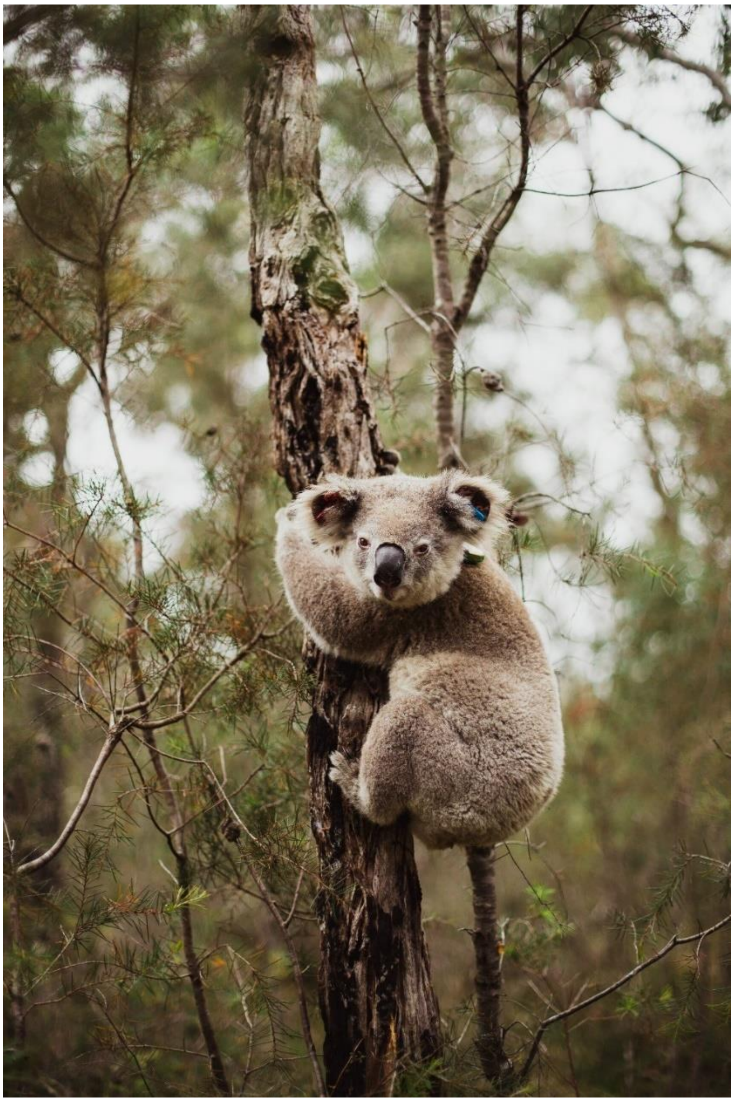
DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Conserving Koalas in the Wollondilly and Campbelltown Local Government Areas



environment.nsw.gov.au

Cover photo: Koala (*Phascolarctos cinereus*). Bear Hunt Photography

Published by:

Environment, Energy and Science
Department of Planning, Industry and Environment
59 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South NSW 1232
Phone: +61 2 9995 5000 (switchboard)
Phone: 1300 361 967 (Environment, Energy and Science enquiries)
TTY users: phone 133 677, then ask for 1300 361 967
Speak and listen users: phone 1300 555 727, then ask for 1300 361 967
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@environment.nsw.gov.au
See also www.environment.nsw.gov.au

ISBN 978 1 922317 36 0
EES 2019/0573
October 2019

Find out more about your environment at:

www.environment.nsw.gov.au

Contents

List of tables

List of figures

1. Summary

This report identifies high-quality koala habitat, core koala habitat, koala movement corridors and koala roadkill hotspots in the Wollondilly and Campbelltown Local Government Areas (LGAs). Existing data were used, along with new data collected in the eastern part of the Wollondilly LGA as part of the Wollondilly Koala Conservation Project. An estimate for koala densities in core koala habitat calculated from the Wollondilly Koala Conservation Project is provided, along with extrapolated koala numbers potentially supported in movement corridors in the Wollondilly and Campbelltown LGAs. A categorisation for the relative importance of different corridors is also provided. Areas of high-quality koala habitat, core koala habitat, koala movement corridors and koala roadkill hotspots form the basis for DPIE's management recommendations in the Wollondilly and Campbelltown LGAs. Key koala conservation principles are coupled with known areas of koala habitat to provide specific recommendations for the conservation of the regional koala population extending from Campbelltown through Wollondilly to Wingecarribee.

Information and recommendations outlined in this report are communicated in the context of residential and urban development in the Wilton and Greater Macarthur Growth Areas (GAs). Information on core koala habitat and koala movement corridors is essential knowledge when planning for development in south-west Sydney. Data collection for koalas in the Wollondilly and Campbelltown areas is ongoing. Data used in this report represents the best available information to inform management decisions related to future development. Previous information for koala habitat and movement corridors (Department of Environment and Climate Change (DECC) 2007) was compiled for a regional scale and is not appropriate for use at the scale needed for the Wilton and Macarthur GAs.

2. Introduction

The NSW Government recently began funding koala research and on-ground management actions under the *Saving our Species* (SoS) conservation program. As part of the SoS program, the Department of Industry, Planning and Environment – Environment, Energy and Science (DPIE–EES) initiated the Wollondilly Koala Conservation Project. This project is collecting new information on koala distribution, abundance, movement, and habitat usage within the Wollondilly Local Government Area (LGA). Work began in March 2016 and data collection and analyses are ongoing.

The Wollondilly and adjacent Campbelltown areas are earmarked for development as part of the Wilton and Greater Macarthur Growth Areas (GAs), with projected development expected to support thousands of new dwellings, town centres and associated infrastructure. DPIE–EES has prepared this document to inform government and non-government stakeholders of priority areas for koala conservation, and key actions required to avoid and minimise impacts and threats from these new developments. This information is essential to ensure that future urban growth does not compromise the viability of the koalas in the area, and the wider regional koala population extending from Campbelltown through Wollondilly to Wingecarribee.

This report combines existing data from a range of sources, including the NSW BioNet database, and new data from the Wollondilly Koala Conservation Project. Core koala habitat, as defined in this report, and koala movement corridors in the Wollondilly and Campbelltown LGAs, specifically southern Campbelltown, Appin and Wilton, are identified at a local scale (approximately 1:10,000). Core koala habitat and koala movement corridors are both critical to the long-term persistence of the regional koala population.

The focus area is the Wilton and Greater Macarthur GAs. However, koala habitat and corridors in the GAs link to important koala habitat and metapopulations (groups of spatially separated populations connected by dispersal) to the north and south. Therefore, mapping was undertaken for a larger area than the GAs, from the Georges River north of Holsworthy to Colo Vale in the Wingecarribee Shire.

Information collected to date for the Wollondilly Koala Conservation Project has improved our understanding of the regional koala population. The data updates existing koala habitat and corridor mapping done at a regional scale (Department of Environment and Climate Change (DECC) 2007) from south Campbelltown to Appin and across to the Wilton area. The new mapping will allow us to prioritise management actions within these areas.

The scientific methods, areas recommended for protection and mitigation measures identified have been peer reviewed by two recognised koala scientists, Associate Professor Mathew Crowther and Dr Stephen Phillips. Their reviews in Appendices 1 and 2 indicate that the conservation areas and measures recommended in this report represent the minimum requirements for koala conservation in the area.

The use of best available information is crucial to understand what is required to maintain the regional koala population, and specifically the metapopulations in the Wollondilly and Campbelltown areas. As more information becomes available, it will be used to refine outcomes.

3. Methods

A number of data input layers were used to identify or validate koala habitat and movement corridors. These are referred to throughout this section and include:

- Koala Linkage (Department of Environment and Climate Change (DECC) 2007)
- Koala habitat model (DECC 2007)
- Koala records and presence–absence spotlighting data (downloaded from BioNet November 2017; Office of Environment and Heritage (OEH) 2017a)
- Koala habitat assessment 20 x 20 metre vegetation plots (downloaded from the BioNet Vegetation Information System November 2017; OEH 2017b)
- Preferred koala-use trees for Wollondilly (OEH unpublished data)
- Native vegetation of the Sydney Metropolitan Area (OEH 2013)
- Native vegetation of the Woronora, O'Hares and Metropolitan Special Areas (National Parks and Wildlife Service (NPWS) 2003)
- Cumberland Plain Native Vegetation Mapping (Tozer 2003)
- Native Vegetation of the Nattai and Bargo Reserves (Department of Environment and Conservation (DEC) 2004).

Other layers referred to but not formally used to derive or validate koala habitat and movement corridors included:

- Cumberland Plain Priority Conservation Lands (Department of Environment, Climate Change and Water (DECCW) 2011)
- Cumberland Subregion Biodiversity Investment Opportunities Map (BIO Map) (OEH 2015)
- Campbelltown Council Biodiversity Corridors (Campbelltown Council 2017)
- Eco Logical Australia (ELA) wildlife corridors for Mt Gilead and surrounds (ELA 2017).

In addition, data used to validate high-quality koala habitat (see Section 3.4) were derived from the Wollondilly Koala Conservation Project using. Only data from the eastern part of the Wollondilly Local Government Area (LGA); i.e. the area bordered by the Wollondilly LGA boundaries in the north, east and south, and Remembrance Drive in the west, were used. This area encompasses the Wilton and Greater Macarthur Growth Areas.

3.1 Using fine-scale vegetation mapping

The vegetation in the Wollondilly and Campbelltown areas has been mapped to a fine and very fine scale, and plant communities are well known. As such, maps for core koala habitat and koala movement corridors were based on these fine-scale vegetation maps. Vegetation communities reflect the geology of the region, with shale, shale-transition and sandstone-derived soils influencing the proportion of koala feed trees in each community.

North from Wedderburn, the vegetation map used was the Native Vegetation of the Sydney Metropolitan Area (OEH 2013). This validated vegetation map of NSW Plant Community Types (PCTs) was developed in-line with the NSW Native Vegetation Interim Type Standards (DECCW 2010). It was produced at a scale of 1:8000 and has very accurate line work and attribution of vegetation communities.

For the remainder of the study area a mosaic of vegetation maps were used, including the Cumberland Plain Native Vegetation Map (Tozer 2003), Native Vegetation of the Nattai and Bargo Reserves (DEC 2004) and the Native Vegetation of the Woronora, O'Hares and Metropolitan Catchments (NPWS 2003) (all at a scale of 1:25,000). These maps are limited by the accuracy of the aerial photography available at the time. Wherever possible, line-work has been updated (using high-resolution ASD40 2014 aerial photography) to improve line-work accuracy and excise new areas of clearing. Areas that had been under-scrubbed or semi-cleared since the mapping was undertaken were reattributed. Although still fine-scale compared to most vegetation maps, the different accuracies of the underlying mapping between the south and the north is a limitation of the final maps.

3.2 State Environmental Planning Policy 44 definitions

State Environmental Planning Policy (SEPP) 44 definitions of 'core koala habitat' were not used in this report because of the high number of known local feed trees used by koalas, particularly for the Wollondilly LGA, that are not listed in SEPP 44. Core koala habitat for the purpose of this report is defined in the Glossary.

3.3 Defining koala habitat

In the Campbelltown and Wollondilly LGAs, there is a long-established association between the presence of koalas and vegetation that grows on higher fertility soils, such as shale or shale-transition soils (e.g. Prevett et al. 2001; Phillips and Callaghan 2002; Ward 2002; Lunney et al. 2010). Koalas favour vegetation growing on fertile soils due to the increased nutrient availability in the eucalypt leaves (Moore et al. 2010). Therefore, all shale and shale-enriched vegetation types with a dominant eucalypt canopy were classified as being high-quality habitat (HQH). HQH patches greater than 100 hectares were identified as 'core koala habitat'.

Eucalypt-dominated riparian sandstone communities, rainforest communities on shale with some eucalypts present and regenerating acacia scrubs on shale were classified as medium-quality habitat (MQH). Low-fertility sandstone vegetation communities including heaths, heathy woodlands, swamps and rocky woodlands were classified as low-quality habitat (LQH).

Table 1 lists mapped vegetation communities, their soil classification and their assigned habitat quality based on the vegetation community descriptions listed in the relevant vegetation map (Tozer 2003; DEC 2004; OEH 2013; NPWS 2003).

