seen or hit. However, our record of only one sighting in June 2006, despite extensive searches by experienced people and the frequent presence of fresh faecal pellets, raises the possibility that resident animals may remain relatively inactive until the September-October period. If so, surveys for both resident and dispersing Koalas may be more successful during September-October. From a management perspective, Koala road kills might be minimised if speed limits were reduced and speed cameras installed during the August-November period. However, Dique *et al.* (2003b) failed to find significant decreases in

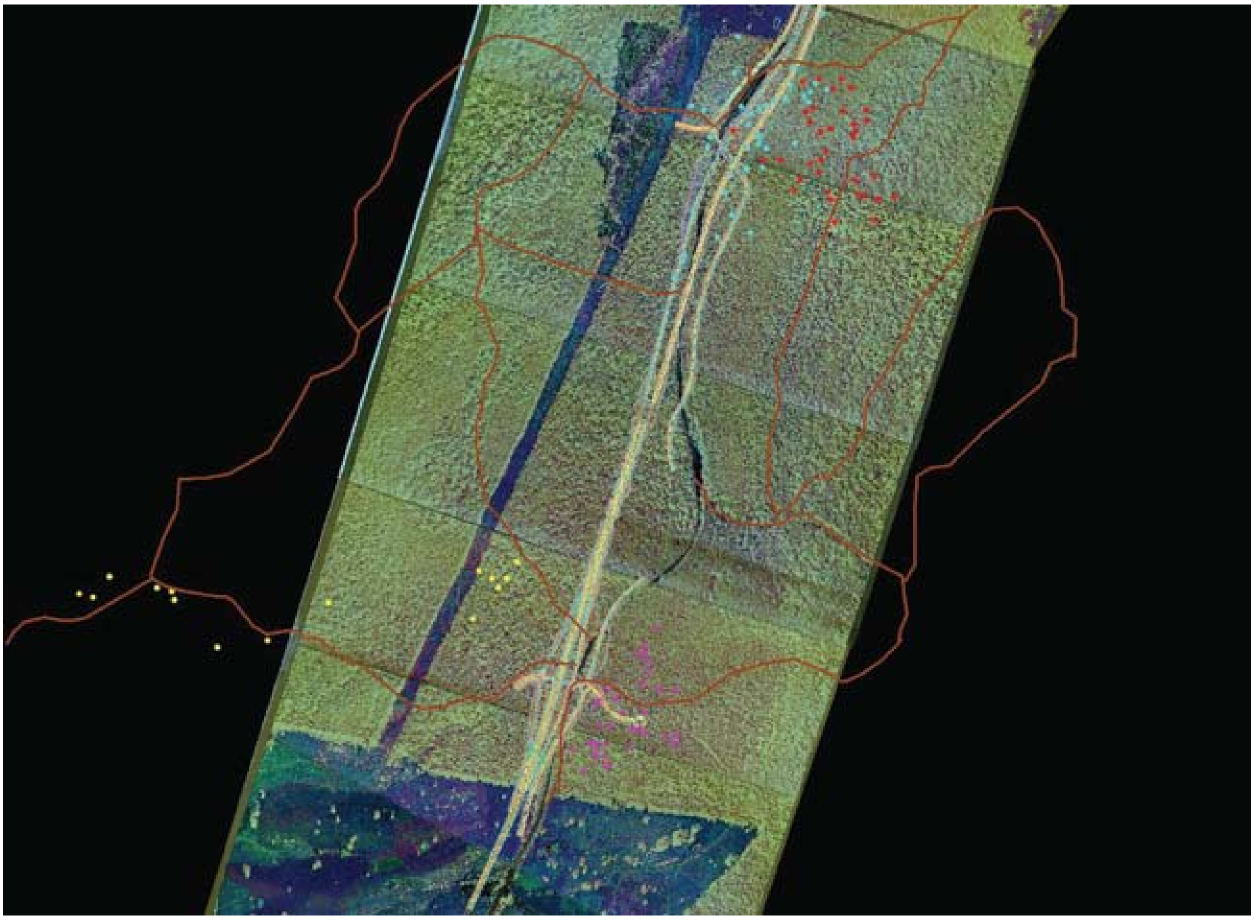

Figure 7. Radio-tracking data of four koalas between September and November 2006. Each colour represents one Koala, and each point represents a recorded sighting.

mortality in south-east Queensland when speed limit and warning signs (but not speed cameras) were installed.

The concentrations of road kills on the highway near the entry of side-roads (Fig. 4) are intriguing. One explanation is that Koalas will follow a track during dispersal. Prevett (1996) showed that three translocated Koalas showed strong directional components in moving 5, 9 and 9 km. Likewise, the movement of both of the two radio-collared Koalas which dispersed was particularly linear. If their dispersal direction coincided with a track, as in Fig. 7, then the animal could proceed faster and with less effort. Therefore, in designing underpasses, overpasses and exclusion fences for fauna, dispersing animals may better be protected if directed under/over the highway at places where side roads meet the highway. It may also be beneficial to construct a narrow path directly from the side road into the fauna crossing. This contradicts the conventional wisdom that fauna underpass accesses be well vegetated.

Such pathways and crossings, however, may not be beneficial to resident animals. The major finding of this study is that Koalas appear to recognise major features (highway, powerline easement) as boundaries to their home ranges, and seldom cross them. Such fidelity to physical boundaries has also been noted in Koalas at Campbelltown, NSW (R. Close, unpublished data). If Koalas do not recognise the fauna crossing as part of their boundary they may be drawn to cross the road. Once across, they may not find the return route and then be at risk recrossing the road. Construction of exclusion fencing, however, should minimise this risk.

Table 1 shows that some resident Koalas attained a significant age in the study area despite the dangers of the highway. Age estimation in Koalas, however, from size and tooth wear, is not precise and there is considerable variation in the age ranges for different tooth wear classes (Gordon 1991). Only two of the radio-collared, resident animals were killed on the road and none during the telemetry period. The relative rarity of road deaths among resident animals that were tracked suggests, therefore, that most of the road deaths that occurred in the study area (Fig. 4) are dispersing animals. The few undamaged skulls that we could acquire from these corpses revealed a mean age of approximately 4 years. That estimate compares with the findings of Dique *et al.* (2003a) that most males dispersed at 20-36 months while three dispersing females were aged more than 36 months. It is likely, therefore, that the proposed fauna crossings and associated exclusion fencing will reduce deaths among dispersing animals without having a major effect on the residents. It is always possible, however, that a resident male will stand sentinel at the crossing or mark it with pheromones that will cause dispersing individuals to retreat. This question will be addressed in Stage 3 of the study.

Approximately 40 % of radio-collared animals died from a range of non-vehicular causes during the initial two year telemetry period: one animal died of chlamydial infection; one was presumed dead since the collar was found with teeth marks; two had advanced cancer; and the remaining two died from complications associated with old age. This mortality rate compares with 14 % non vehicular mortality for a study of 77 Koalas conducted elsewhere in Bongil Bongil NP (but some distance from the highway) during the same period (Radford *et al.* 2006). In the latter study no attempt was made to select suitable animals for telemetry.

Home ranges

Average areas of home ranges in this study were 22.7 (+/- 5.1 s.e.) and 9.7 (+/- 1.1) ha for males and females respectively, and sizes were consistent over the 2 year telemetry period (Fig.5). These values are moderately large and compare with values of 34.4 and 15.0 ha in rural south-east Queensland (White 1999) and 1.7 and 1.18 ha on French Island in Victoria (Mitchell 1990b). Considerable overlap of home ranges was detected particularly among the eight collared animals with home-ranges on the western side of the highway. In addition to these eight, one mature and two young females, two mature males and four cubs were captured in the western area but not radio-collared. Other resident animals may have not been detected. At least 13 animals, therefore, were living in that area. An estimated 65 ha loss of habitat from the road construction from a total western area of 120 ha (between the highway and powerline) is therefore likely to have a significant effect on several of the resident animals.

While several animals that occupied those home ranges have died during this study (Table 1), it is likely that other animals will have filled those vacancies in the forest. Animals on the western side of the highway that are not directly impacted may suffer a reduction in home range size through compression of the existing animals into the available habitat between the highway and the powerline corridor. It is possible that this impact will be more severe on female Koalas than on males because they have smaller home ranges located in habitats suitable for successfully raising young.

Although Koalas living immediately west of the highway appear to recognise the current road and the powerline easement as boundaries of their home ranges, the features are not complete barriers. Given that one tagged and three collared animals have succeeded in crossing the highway, it is likely that a proportion of the animals normally dispersing through the study area are also likely to cross the highway successfully. Any Koalas moving away from the construction area to forest west of the powerline or to the east across the existing highway are likely to be moving into the established home ranges of other Koalas. Nattrass and Fieldler (1996) suspect that animals moved into the home ranges of others can suffer from "relocation shock". Animals moving to the east would have the additional risk of exposure to traffic.