Table 1 **Vegetation communities within the study area, soil classification and koala habitat quality**

Vegetation community	Soil classification	Koala habitat quality
Cumberland Plain alluvial woodland	Shale	High-quality habitat (HQH)
Cumberland Plain shale hills woodland	Shale	HQH
Cumberland Plain shale plains woodland	Shale	HQH
Cumberland Plain shale sandstone transition forest (high sandstone influence)	Shale transition	HQH
Cumberland Plain shale sandstone transition forest (low sandstone influence)	Shale transition	HQH
Eastern gully forest	Sandstone	Medium-quality habitat (MQH)
Exposed sandstone scribbly gum woodland	Sandstone	MQH
Highlands shale tall open forest: form C tall open variant	Shale	HQH
Moist shale woodland	Shale	HQH
Nattai sandstone river peppermint forest	Sandstone	MQH
Nepean enriched sandstone woodland	Shale-enriched	HQH
Nepean Gorge moist forest	Sandstone	MQH
O’Hares Creek shale forest	Shale transition	HQH
Riparian forest	Shale transition	HQH
Riparian scrub	Sandstone	Low quality habitat (LQH)
Rock pavement heath	Sandstone	LQH
Rock plate heath-mallee	Sandstone	LQH
Sandstone gully apple-peppermint forest	Sandstone	MQH
Sandstone gully peppermint forest	Sandstone	MQH
Sandstone heath-woodland	Sandstone	LQH
Sandstone ridgetop woodland	Sandstone	LQH
Sandstone riparian scrub	Sandstone	LQH
Sheltered sandstone blue-leaved stringybark forest	Sandstone	MQH
Transitional shale dry ironbark forest	Shale transition	HQH
Transitional shale open blue gum forest	Shale transition	HQH
Transitional shale stringybark forest	Shale transition	HQH
Upland swamps: banksia thicket	Sandstone	LQH
Upland swamps: fringing eucalypt woodland	Sandstone	LQH
Upland swamps: sedgeland-heath complex	Sandstone	LQH
Upland swamps: tea-tree thicket	Sandstone	LQH

Vegetation community	Soil classification	Koala habitat quality
Upper Georges River sandstone woodland	Shale-enriched	HQH
Western sandstone gully forest	Shale-enriched	HQH
Western Sydney dry rainforest	Shale	MQH
Woronora tall mallee-heath	Sandstone	LQH
Regenerating vegetation		LQH/MQH
Weeds and exotics		LQH
Exposed rock		LQH

3.4 Validating high-quality habitat

High-quality koala habitat was subject to a series of validation steps using four independent datasets obtained from the Wollondilly Koala Conservation Project.

3.4.1 Floristic validation

The draft high-quality habitat map was validated using floristic plot data collected as part of the Wollondilly Koala Conservation Project. A total of 143 20 x 20-metre full floristic plots were completed within the study area and used to validate HQH. Tree species recorded in vegetation plots were used to confirm the presence and association of koala-use trees with mapped HQH. These plots have been entered into the OEH Vegetation Information System (VIS) (OEH 2017b). The plots were not used to develop the vegetation mapping used to assign koala habitat quality and are therefore a suitable validation dataset.

3.4.2 Systematic presence–absence spotlighting data

The correlation between the presence of koalas and shale, shale-transition and shale-enriched vegetation types (e.g. Prevett et al. 2001; Phillips and Callaghan 2002; Ward 2002; Lunney et al. 2010) was assessed using systematic presence–absence spotlighting data (OEH 2017a). Between 2014 and 2018, over 800 systematic, two-hectare spotlighting surveys were undertaken as part of the Wollondilly and Southern Highlands Koala Conservation Projects. For the purposes of this report, spotlighting sites within the eastern part of the Wollondilly LGA were used (Figure 2). Survey sites within 500 metres of another site were excluded to promote independence, leaving 173 sites in total.

Spotlighting site data, including koala observations, were overlayed on the HQH map. The number of spotlighting sites and koalas recorded in and out of high-quality habitat was determined using a geographic information system (GIS).

An estimate of density of koalas in each habitat category (high-quality versus non-high-quality) was calculated by dividing the number of koalas observed by the area surveyed. Pearson’s Chi-squared test was used to determine whether there was a significant difference in koala density in HQH and non-HQH using R.3.3.0 (R Core Team 2013).

Spotlighting is likely to underestimate koala numbers and densities. It is an imperfect technique and it is possible some koalas within survey areas were not detected.

3.4.3 Incidental koala sightings

The correlation between shale and shale-transition vegetation types and koalas was also assessed using koala sightings for the eastern part of the Wollondilly LGA from the NSW

Atlas of Wildlife (OEH 2017a). Records with an accuracy over 1 kilometre were discarded, leaving 582 valid records. Of these, 500 records (86%) had an accuracy of 100 metres or less.

Koala records were clipped to the map of high-quality and non-high-quality koala habitat with a 100-metre buffer. The buffer was included so that koala records on roads that intersect with HQH were classified as HQH rather than non-HQH. The percentage of records on identified HQH and non-HQH was calculated.

3.4.4 Association with preferred koala-use trees

A list of preferred koala-use trees in the Wollondilly LGA was determined through radio tracking eight collared koalas, as part of the Wollondilly Koala Conservation Project (OEH unpublished data). Weekly diurnal and nocturnal observations of radio-collared koalas were undertaken for up to six months. Tree species, diameter at breast-height and tree height were recorded for each direct koala observation. Individual koalas were observed between 30 and 53 times in the field. Data for two females (named Daenerys and Ellaria) with lower numbers of observations and overlapping home ranges were combined. Data from one koala was excluded due to insufficient data. Trees that were used at least 15% of the time by at least one koala were identified as preferred koala-use trees.

The canopy species for each vegetation community within the study area were listed as described in the associated technical report for each relevant vegetation map (DEC 2004; NPWS 2003; OEH 2013; Tozer et al. 2003). Identified preferred koala-use trees for Wollondilly LGA were highlighted for each vegetation type, and the number of preferred tree species per vegetation type counted. The number of vegetation communities with preferred koala trees and the average number of preferred koala trees was then calculated for sandstone vegetation communities and shale/shale-enriched vegetation communities.

3.5 Delineating koala movement corridors

We identified the most important connections of koala habitat in the region and defined these as primary, secondary and tertiary movement corridors. This was done by joining large patches of HQH areas, including or excluding habitat within or adjacent to these joined patches, then categorising these by the strength of links within and between connections, according to the following rules:

- HQH patches greater than 100 hectares (ha), with known koala feed-tree species and records of koalas, were identified as 'core' habitat. Tracking of koalas in the region has shown that 100 ha is sufficient to support the home range of at least one male koala and multiple females. In this region, the average home-range size of tracked koalas is 94 hectares, with males averaging 114 ha (n = 8) and females averaging 38 ha (n = 3) (unpublished OEH data from the Wollondilly and Southern Highlands Koala Conservation Projects).
- Patches of 'core' habitat separated by more than 1 kilometre (km) by cleared land were excluded from movement corridors. This 1 km threshold was sourced from the maximum distances of open land crossed by tracked koalas during the Wollondilly and Southern Highlands Koala Conservation Project (OEH unpublished data).
- Smaller patches of HQH within 100 metres (m) of 'core' habitat were included as part of movement corridors.
- Patches of MQH or LQH that were between 'core' habitat, or were entirely within 'core' habitat, were included as part of movement corridors.
- MQH or LQH patches peripheral to the corridors were not included in corridors.

- Scattered trees were included when they were completely or largely contained within corridors.
- Scattered trees peripheral to corridors will be used by koalas, but these were identified as ‘supporting’ habitat and excluded from corridors.
- Strips of HQH less than 200 m wide and less than 2 km long that led into the low-quality sandstone habitat of the Woronora Plateau surrounds were truncated (i.e. not mapped).

Identified corridors were then categorised into primary, secondary, and tertiary rankings.

- Primary corridors were those that contained ‘core’ koala habitat which were contiguous (gaps between trees less than 100 m) and were greater than 380 ha in size.
- Secondary corridors were those that contained ‘core’ habitat patches and smaller habitat patches or scattered trees that were separated by more than 100 m (were not contiguous), or were narrow or had pinch points less than 50 m wide and contained between 100 ha and 380 ha of ‘core’ habitat. Secondary corridors sometimes comprised ‘core’ habitat that totalled more than 380 ha and were wider than 50 m, but where this was the case, they were classified as secondary corridors if they did not connect to primary corridors on both ends.
- Tertiary corridors were those that contained patches of HQH that were poorly linked to primary corridors, contained between 30 ha and 100 ha of HQH, and did not connect to primary corridors on both ends. Tertiary corridors sometimes contained more than 100 ha of habitat, but where this was the case, they were classified as tertiary corridors if they did not connect to other corridors on both ends.

The corridor network was broken down into sub-catchments and named accordingly; e.g. Georges, Nepean, Cataract, and Allens Creek corridors. In the digital layer, each corridor was attributed its name; classification as a primary, secondary or tertiary corridor; the width of its connection to a primary corridor; its width at the narrowest point; and source layer.

Cleared land was excluded from mapped movement corridors, despite cleared land forming part of movement corridors. Rehabilitation of cleared land is a priority for improving corridor function.

3.6 Validating koala movement corridors

The koala movement corridor map developed for this report was validated by comparing it with a generalised linear model of koala habitat and associated corridor map (DECC 2007). The 2007 corridor habitat model was laid over the newly-defined corridors from this study and correlation between the pathways was identified. The DECC (2007) layer is a computer-based spatial interpolation (S-PLUS and ArcGIS Spatial Analyst) of koala corridors generated from known sightings of koalas modelled with environmental variables (DECC 2007). The layer products cover the Greater Southern Sydney region, which includes the current study area, and were derived at a scale of 1:25,000. These maps and the modelling process have been extensively reviewed, and the habitat model features in a peer-reviewed publication (Lunney et al. 2010). The dataset used to derive the 2007 model was independent from the dataset used to create the current layers; therefore, it is suitable as a validation tool for the current corridor layer.

3.7 Calculating koala numbers and densities in corridors

To demonstrate the relative importance of the individual movement corridors for koalas, we extrapolated koala numbers potentially supported in each of the movement corridors based on the amount of available habitat. Extrapolations were based from a density estimate using data collected from 67 systematic, 2 ha spotlights surveys undertaken within the identified corridors as part of the Wollondilly Koala Conservation Project (Figure 7). Koala density was calculated based on koalas directly observed in the 2 ha survey areas. No indirect calculations via scats, and/or scratches were made. Density was calculated by dividing the total number of koalas observed (7 koalas) by the search area (67 x 2 ha).

Although used by koalas, cleared land, scattered trees and regrowth areas around core koala habitat areas were excluded for these calculations. Therefore, this is a conservative, minimum estimate of koala numbers for corridors. Note that figures for the Georges River corridor were not calculated because this is mostly outside the Wollondilly LGA and there were insufficient presence–absence spotlighting sites to incorporate into this report.

4. Results

4.1 Core koala habitat

Core koala habitat in the Wilton and Greater Macarthur Growth Areas (GAs) is shown in Figure 1. Koalas in the area are living in an increasingly fragmented landscape. Strongholds for the koala metapopulations of the Campbelltown and Wollondilly Local Government Areas (LGAs) are large patches of core habitat on the eastern edge of the Cumberland Plain. The remaining areas of shale sandstone transition forest along the Nepean River and its major tributaries provide the only other core habitat for koalas in these areas. This habitat is more limited in extent and linear in configuration. However, it supports significant numbers of resident koalas and is therefore vital to the persistence of the regional koala population.

Figure 1 Core and supporting koala habitat in the Wilton and Greater Macarthur Growth Areas. Note that koala records shown are sightings and do not indicate koala densities.

4.2 Validation of high-quality koala habitat

4.2.1 Floristic validation

High-quality koala habitat validated well against the 143 new floristic plots. There was good agreement between the mapped high-quality habitat (HQH) and the koala feed trees identified in the floristic plots.

4.2.2 Systematic presence–absence spotlighting data

There was a strong correlation between koalas recorded during spotlighting surveys and areas classified as HQH (Table 2 and Figure 2). Of the 173 sites surveyed, 16 koalas were observed and 13 of these were recorded in HQH. Koala densities were significantly higher in mapped HQH than in non-HQH (chi-square = 5.4161, df = 1, p = 0.01995). The other three koalas were recorded in vegetation communities not classified as HQH. However, two of these three koalas were observed 150 metres or less from areas identified as HQH. This is likely to reflect under-mapping of the shale-influenced vegetation types, which is coarser in the southern part of the study area.