Conclusion

The rate of road-kills is high in September/October where the Pacific Highway crosses Bongil Bongil NP. It is most likely that the vast majority of road deaths result from young, dispersing Koalas attempting to cross the highway, which they may approach via forest tracks. Resident Koalas live right beside the highway and seldom cross it, nor do they often cross an 80 m wide powerline easement. These observations suggest that resident Koalas recognise structural features as boundaries to their home-ranges. During construction of an upgrade for the highway, habitat for Koalas is removed which reduces the size of existing home ranges of resident animals and may cause some to move. After construction of the upgrade is complete, we predict that resident or immigrant Koalas will establish home ranges to the edge of the realigned highway. The inclusion of well designed and appropriately located fauna underpasses and overpasses, with appropriate exclusion fencing, is expected to reduce the incidence of road kills on the Pacific Highway, while maintaining genetic links. Other important mitigative measures include checking all exclusion fencing for damage, planting over-growth in June before the dispersal period (August–December), and enforcing traffic speed limits in the area with speed cameras. Signage should be erected in the area emphasising the need for special attention from drivers during the dispersal months.

Acknowledgements

This research was funded by a consultancy to Australian Museum Business Services (AMBS) from the Roads and Traffic Authority (RTA), New South Wales. For assistance with the project we thank staff from the following New South Wales government agencies: RTA; Department of Primary Industries (Forests), and Department of Environment and Climate Change. We also thank M. Whackett and other local members of the Wildlife Information Rescue and Education Service (WIRES), for collecting roadkill data and tissues. The staff at Pet Porpoise Pools also kindly allowed us to store frozen road kills. We thank vets C. Ley, D. Johnstone and A. Dunn of Pacific VetCare Coffs Harbour for examining and caring for animals. L. Gibson and J. Coughlan were Project Managers for AMBS in the early stages of the study. For their assistance in the field, we thank L. Bowden, S. Browne, K. Glover, G. Lloyd and D. Lloyd. For comments we thank D. James.

References

Bali, R. and Delaney, R. 1996. *A Review of Koala Radio-collaring Research*. A draft report for NSW National Parks and Wildlife Service.

Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: a review. Pp. 99-118 in *Nature Conservation 2: The role of corridors*, edited by D. A. Saunders and R. J. Hobbs. Surrey Beatty and Sons, Sydney.

Boulanger, J.G. and White, G.C. 1990. A comparison of home-range estimators using Monte Carlo simulation. *Journal of Wildlife Management* **54**: 310-15.

Coulson, G. 1985. Road kills: wheels v wildlife. *Wildlife Australia* **(Summer):** 26-8.

Dickman, C.R. 1987. Habitat fragmentation and vertebrate species richness in an urban environment. *Journal of Applied Ecology* **24**: 337-51.

Dique, D.S., Thompson, J., Preece, H.J., de Villiers, D., and Carrick, F.N. 2003a. Dispersal patterns in a regional koala population in south-east Queensland. *Wildlife Research* **30**: 281-90.

Dique, D.S., Thompson, J., Preece, H.J., Penfold, G.C., de Villiers, D.L., and Leslie, R.S. 2003b. Koala mortality on roads in south-east Queensland: the koala speed-zone trial. *Wildlife Research* **30**: 419-26**.**

Fisher, J. and Murray, J. (eds.) 2000. *Koala management plan Pine Creek State Forest*. State Forests of NSW, North East region.

Gordon, G. 1991. Estimation of the age of the koala, *Phascolarctos cinereus* (Marsupialia: Phascolarctidae) from tooth wear and growth. *Australian Mammalogy* **14**: 5-12.

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.

Hasegawa, M. and Carrick, F.N. 1995. First catch your koala! Use of a trap to capture koalas *Phascolarctos cinereus* for ecological studies. *Australian Zoologist* **30:** 68-70.

Hooge, P.N. and B. Eichenlaub, B. 1997. Animal movement extension to arcview. ver. 1.1. Alaska Science Center - Biological Science Office, U.S. Geological Survey, Anchorage, AK, USA.

Hume, I. D. 1990. Biological basis for the vulnerability of koalas to fragmentation. Pp. 32-5 in *Koala Summit: Managing Koalas in New South Wales* edited by D. Lunney, C. A. Urquhart and P. Reed. NSW National Parks and Wildlife Service, Sydney.