Table 2 Koala density estimates calculated using spotlight data from high-quality and non-high-quality habitat

	2-hectare Spotlight surveys (n =)	Koalas observed on spotlight (n =)	Estimated koala density/hectare	Estimated koalas per 100 hectares
High-quality habitat	83	13	0.078	7.8
Non-high-quality habitat	90	3	0.017	1.7

4.2.3 Incidental koala sightings

Of the 582 valid koala sighting records, 499 (86%) were recorded in HQH, confirming the results of previous studies in the region (Figure 3). It should be noted that incidental records collated in BioNet are often biased, with an over-representation of records in areas with high human–wildlife interaction or high visibility (i.e. areas where koalas are easier to see). However, koala sightings supported the assumptions underpinning the classification of vegetation communities as HQH or non-HQH for koalas.

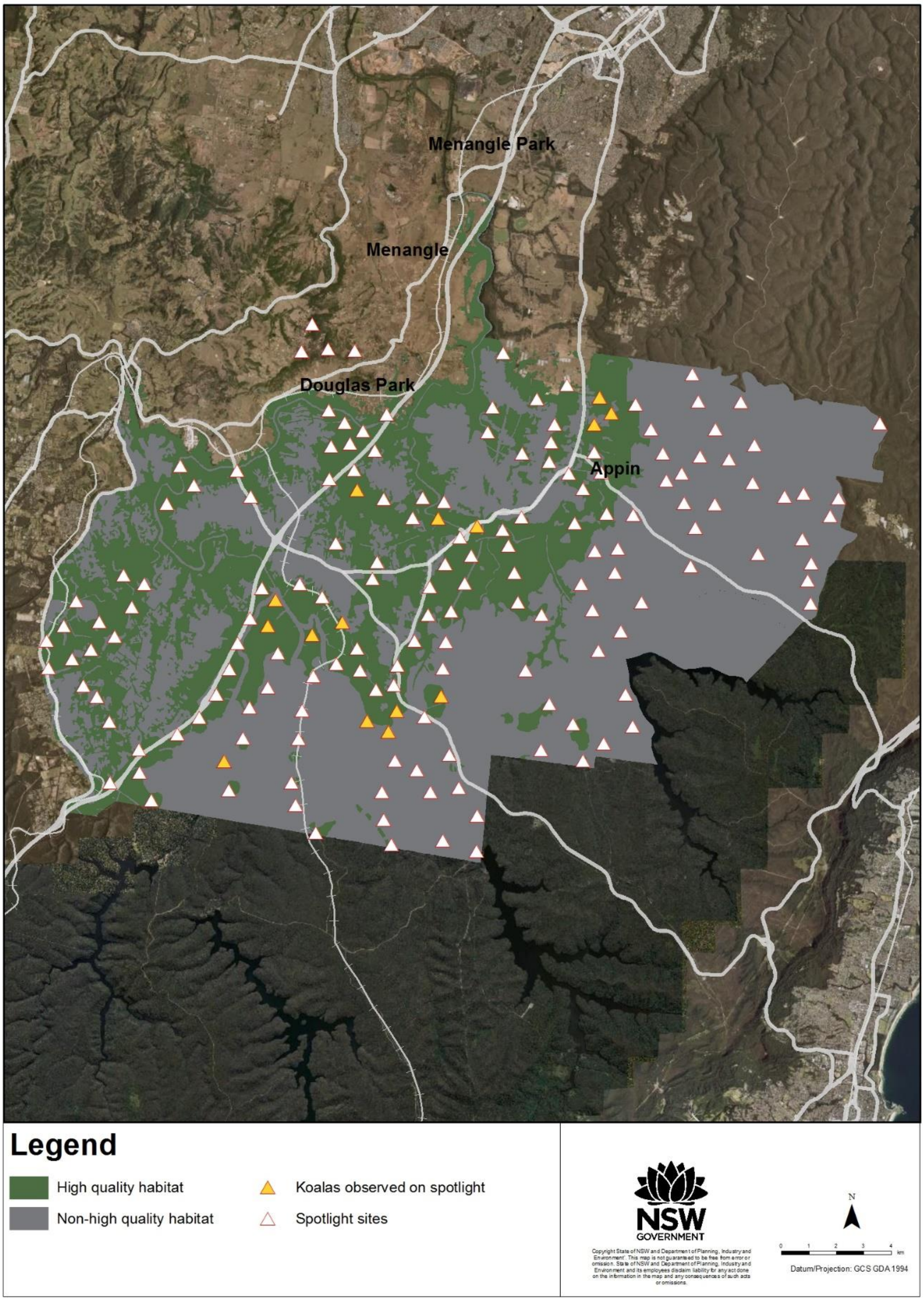


Figure 2 **Spotlighting sites and positive koala records within the Wollondilly East Study Area.**

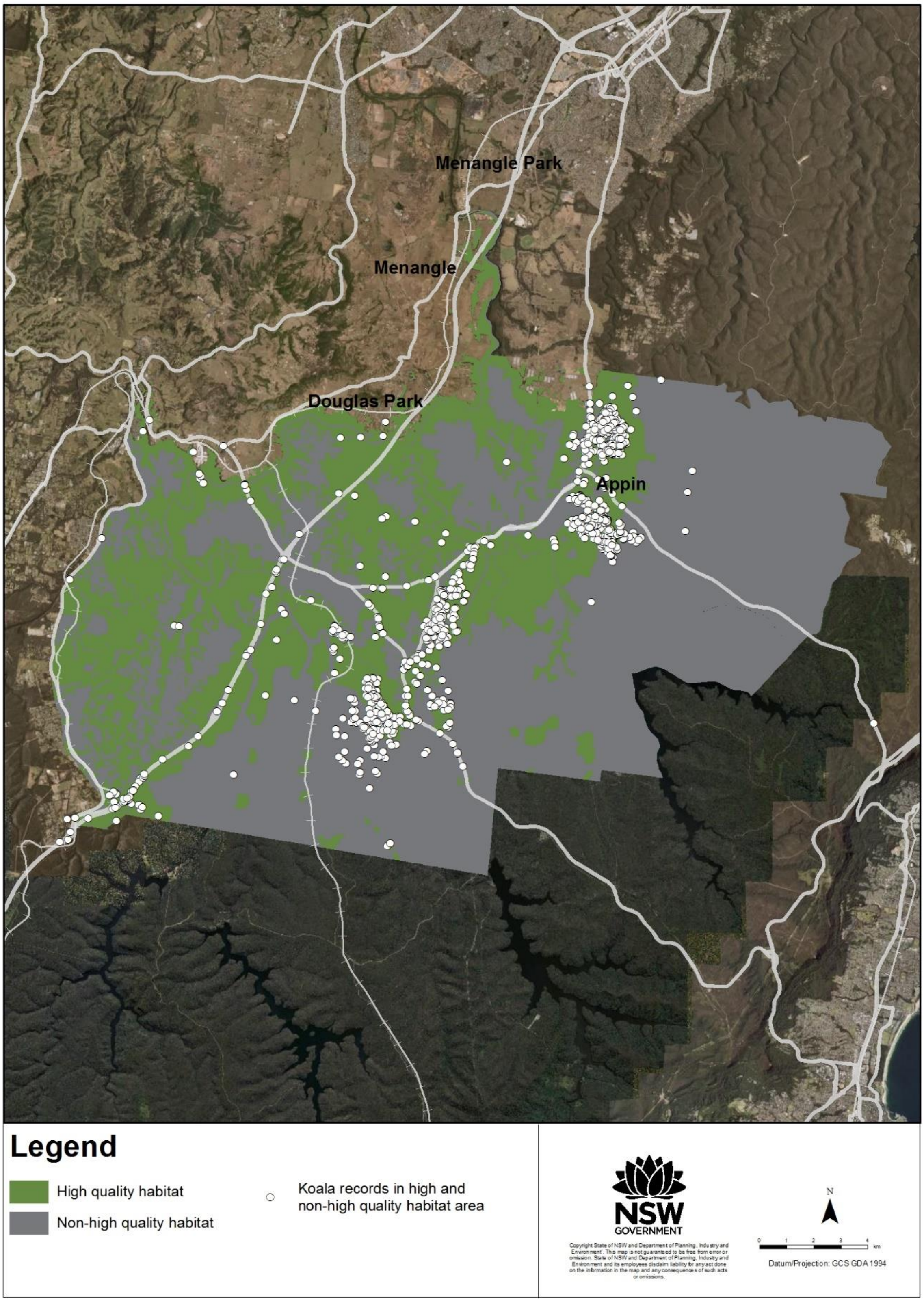


Figure 3 All koala records intersected with high-quality and non-high-quality koala habitat. Note that koala records shown are sightings and do not indicate koala densities.

4.2.4 Association with preferred koala use trees

A total of 243 observations of radio-tracked koalas revealed the animals used 22 different tree species, with each individual using between 5 and 12 species (Table 3). The observations indicate that each radio-tracked koala used two to four preferred tree species (trees used at least 15% of the time by at least one koala). Using this measure, seven preferred koala-use trees have been identified from the koala radio-tracking data (Table 4).

Table 3 Observed and percentage tree-use by individual koalas

Tree species	Koala name/s											
	Daenerys/Ellaria		Gendry		Hodor		Ilyn payne		Jon snow		Khal drogo	
	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%
Acacia (A.) decurrens											8	15.1
A. floribunda											2	3.8
Corymbia gummifera	1	3.2					1	2.6	1	2.6	1	1.9
Eucalyptus (E.) amplifolia											3	5.7
E. beyeriana	2	6.5	1	3.3	3	5.7	1	2.6				
E. bosistoana					1	1.9					3	5.7
E. crebra			1	3.3	1	1.9					3	5.7
E. eugenoides											1	1.9
E. fibrosa	3	9.7	1	3.3	4	7.5	1	2.6				
E. globoidea	3	9.7	5	16.7	5	9.4	8	21.1			12	22.6
E. longifolia	2	6.5	9	30	23	43.4			1	2.6		
E. mollucana			1	3.3								
E. oblonga	2	6.5	3	10			5	13.2				
E. paniculata	5	16.1			1	1.9					3	5.7
E. pilularis	1	3.2							20	52.6		

Tree species	Koala name/s											
	Daenerys/Ellaria		Gendry		Hodor		Ilyn payne		Jon snow		Khal drogo	
	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%
E. piperita							2	5.3			1	1.9
E. punctata	6	19.4	8	26.7	15	28.3	18	47.4	13	34.2	8	15.1
E. quadrangulata	3	9.7										
E. resinifera			1	3.3			1	2.6	1	2.6		
E. sclerophylla	1	3.2					1	2.6				
E. seiberi	2	6.5										
E. tereticornis											8	15.1
Total	**31**		**30**		**53**		**38**		**38**		**53**	

Notes: Orange indicates that more than 15% of observations for an individual koala were recorded in a particular tree species, and associated tree species are highlighted in green.

Table 4 Preferred koala-use trees in the Wollondilly study area

Species	Common name
Eucalyptus (E.) punctata	Grey gum
E. globoidea	White stringybark
E. longifolia	Woollybutt
E. tereticornis	Forest red gum
E. paniculata	Grey ironbark
E. pilularis	Blackbutt
Acacia decurrens	Green wattle

The number of species of preferred koala-use tree (PKT) was calculated for each vegetation community, with a range of between zero and six PKTs identified for each community (Appendix 1). There was a strong correlation between shale-influenced vegetation communities and presence of PKT: 15 of 16 shale-influenced vegetation communities contained at least 1 PKT, with an average of 2.4 PKTs per community. In contrast, 5 of 18 sandstone vegetation communities contained a PKT, with an average of 0.5 PKT per vegetation community.

4.3 Koala movement corridors

The primary, secondary and tertiary koala movement corridors are shown in Figure 4. Koala movement corridors have further been mapped and named according to sub-catchments (Figure 5). Each corridor was ranked as primary, secondary or tertiary, based on the area of core koala habitat it contained, width, and level of connectivity (see Section 3.5 and Table 5).

As for core koala habitat in the area (Figure 1), the primary corridor identified for the persistence of koalas ran continuously along the eastern edge of the Cumberland Plain from Campbelltown through Wedderburn and the eastern part of Appin, crossing Picton Road south of Wilton and skirting the southern edge of the Wilton GA (Figure 4).

The koala movement corridors did not extend into sandstone country, as native vegetation on sandstone derived soils is not considered HQH for koalas. The primary corridor on the east was directly and continuously linked with other primary corridors along the Nepean River, Allens Creek and Cataract Creek north to Menangle. Secondary corridors linked the Nepean corridor with the Georges River across the Greater Macarthur GA.

The configuration of the remaining core habitat in this region presents significant challenges for maintaining connectivity for the population. Residential development in much of the area between core habitats will place significant pressure on the smaller, narrower corridors that link koala populations.

4.4 Validation of koala movement corridors

The koala movement corridors validated well against the independently derived generalised linear model (GLM) of koala habitat/linkage. There was a high degree of overlap (approximately 80%, although this was not formally calculated) between the GLM of koala habitat/linkage and the new corridor map despite different vegetation mapping base layers and koala presence information (Figure 6). Note that the GLM of koala habitat/linkage was completed at a larger scale, so would not include smaller corridors newly mapped.

Table 5 Extent of core koala habitat within koala movement corridors and rankings for corridors

Corridor name	Corridor rank	Habitat	Area of core habitat (hectares)
Nepean	Primary	Core	1742.58
Allens	Primary	Core	1235.17
Wallandoola–Cataract	Primary	Core	1193.03
Avon–Nepean	Primary	Core	1089.23
Cordeaux	Primary	Core	628.64
Cascade	Primary	Core	605.28
Cataract	Primary	Core	381.38
Sub-total			**6875.31**
Ousedale–Mallaty	Secondary	Core	390.08
Simpsons–Elladale	Secondary	Core	255.31
Woodhouse–Menangle	Secondary	Core	220.33
Noorumba	Secondary	Core	122.01
Clements	Secondary	Core	107.86
Sub-total			**1095.59**
Stonequarry	Tertiary	Core	124.15
Myrtle	Tertiary	Core	84.48
Strongybark	Tertiary	Core	78.43
Leafs Gully	Tertiary	Core	34.52
Sub-total			**321.58**
Total	**All**		**8292.46**

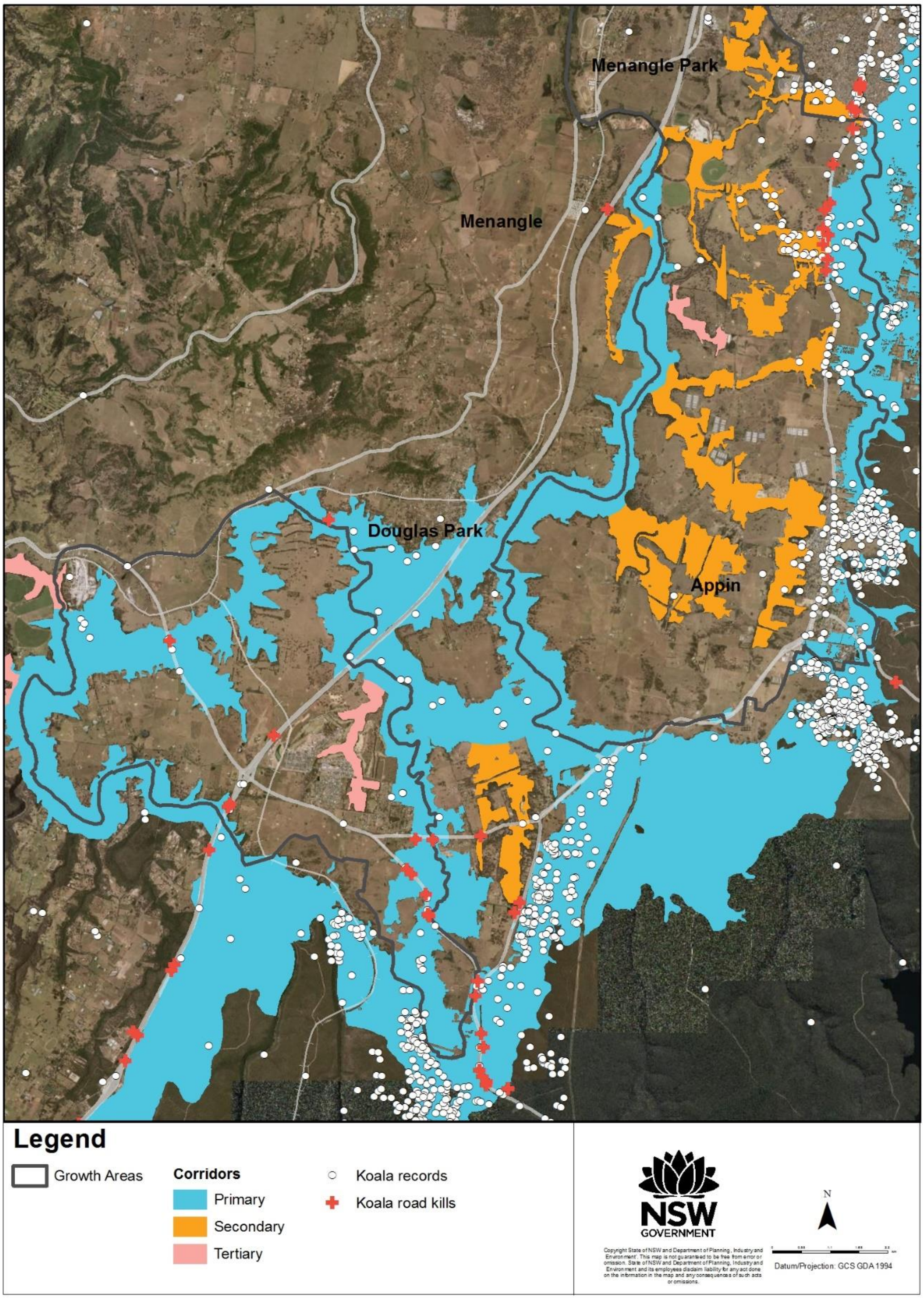


Figure 4 Rankings for koala corridors across the Wilton and Greater Macarthur Growth Areas. Note that koala records shown are sightings and do not indicate koala densities.

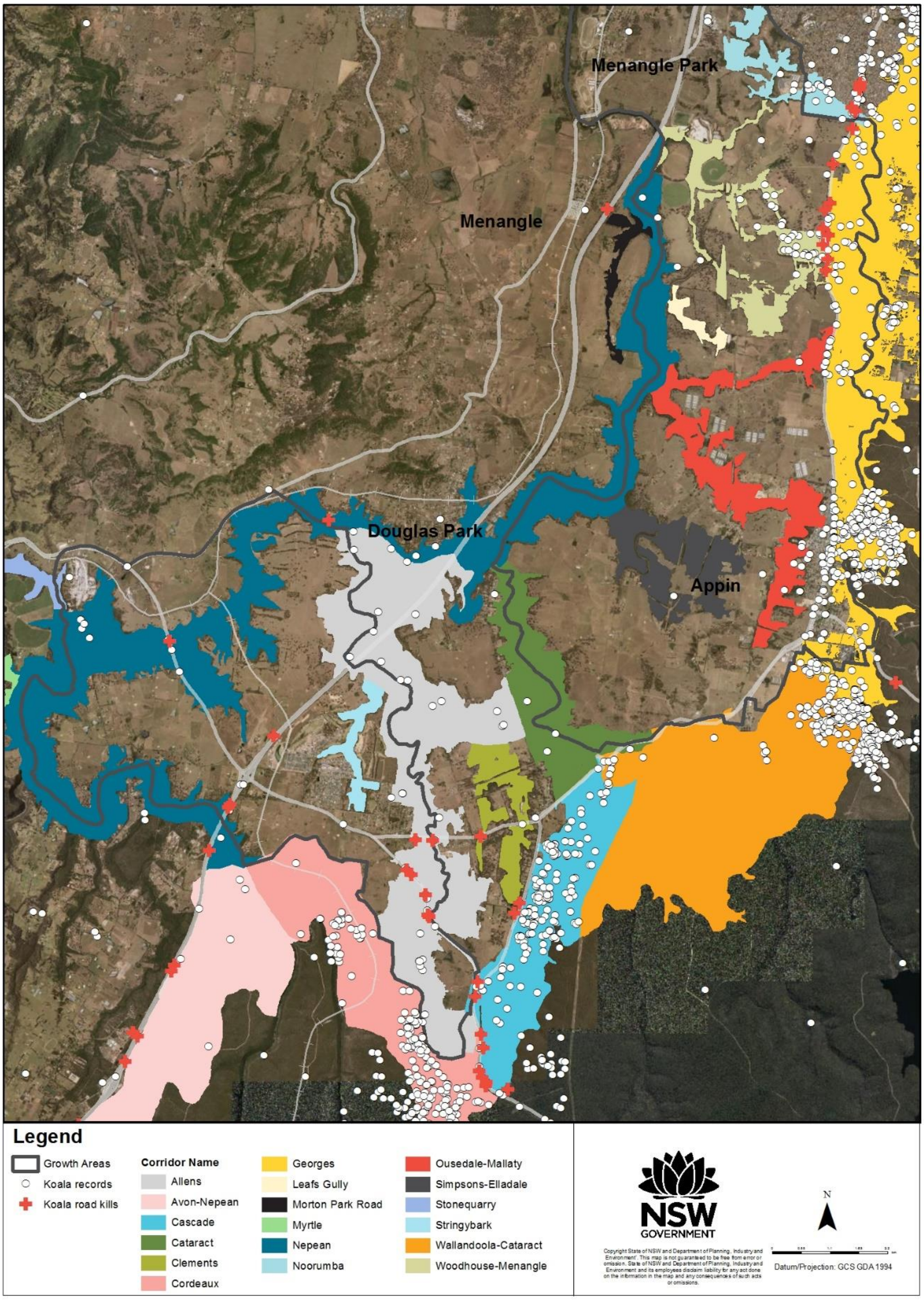


Figure 5 The 17 koala movement corridors across the Wilton and Greater Macarthur Growth Areas. Note that koala records shown are sightings and do not indicate koala densities.

Figure 6 Comparison of the generalised linear model (GLM) of koala habitat/linkage and the new corridor map.

4.5 Koala densities and numbers in corridors

Table 6 lists the amount of core koala habitat and estimates of koala numbers potentially supported by each identified movement corridor based on available habitat and the density estimate (0.052 koalas/hectare) calculated from the spotlight surveys of koalas shown in Figure 7. Primary corridors contained a significant amount of core koala habitat (6,875.31 ha), providing habitat for at least 359 koalas. Secondary and tertiary corridors contained less core koala habitat and therefore lower estimated densities of koalas. Primary corridors are key for the extent and stretches of contiguous habitat they provide. They need to be protected and enhanced for their value in connectivity and as important koala habitat in their own right.

Figure 5 shows the names and locations of the individual koala corridors identified in Table 6. The most important corridor in regard to the amount of core koala habitat, the highest densities of koala potentially supported, and largest and longest link across the GAs was the Nepean corridor (1742.58 ha and 91 koalas). The Allens Creek and Cataract corridors, which are key links between the Nepean corridor and intact bushland to the east (towards the Cordeaux, Cascade, and Wallandoola–Cataract corridors), also contained large amounts of core koala habitat and potentially supported 64 and 20 koalas, respectively. Although this analysis was not undertaken on the Georges corridor, this corridor is known to be important as a key component of the main north–south corridor which links the known Campbelltown koala population with the Wollondilly koala population and the Southern Highlands population further south.