Martin, R. and Handasyde, K. 1990. Population dynamics of the koala. (*Phascolarctos cinereus*) in southeastern Australia. Pp. 75-84 in *Biology of the Koala,* edited by A. K. Lee, K. A. Handasyde and G. D. Sanson. Surrey Beatty and Sons, Chipping Norton, NSW.

Martin, R. and Handasyde, K. 1999. *The Koala: Natural History, Conservation and Management.* University of New South Wales Press, Sydney.

Mitchell, P. 1990a. Social behaviour and communication of koalas. Pp.151-70 in *Biology of the Koala*, edited by A. K. Lee, K. A. Handasyde and G. D. Sanson. Surrey Beatty and Sons, Chipping Norton, NSW.

Mitchell, P. 1990b. The home ranges and social activity of koalas- a quantitative analysis. Pp. 171-87 in *Biology of the Koala*, edited by A. K. Lee, K. A. Handasyde and G. D. Sanson. Surrey Beatty and Sons, Chipping Norton, NSW.

Moore, B.D. and Foley, W.J. 2000. A review of feeding and diet selection in koalas (*Phascolarctos cinereus*). *Australian Journal of Zoology* **48:** 317-33.

Nattrass, A.E.O. and Fiedler, K.B. 1996. Koala rescue – the perception and the reality. Pp.129-36 in *Koalas – Research for Management. Proceedings of the Brisbane Koala Symposium*, 22nd-23rd *September 1990,* edited by G. Gordon. World Koala Research Inc., Brisbane.

Prevett, P. 1996. Biology and management of an urban population of Koalas at Ballarat in Victoria. Pp137-47 in *Koalas – Research for Management. Proceedings of the Brisbane Koala Symposium, 22nd-23rd September 1990,* edited by G. Gordon. World Koala Research Inc., Brisbane.

Radford, S.L., McKee, J., Goldingay, R.L. and Kavanagh, R.P. 2006. The protocols for koala research using radio-collars: a review based on its application in a tall coastal forest in New South Wales and the implications for future research. *Australian Mammalogy* **28**:187-200.

Rhodes, J.R., Tyre, A.J., Jonzen, N., McAlpine, C.A. and Possingham, H.P. 2006. Optimizing presence-absence surveys for detecting population trends. *Journal of Wildlife Management* **70:** 8-18.

Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brundige, G.C., Raedeke, K.J. and Gitzen, R.A. 1999. Effects of sample size on Kernel home range estimates. *The Journal of Wildlife Management* **63**: 739-47.

Seaman, D.E. and Powell, R.A. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* **77**: 2075-85.

Smith, A. P. 2004. Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. Pp 591-611 in *Conservation of Australia's Forest Fauna* (second edition), edited by D. Lunney. Royal Zoological Society of NSW, Mosman, NSW.

Smith, A.P. and Andrews, S. 1997. *Koala Habitat, Abundance and Distribution in the Pine Creek Study area.* Unpublished report to State Forests of NSW.

Sullivan, B.J., Baxter, G.S., Lisle, A.T., Pahl, L. and Norris, W.M. 2004. Low-density koala (*Phascolarctcos cinereus*) populations in the mulgalands of south-west Queensland. IV. Abundance and conservation status. *Wildlife Research* **31**: 19-29.

Taylor, B.D. and Goldingay, R.L. 2004. Wildlife road-kills on three major roads in north-eastern New South Wales. Wildlife Research **31** 83-91.

Ward, S.J. **2002**. *Koalas and the community: a study of low density populations in southern Sydney.* Unpublished PhD thesis, University of Western Sydney.

Ward, S.J. and Close, R.L. 1998. Community assistance with koala *Phascolarctos cinereus* sightings from a low density population in the south-west Sydney region. Pp. 97-102 in *Ecology for Everyone* edited by R. Willis and R. Hobbs. Surrey Beatty and Sons, Chipping Norton, NSW.

White, N.A. 1999. Ecology of the koala (*Phascolarctos cinereus*) in rural south-east Queensland, Australia. *Wildlife Research* **26**: 731-4.

White, N.A. and Kunst, N.D. 1990. Aspects of the ecology of the koala in southeastern Queensland. Pp. 109-16 in *Biology of the Koala*, edited by A. K. Lee, K. A. Handasyde and G. D. Sanson. Surrey Beatty and Sons, Chipping Norton, NSW.

Wilkins, K.T. 1982. Highways as barriers to rodent dispersal. *Southwestern Naturalist* **27:** 459-60.

Yanes, M., Velasco, J.M. and Suarez, F. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* **71**: 217-22.