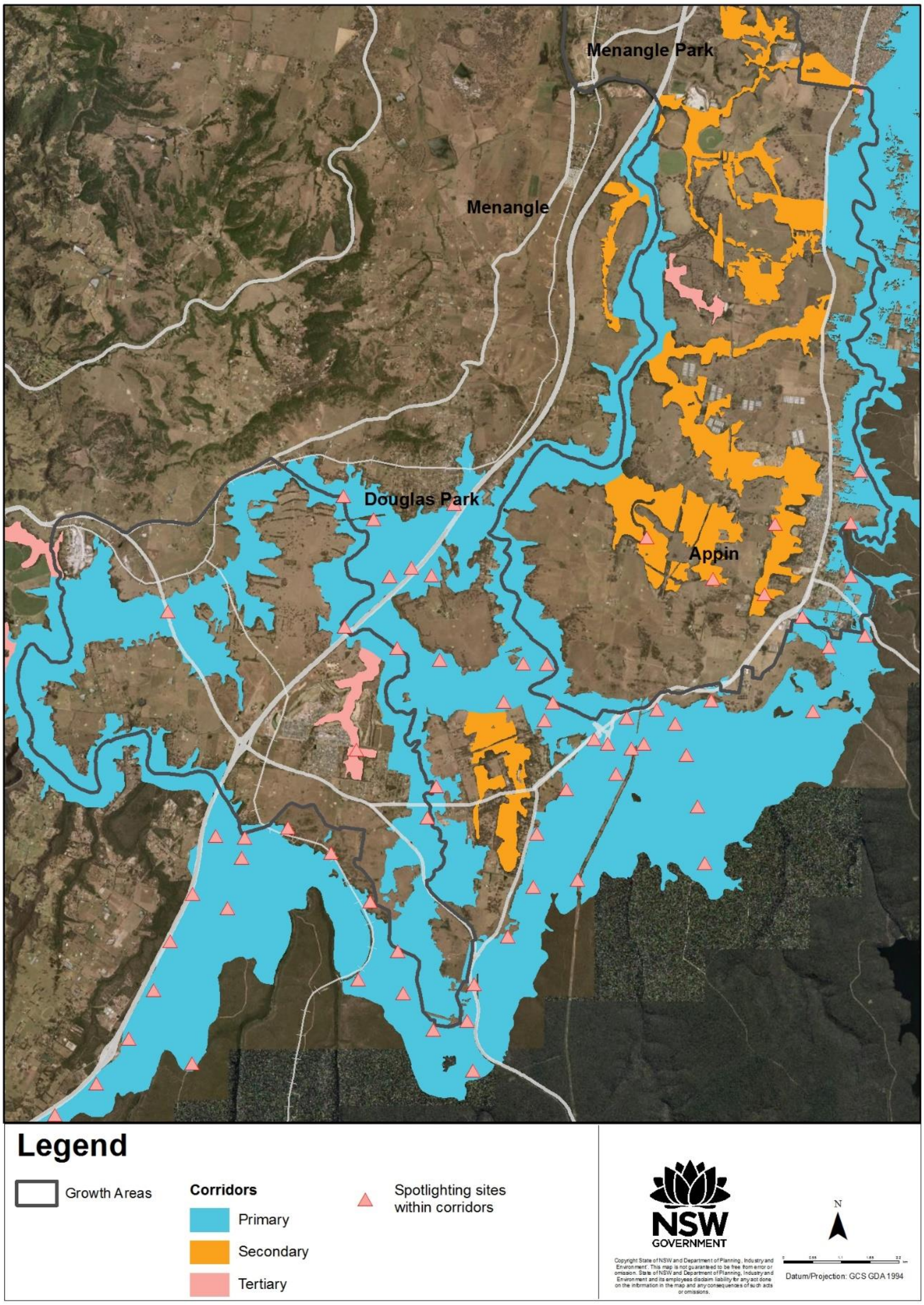


Figure 7 Map of systematic spotlight surveys for koalas within the corridors of the Wilton and Greater Macarthur Growth Areas used to estimate koala densities and extrapolate koala numbers.

Table 6 **Extent of core koala habitat and estimated koala numbers within corridors based on a density estimate of 0.052 koalas/hectare**

Corridor name	Corridor rank	Habitat	Area of core habitat	Extrapolated koala numbers based on habitat extent
Nepean	Primary	Core	1742.58	91
Allens	Primary	Core	1235.17	64
Wallandoola–Cataract	Primary	Core	1193.03	62
Avon–Nepean	Primary	Core	1089.23	57
Cordeaux	Primary	Core	628.64	33
Cascade	Primary	Core	605.28	32
Cataract	Primary	Core	381.38	20
Sub-total			**6875.31**	**359**
Ousedale–Mallaty	Secondary	Core	390.08	20
Simpsons–Elladale	Secondary	Core	255.31	13
Woodhouse–Menangle	Secondary	Core	220.33	12
Noorumba	Secondary	Core	122.01	6
Clements	Secondary	Core	107.86	6
Sub-total			**1095.59**	**57**
Stonequarry	Tertiary	Core	124.15	6
Myrtle	Tertiary	Core	84.48	4
Strongybark	Tertiary	Core	78.43	4
Leafs Gully	Tertiary	Core	34.52	2
Sub-total			**321.58**	**16**
Total			**8292.46**	**433**

5. Principles and recommendations for koala conservation in Wollondilly and Campbelltown

South-western Sydney is facing large-scale land-use change with the development of the Wilton and Greater Macarthur Growth Areas (GAs). The proposed change from rural to low/medium density residential development across the GAs has significant implications for the koalas of this area.

Notwithstanding the implementation of measures to avoid, minimise and reduce impacts, major residential development in the GAs would result in:

- the direct loss of core and supporting koala habitat, and potentially habitat fragmentation, resulting from the upgrade of existing principal roads into the new residential areas, as well as from new roads and other urban development
- an increased urban interface with koala populations
- increased traffic volumes
- increased indirect impacts to koala habitat through more frequent fire, weed incursion, feral pests, domestic animals, light spill, noise and rubbish dumping.

The direct loss of core and supporting koala habitat and any subsequent habitat fragmentation would have the most significant impact on koalas in the area. It has been demonstrated that as areas of habitat for koalas are reduced, koala population sizes are directly impacted, and the likelihood of local extinction increases. The survival of metapopulations relies on the ability of animals to recolonise habitat patches where a sub-population has become extinct. For koala populations to thrive and maintain genetic biodiversity, habitat must remain intact and available for koalas to disperse.

Increased urban interfaces, traffic volumes, and disturbance would also significantly impact koalas. Higher traffic volumes would result in a greater risk of koala–vehicle collisions and koala roadkill. Increased urban interfaces would lead to a rise in interactions with people, houses, pools, domestic dogs and vehicles, in turn potentially leading to koala stress, injury, or death. Exposure to novel and prolonged stressors, such as those associated with human-induced landscape change, has the potential to suppress immune function in koalas, thereby increasing their susceptibility to diseases such as chlamydia.

The most rapid declines in koala numbers in New South Wales and Queensland have been in the high-density urban and remnant source populations, which are undergoing rapid conversion from agriculture to urban environments (McAlpine et al. 2006a; Adams–Hosking 2017). High rates of mortality associated with development and dogs were found for radio-tracked koalas in an urban area of Queensland (Redlands City; de Oliveira et al. 2013). A Queensland study found that koalas were unable to successfully disperse through urban areas due to attacks by domestic dogs and collisions with vehicles (Dique et al. 2003). McAlpine et al. (2017) found that landscape change influences the susceptibility of koala to disease, and that urbanisation is associated with an increased prevalence of chlamydia. The impact of chlamydia on koala populations may not be evident for several years, until there is a reported impact on reproductive success.

5.1 Principles and recommendations

We have assessed existing and new information on koalas, including the identification of core koala habitat and koala movement corridors in southern Campbelltown, and around Appin and Wilton (Section 3), as well as the relative importance of koala corridors in terms of their positions in the landscape, estimated koala density and available core koala habitat (Section 4). In combination with this information, an assessment of the known threats to koalas in the area, and the extent of proposed development in the GAs and their impacts, we have designed a strategy to conserve the koala metapopulations in the Wollondilly and Campbelltown Local Government Areas (LGAs).

Underlying the strategy are four key principles:

1. avoid new residential development within core koala habitat and primary corridors
2. separate residential development and koala populations to minimise ongoing threats from domestic dogs and vehicles
3. identify critical revegetation zones that will augment and strengthen core habitat and corridors
4. identify koala roadkill hotspots requiring road-kill mitigation fencing and/or underpasses to allow safe passage of koalas.

These principles generally align with existing koala principles or guidelines, such as the Planning Guidelines for Koala Conservation and Recovery: A Guide to Best Planning Practice (McAlpine et al. 2006b) prepared to help land managers plan for the long-term conservation of koalas. The guidelines recommend that:

- the maintenance and protection of networks of koala habitat patches and corridors linking blocks of koala habitat be of highest priority
- approval bodies ensure development does not further fragment koala habitat areas by removing habitat/linkage areas or imposing significant threats to koalas
- development and roads are separated from koala habitat, and potential conflict between threats such as dogs are minimised – the presence of koalas is greatly reduced by high road densities, especially in areas within or adjacent to koala habitat
- approval bodies for development encourage koala habitat restoration and avoid internal fragmentation of koala habitat patch and linkages, and reductions in tree density
- sufficient structural diversity in koala habitat is maintained – while feed trees, soil fertility and water availability are the most important determinants of koala habitat quality, the presence of factors such as large trees, species diversity, and structure can enhance koala habitat quality
- larger koala habitat patches and wider corridors are better – patches should have low perimeter-to-area ratios to decrease edge effects since for koalas, edge effects may lead to increased predation risk by dogs or increased stress leading to disease
- blocks of koala habitat and corridors linking these be kept free from barriers to koala movement – where there are known black-spot areas, it recommends constructing exclusion fencing.

Next we outline our strategy and management recommendations to conserve the koala metapopulations in the Wollondilly and Campbelltown LGAs in line with the four key principles.

5.1.1 Avoid development within core habitat and primary corridors

All development within core koala habitat and primary corridors should be avoided. As outlined above, the direct loss of core koala habitat and habitat fragmentation would have the biggest impact on koalas in the area. Koala populations operate at the landscape level and require habitat connectivity for animal movement, particularly in the spring breeding season. This connectivity is also important for the dispersal of young animals or animals recolonising areas where a metapopulation has gone extinct.

Development in currently cleared areas adjacent to primary corridors should also be avoided. Primary corridors, particularly to the east of Appin Road adjacent to the Greater

Macarthur GA and in the south-east section of the Wilton GA, are currently mapped adjacent to cleared areas (Figures 5 and 6). These cleared areas have been excised from the primary corridors as they do not currently support core koala habitat and koala records; they have been historically cleared of core koala habitat. Nevertheless, koalas will traverse cleared areas. In this context, cleared areas adjacent to primary koala corridors could be informally considered part of primary corridors (outside of criteria used to categorise corridors). Key areas of cleared land adjacent to primary corridors where development is to be avoided include those to the east of Appin Road along the entire eastern length of the Greater Macarthur GA and in the south-east section of the Wilton GA.

5.1.2 Separate residential development from koala habitat and movement corridors

Residential development poses a suite of direct and indirect threats to koalas. Facilitating koala access into residential areas exposes them to novel and more serious threats such as domestic dogs, cars and swimming pools. These persistent threats inhibit long-term koala survival in proximity to urban settlement. 'Koala-friendly urban design', which has been trialled in other locations, is not recommended.

Keeping koalas out of future residential areas in the GAs is key to minimise the direct and indirect threats associated with residential development. Koalas should be excluded in two ways:

- Firstly, residential subdivision should be designed to limit the interface between core habitat and corridors. The integrity of corridors is increased by increasing width, so avoiding housing infill within primary corridors to provide maximum movement potential and minimal disturbance is critical.
- Secondly, where development proceeds adjacent to core koala habitat and movement corridors, fencing and other barrier solutions should be installed to separate koalas from houses and their occupants. Creating access points for residents to enjoy the bush is important to link communities with their landscape, so identifying a small number of well-considered access points will limit the likelihood of koalas traversing residential settlements.

Figure 8 indicates approximate locations where barriers (residential enclave fence) can be added to separate residential areas/development and core koala habitat/corridors in the Wilton and Greater Macarthur GAs.

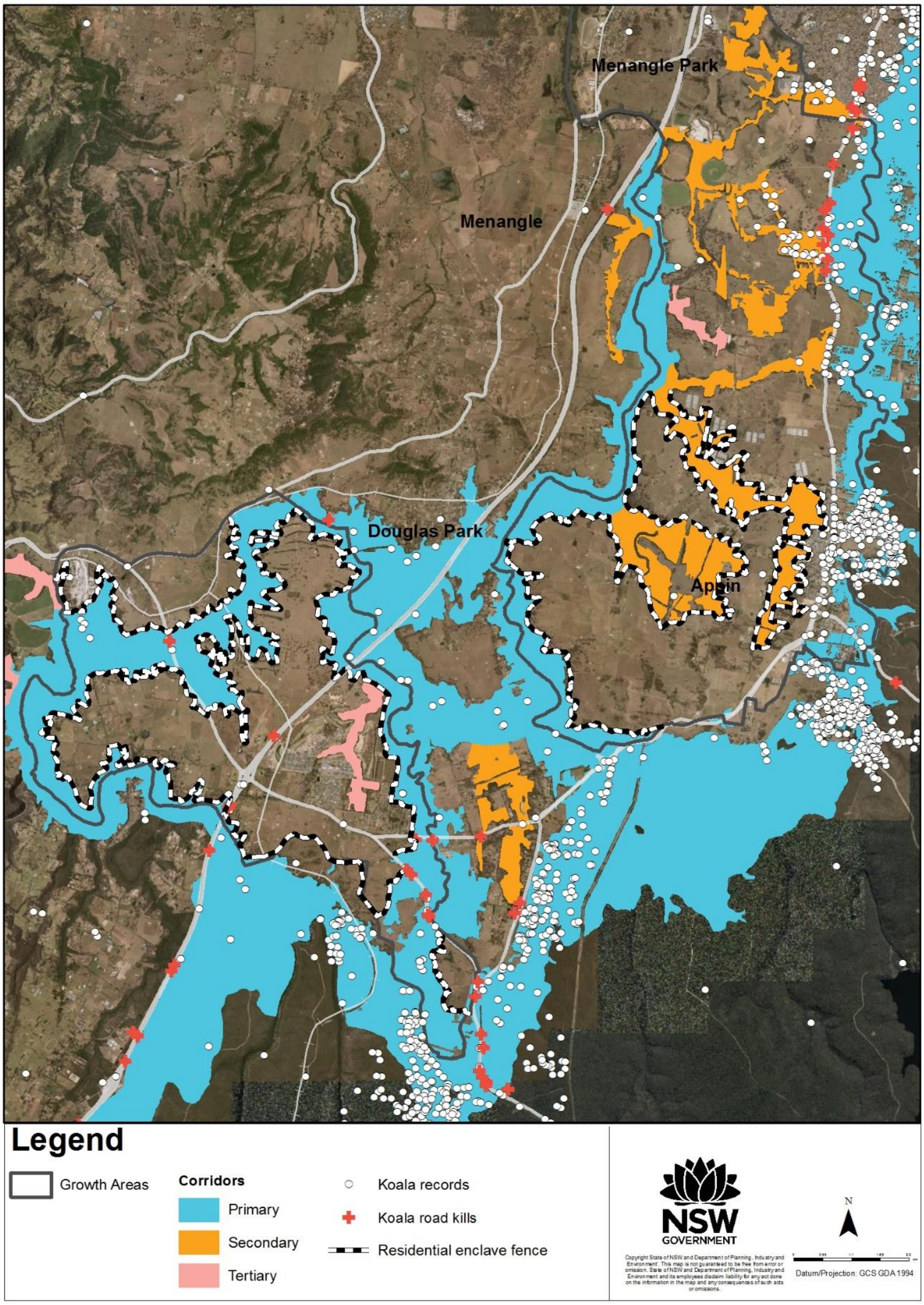


Figure 8 Approximate locations of residential enclave fencing or other barrier solutions where development and core koala habitat/corridors can be separated in the Wilton and Greater Macarthur Growth Areas. Note that koala records shown are sightings and do not indicate koala densities.

5.1.3 Restore and revegetate koala habitat and movement corridors

Wider corridors and larger areas of habitat are superior to narrow corridors and smaller areas of habitat, partly because wider corridors and larger habitat areas have lower perimeter-to-area ratios (less edge effects). Some habitat linkages are compromised or incomplete in some areas due to historical clearing. Some of these areas of core habitat can be augmented and strengthened to widen corridors and increase the area of core habitat. Habitat restoration and revegetation is effective in filling gaps.

When considered along with the principle of separating urban development and koala habitat and corridors, clear priorities for habitat restoration in the Wilton and Greater Macarthur GAs emerge. The highest priority in the Wilton GA is in the south-east section, where core koala habitat surrounds an almost fully enclosed area of cleared land at the beginning of the primary corridor along Allens Creek (Allens corridor) (Figure 9).

Many high-priority restoration areas exist within the Greater Macarthur GA. The most apparent areas are along the length of the eastern side of the GA, to the east of Appin Road, directly adjacent to the Georges River corridor (Figure 9). Additional areas (not shown in Figure 9) include areas to the east of the Ousedale–Mallaty corridor near Appin. Restoring these areas would connect the Ousedale–Mallaty corridor to primary corridors on both ends. The Ousedale–Mallaty corridor is currently connected to a primary corridor (the Nepean corridor) at its western end.

If the identified cleared land was developed rather than restored, this would introduce significant threats and compromise these adjacent corridor values. Conservation of the regional koala population would be greatly enhanced by restoring the cleared areas to HQH, an outcome that would consolidate and double the width of the existing Allens and Georges River primary corridors and result in a far more sensitive urban design. Although it would take time for trees to grow, koalas are known to use saplings. Indeed, the leaves of younger trees often have higher nutrient levels than older trees.

Protection of the vegetation and restoration of the degraded areas could potentially be funded through biodiversity offset arrangements for other developments or major projects in Western Sydney. There is strong demand in the market for biobank/biodiversity stewardship agreement sites in Western Sydney.

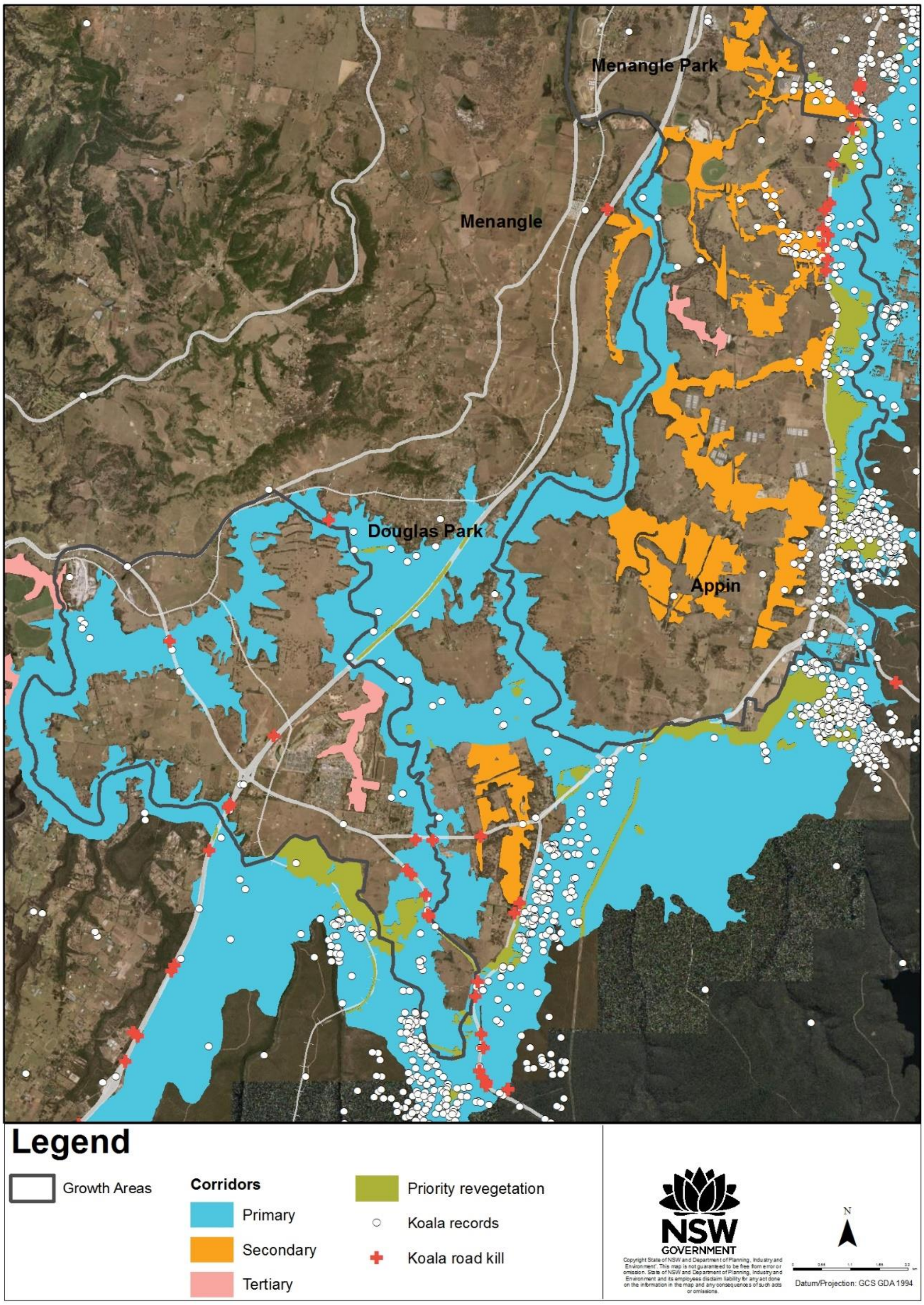


Figure 9 Key areas for restoration in the Wilton and Greater Macarthur Growth Areas. Note that koala records shown are sightings and do not indicate koala densities.

5.1.4 Prevent koala roadkill

Koala roadkill is a highly visible and increasing threat to koalas in the Campbelltown and Wollondilly LGAs. Much of the remaining core koala habitat is intersected by major roads, with the Hume Motorway, Picton Road, Wilton Road, MacArthur Drive and Appin Road all traversing areas of core habitat and primary corridors. Traffic on Picton and Appin Roads has rapidly increased over the last 5 years and with this there has been an increase in the number of koala roadkill incidents. With land-use changes and further increases in traffic, the number of koalas being hit, injured and killed will continue to rapidly increase unless there is significant investment in roadkill mitigation. Increases in koala roadkill will potentially affect the viability of the population. This has been demonstrated in koala populations elsewhere (Polak et al. 2014). Widening and upgrades of major arterial roads provides an opportunity to implement roadkill mitigation measures, which will help slow the decline of koalas in the area (Polak et al. 2014).

Roadkill hotspots have been identified based on collation of records in the NSW Wildlife Atlas (OEH 2017a; Figure 10). Hotspots have been identified as stretches of road with greater than four roadkill koala incidents within a two-kilometre stretch. Hotspots are along Picton Road between Cordeaux Dam and Wilton, MacArthur Drive, the eastern end of Wilton Road, and Appin Road between Appin and Campbelltown. Another important hotspot occurs on the Hume Motorway at the Bargo exit, just south of the Wilton GA. These identified hotspots occur where a major road intersects a primary koala corridor, typically at the headwaters of a watercourse.

Options to reduce koala mortality on these roads include exclusion fencing, with improved road underpasses installed along existing gully line underpasses, such as on Allens Creek, to retain connectivity (Figure 10). Exclusion fences could also be installed on the east side of Appin Road (Figure 10). Exclusion fencing and underpasses would require ongoing maintenance, however, fencing is considered the most effective roadkill mitigation measure on major roads. We do not consider signage an effective roadkill mitigation measure on major roads.

5.2 Predicted outcomes

If management recommendations outlined in Sections 5.1.1 to 5.1.4 are implemented, the extent of core koala habitat would increase and koala movement corridors would be consolidated. Koalas would be separated from future residential areas in the GAs and existing roadkill hotspot locations, reducing the threats associated with residential areas and major roads.

Figure 11 illustrates consolidated koala movement corridors post-revegetation and recommended mitigation measures to minimise threats associated with residential areas and major roads. It is noted that as currently cleared areas adjacent to the Wilton GA were restored, additional exclusion fencing would be required (indicated in Figure 11).

Exclusion fencing progressively built along Appin Road would prevent east–west koala movements across the Greater Macarthur GA. Underpass structures would need to be built to provide east–west access to koalas. However, we do not consider the east–west corridors essential for the long-term survival of the regional koala population. Koalas could continue to move through the landscape via primary movement corridors, rather than via the east–west secondary corridors. The distance from the top of the Georges corridor to the Cataract corridor is approximately 15 kilometres and is within the distance that koalas can disperse. Allowing koalas access to the secondary corridors would expose them to threats associated with residential areas and would be inconsistent with the second key principle of our strategy to conserve these koala populations (to separate koalas from residential areas).

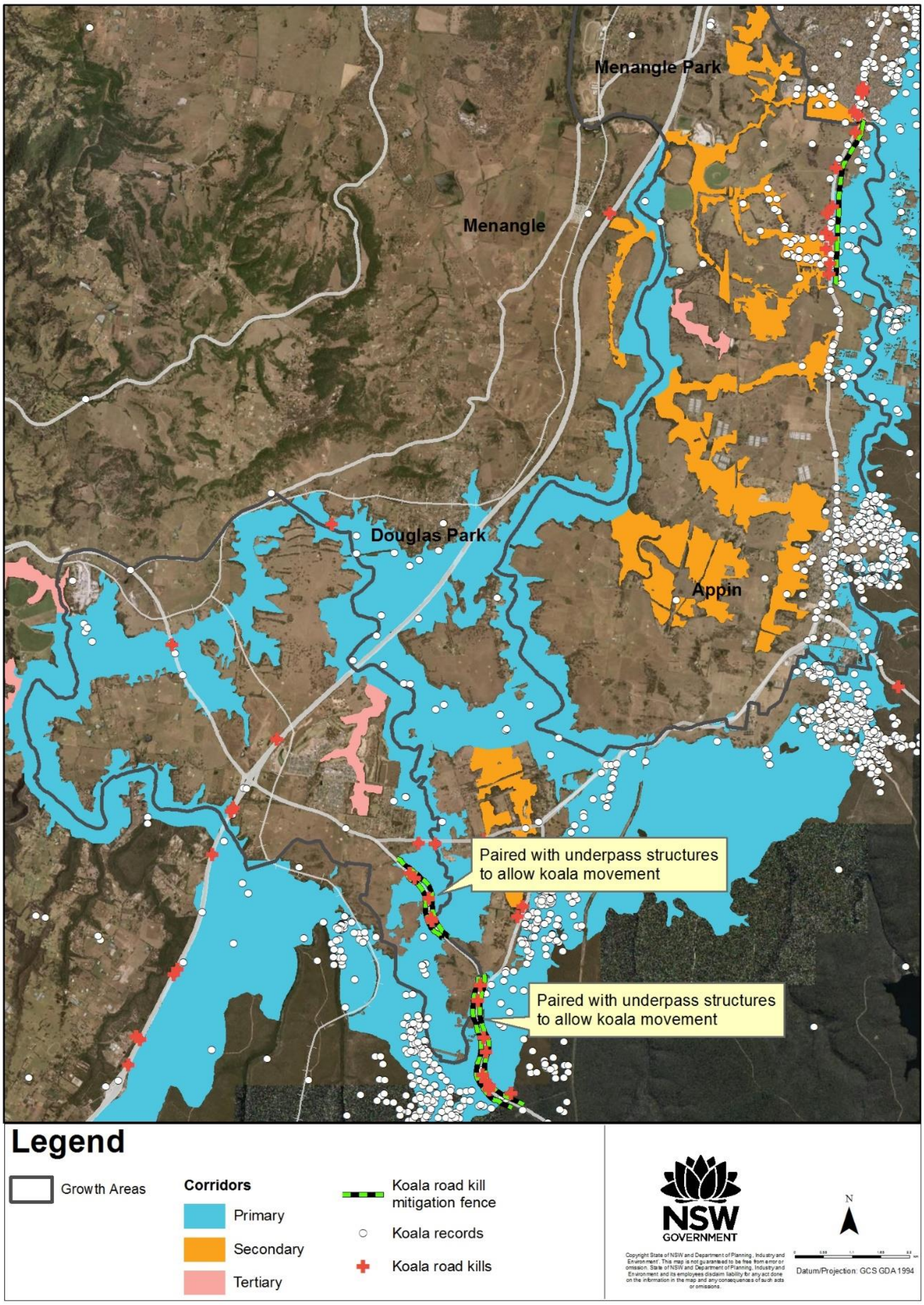


Figure 10 Koala roadkill mitigation infrastructure (fences with some paired with underpass structures) recommended to be implemented in the Wilton and Greater Macarthur Growth Areas. Note that koala records shown are sightings and do not indicate koala densities.

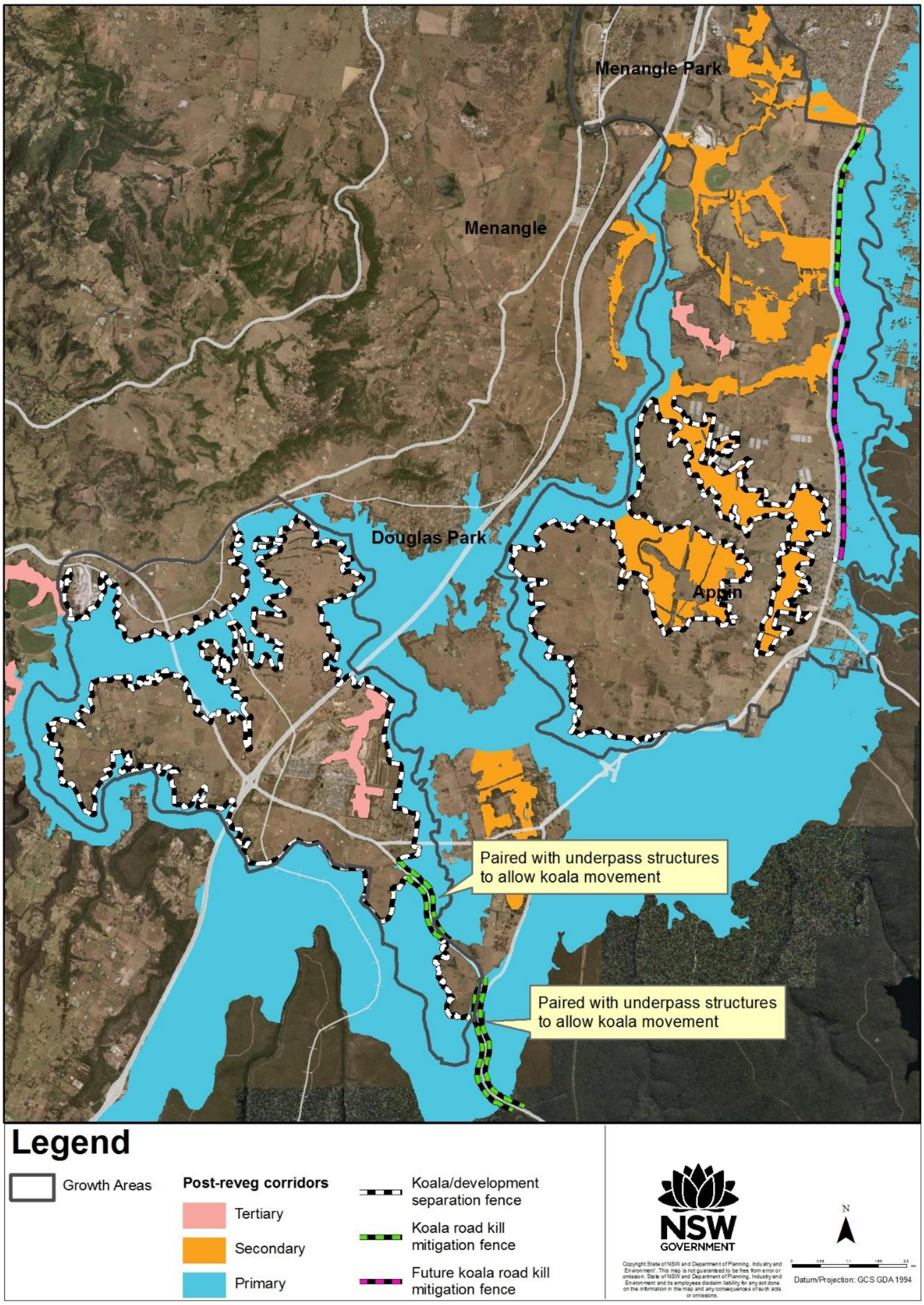


Figure 11 Koala movement corridors post-revegetation and recommended mitigation measures (including separation and roadkill mitigation fences and roadkill mitigation fences paired with underpass structures) in the Wilton and Greater Macarthur Growth Areas.

6. Glossary

High-quality koala habitat: All shale and shale-enriched vegetation types with a dominant eucalypt canopy in the area around the Wilton and Greater Macarthur Growth Areas (GAs).

Medium-quality koala habitat: Eucalypt-dominated riparian sandstone vegetation communities, rainforest vegetation communities on shale with some eucalypts present, and regenerating acacia scrubs on shale in the area around the Wilton and Greater Macarthur GAs.

Low-quality koala habitat: Low-fertility sandstone vegetation communities including heaths, heathy woodlands, swamps and rocky woodlands in the area around the Wilton and Greater Macarthur GAs.

Core koala habitat: Large patches (>100 hectares (ha)) of high-quality koala habitat that contain known koala feed tree species, determined through the Wollondilly and Southern Highlands Koala Conservation Projects, and records of koalas. The SEPP 44 definition of core koala habitat is not used in this document because koalas in the area use a range of tree species not listed in SEPP 44.

Supporting habitat: Scattered trees peripheral to and outside of identified koala movement corridors.

Koala movement corridors: Areas of habitat koalas can move through and potentially use to recolonise other core habitat patches where a metapopulation has gone extinct. Note that koala movement corridors are not necessarily strips of core koala habitat surrounded by cleared areas. Core habitat surroundings may include other intact vegetation that is not favoured by koalas, such as open woodland on sandstone.

Primary corridors: The most important linkages of koala habitat for the koala population in the local area around the Wilton and Greater Macarthur GAs. They contain patches of core koala habitat which are contiguous (gaps between trees are less than 100 metres (m)) and contain over 380 ha of core habitat per named corridor. They are the most important koala habitat in which the bulk of koalas in the area live and breed. The breaking or weakening of primary corridors would have serious ramifications on the long-term viability of koalas in the area, and thereby, the regional koala population.

Secondary corridors: Linkages that contain patches of core koala habitat, smaller habitat patches, and scattered trees separated by more than 100 m (are not contiguous), are narrow or have pinch points of less than 50 m wide, and contain between 100 and 380 ha of core habitat per named corridor. Secondary corridors may include corridors that contain more than 380 ha of habitat or corridors that are more than 50 m wide, if they do not connect to primary corridors on both ends. The retention of secondary corridors is not critical to the long-term viability of the regional koala population; however, enhancement of these corridors would support primary corridors and core koala habitat.

Tertiary corridors: Linkages that contain patches of high-quality koala habitat that are poorly linked to primary corridors, together contain between 30 ha and 100 ha of high-quality habitat per named corridor, and do not connect to primary corridors on both ends. Tertiary corridors may contain corridors that contain more than 100 ha of habitat, but are classified as tertiary corridors if they lead away from other corridors or do not connect to other corridors. Tertiary corridors may be enhanced to provide greater connectivity and habitat for the koalas in the local area around the Wilton and Greater Macarthur GAs, but are the least-valuable connectivity asset to retain for koalas and the regional koala population.

Regional koala population: The single, contiguous koala population extending from Campbelltown through Wollondilly to Wingecarribee.

Metapopulation: A group of spatially separated sub-populations connected by dispersal. In this report, the term is applied to koalas in the Campbelltown and Wollondilly Local Government Areas; i.e. the Campbelltown koala metapopulation and the Wollondilly koala metapopulation.

7. References

Adams-Hosking C 2017, *Current Status of the Koala in Queensland and New South Wales*. Report for WWF Australia.

Campbelltown Council 2017, *Campbelltown Council Biodiversity Corridors*. Campbelltown Council.

de Oliveira SM, Murray PJ, de Villiers DL, and Baxter GS 2013, Ecology and movement of urban koalas adjacent to linear infrastructure in coastal south-east Queensland. *Australian Mammalogy* 36(1): 45–54.

Department of Environment and Conservation (DEC) 2004. *The Native Vegetation of the Nattai and Bargo Reserves*. Department of Environment and Conservation, Hurstville. nattai_VISmap_2332.

Department of Environment and Climate Change (DECC) 2007, *Terrestrial vertebrate fauna of the greater southern Sydney region*. Department of Environment and Climate Change, Hurstville.

Department of Environment, Climate Change and Water (DECCW) 2010, *Native Vegetation Interim Type Standard*. New South Wales Department of Environment, Climate Change and Water, Sydney.

Department of Environment, Climate Change and Water (DECCW) 2011, *Cumberland Plain Priority Conservation Lands*. New South Wales Department of Environment, Climate Change and Water, Sydney. http://data.environment.nsw.gov.au/dataset/cumberland-plain-priority-conservation-landsc5f52

Dique DS, Thompson J, Preece HJ, de Villiers DL and Carrick FN 2003, Dispersal patterns in a regional koala population in south-east Queensland, *Wildlife Research* 30(3): 281–290.

Eco Logical Australia (ELA) 2017, *Wilton and Greater Macarthur Priority Growth Areas – Biodiversity study*. Unpublished report prepared for the NSW Department of Planning and Environment.

Lunney D, Close R, Bryant J, Crowther M, Shannon I, Madden K and Ward S 2010, The koalas of Campbelltown, south-western Sydney: does their natural history foretell of an unnatural future? In Daniel Lunney, Pat Hutchings and Dieter Hochuli (eds), *The Natural History of Sydney*, Mosman NSW 2088: Royal Zoological Society of New South Wales, pp. 339–370.

McAlpine CA, Rhodes JR, Callaghan JG, Bowen ME, Lunney D, Mitchell DL, Pullar DV, and Possingham HP 2006a, 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.

McAlpine C, Rhodes J, Peterson A, Possingham H, Callaghan J, Curran T, Mitchell D and Lunney D 2006b, *Planning Guidelines for Koala Conservation and Recovery: A guide to best planning practice*. Australian Koala Foundation and The University of Queensland, Brisbane, Australia.

McAlpine C, Brearley G, Rhodes J, Bradley A, Baxter G, Seabrook L, Lunney D, Liu Y, Cottin M, Smith AG and Timms P 2017, Time-delayed influence of urban landscape change on the susceptibility of koalas to chlamydiosis. *Landscape Ecology* 32 (3): 663–679.

Moore BD, Lawler IR, Wallis IR, Beale CM and Foley WJ 2010, Palatability mapping: a koala's eye view of spatial variation in habitat quality. *Ecology*, 91 (11): 3165–3176.

National Parks and Wildlife Service (NPWS) 2003, *Native vegetation of the Woronora, O'Hares and Metropolitan Special Areas*. NSW National Parks and Wildlife Service.

Office of Environment and Heritage (OEH) 2013, *Native vegetation of the Sydney Metropolitan Area*. NSW Office of Environment and Heritage, Sydney.

Office of Environment and Heritage (OEH) 2015. Cumberland Subregion Biodiversity Investment Opportunities Map (BIO Map). NSW Office of Environment and Heritage, Sydney.

Office of Environment and Heritage (OEH) 2017a, NSW Bionet, http://www.bionet.nsw.gov.au/

Office of Environment and Heritage (OEH) 2017b, *NSW Bionet Vegetation Classification System,* http://www.bionet.nsw.gov.au/

Phillips S and Callaghan J 2000, Tree species preferences of koalas (*Phascolarctos cinereus*) in the Campbelltown area south-west of Sydney, New South Wales. *Wildlife Research* 27: 509–516.

Prevett P, Pope R, Callaghan J, and Bailey L 2001, The koala habitat atlas: preliminary results for koala tree species preferences in the city of Ballarat local government area, Victoria. The Research and Management of Non-Urban Koala Populations. Koala Research Centre of Central Queensland, pp 122.

Polak T, Rhodes JR, Jones D and Possingham HP 2014, Optimal planning for mitigating the impacts of roads on wildlife. *Journal of Applied Ecology*. 51 (3): 726–734.

R Core Team 2013, R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Tozer MG 2003, The native vegetation of the Cumberland Plain, western Sydney: a systematic classification and field identification of communities. *Cunninghamia* 8: 1–75.

Ward SJ 2002, *Koalas and the community: a study of low density populations in southern Sydney utilising community reports, opportunistic captures, and radio-tracking techniques*. PhD thesis, University of Western Sydney, Campbelltown.

8. Appendix 1

Table A.1. Mapped vegetation communities in the study area with details for canopy floristics, preferred koala feed trees, soil classification, koala habitat quality and status

Vegetation community	Hectare extant	Canopy floristic (Preferred koala use trees bolded)	Number of preferred tree species	Soil classification	Habitat quality	Koala habitat status
Cumberland Plain alluvial woodland	445	*E. amplifolia*, ***E. tereticornis***, *A. floribunda, E. deanei, E. eugenioides, A. subvelutina, E. moluccana*, ***E. globoidea, E. punctata***, *E. baueriana, C. maculata, E. elata, E. piperita, E. sclerophylla*	3	Shale	HQH	Core
Cumberland Plain shale hills woodland	809	*E. moluccana*, ***E. tereticornis***, *E. crebra, E. eugenioides, E. amplifolia. A. floribunda, C. maculata, A. subvelutina, E. fibrosa*	1	Shale	HQH	Core
Cumberland Plain shale plains woodland	462	*E. moluccana*, ***E. tereticornis***, *E. crebra, E. eugenioides, E. fibrosa, A. floribunda, A. subvelutina, C. maculata, E. amplifolia*, ***E. punctata***, *E. baueriana*, ***E. globoidea***, *E. longifolia*, ***E. paniculata***	4	Shale	HQH	Core
Cumberland Plain shale sandstone transition forest (high sandstone influence)	5067	***E. punctata***, *E. crebra, E. eximia, E. notabilis, E. beyeriana, E. fibrosa, C. gummifera, A. bakeri, E. eugenioides*, ***E. pilularis***, *C. maculata*, ***E. globoidea***, *A. floribunda, E. oblonga*, ***E. tereticornis***, *A. costata, E. resinifera, E. sclerophylla*, ***E. longifolia,*** *E. moluccana*	5	Shale transition	HQH	Core
Cumberland Plain shale sandstone transition forest (low sandstone influence)	718	***E. tereticornis***, *E. eugenioides, E. crebra, E. fibrosa*, ***E. punctata***, *E. moluccana, A. floribunda*, ***E. globoidea***, *C. maculata, A. bakeri, E. resinifera, C. gummifera*, ***E. pilularis***, *E. saligna, E. sideroxylon*	4	Shale transition	HQH	Core

Eastern gully forest	292	*A. costata, C. gummifera, E. piperita, E. seiberi*	0	Sandstone	MQH	Non-core
Exposed sandstone scribbly gum woodland	8679	*E. Sclerophylla. E. racemosa, E. haemastoma, C. gummifera, E. oblonga, E. seiberi, E. piperita, A. costata*	0	Sandstone	LQH	Non-core
Highlands shale tall open forest: form C tall open variant	17	*E. piperita,* ***E. globoidea****, E. radiata, E. obliqua, E. cypellocarpa, E. quadrangilata, E. elata, E. agglomerata,* ***E. punctata****, E. amplifolia, E. dives, E. smithii, E. ovata*	2	Shale	HQH	Core
Moist shale woodland	348	***E. tereticornis****, E. moluccana, E. crebra, C. maculata*	1	Shale	HQH	Non-core
Nattai sandstone river peppermint forest	47	*E. elata, E. piperita, E. cypellocarpa, E. oreades*	0	Sandstone	LQH	Non-core
Nepean enriched sandstone woodland	302	*C. gummifera,* ***E. globoidea****, E. oblonga, E. eugenoides, E. piperita, E. seiberi,* ***E. punctata***	2	Shale-enriched sandstone	HQH	Core
Nepean Gorge moist forest	6	*E. elata, E. agglomerata,* ***E. punctata****, E. piperita, C. gummifera*	1	Sandstone	MQH	Non-core
O'Hares Creek shale forest	9	***E. globoidea****, E. piperita, A. costata, C. gummifera, E. seiberi*	1	Shale transition	HQH	Core
Riparian forest	184	*E. botryoides, E. benthamii, A. subvelutina, E. elata, A. floribunda, E. baueriana, E. saligna X botryoides,* ***E. tereticornis***	1	Shale transition	HQH	Core
Riparian scrub	133	*A. costata,* ***E. pilularis***	1	Sandstone	LQH	Non-core
Rock pavement heath	2	None	0	Sandstone	LQH	Non-core
Rock plate heath-mallee	19	*E. stricta, E. apiculata, E. multicaulis, E. sclerophylla, E. seiberi, C. gummifera, E. oblonga*	0	Sandstone	LQH	Non-core
Sandstone gully apple-peppermint forest	907	*A. costata, E. piperita, C. gummifera, E. seiberi*	0	Sandstone	MQH	Non-core

Sandstone gully peppermint forest	1022	*E. piperita, C. gummifera, E. seiberi,* ***E. globoidea***	1	Sandstone	MQH	Non-core
Sandstone heath-woodland	37	*E. haemastoma.racemosa, E. seiberi, E. oblonga, C. gummifera*	0	Sandstone	LQH	Non-core
Sandstone ridgetop woodland	766	*C. gummifera, E. sclerophylla,* ***E. punctata****, A. costata, E. Oblonga, E. piperita, A. bakeri, E. sieberi,* ***E. globoidea****, E. agglomerata, E. haemastoma, E. parramattensis,* ***E. pilularis****, E. squamosa,*	3	Sandstone	LQH	Non-core
Sandstone riparian scrub	326	*A. costata, E. piperita,* ***E. punctata, E. pilularis***	2	Sandstone	LQH	Non-core
Sheltered sandstone blue-leaved stringybark forest	1200	*C. gummifera,* ***E. punctata****, E. piperita, E. agglomerata*	1	Sandstone	LQH	Non-core
Transitional shale dry ironbark forest	1350	*E. crebra, E. fibrosa,* ***E. paniculata, E. globoidea****, E. eugenoides,* ***E. punctata****, E. moluccana, E. bosistoana,* ***E. tereticornis, E. longifolia****, C. gummifera,* ***E. pilularis****, E. oblonga, E. sparsifolia, E. resinfera, E. beyeriana, A. floribunda,*	6	Shale transition	HQH	Core
Transitional shale open blue gum forest	36	*E. salignaXbotryoides*	0	Shale transition	HQH	Core
Transitional shale stringybark forest	252	***E. globoidea****, E. eugenoides,* ***E. punctata****, C. gummifera, E. crebra, E. piperita, E. sclerophylla*	2	Shale transition	HQH	Core
Upland swamps: banksia thicket	6	*E. racemosa/haemastoma/sclerophylla, E. oblonga, E. seiberi*	0	Sandstone	LQH	Non-core
Upland swamps: fringing eucalypt woodland	264	*E. sclerophylla, C. gummifera, E. seiberi*	0	Sandstone	LQH	Non-core
Upland swamps: sedgeland-heath complex	138	none	0	Sandstone	LQH	Non-core

Upland swamps: tea-tree thicket	7	none	0	Sandstone	LQH	Non-core
Upper Georges River sandstone woodland	3416	***E. punctata***, *C. gummifera*, ***E. globoidea***, *E. oblonga, E. racemosa, A. costata, E. eugenoides, E. pierita, E. seiberi, E. fibrosa*	2	Shale-enriched sandstone	HQH	Core
Western sandstone gully forest	1934	***E. pilularis, E. punctata***, *A. costata, C. gummifera, E. piperita, E. agglomerata, A. floribunda*	2	Shale-enriched sandstone	HQH	Core
Western Sydney dry rainforest	73	*C. maculata*, ***E. tereticornis, E. pilularis***	2	Shale	MQH	Non-core
Woronora Tall Mallee-heath	1	*E. luehmanniana, C. gummifera, E. racemosa*	0	Sandstone	LQH	Non-core
Regenerating vegetation	14				LQH/MQH	Non-core
Weeds and exotics	13				LQH	Non-core
Exposed rock	4				LQH	Non-core

Notes: a = acacia; C = Corymbia; E = Eucalyptus; HQH = high-quality habitat; MQH = medium-quality habitat; LQH = low-quality habitat

9. Appendix 2

THE UNIVERSITY OF SYDNEY

Associate Professor Mathew Crowther
School of Life and Environmental Sciences

18 December 2017

Dear Liza Schaeper

Office of Environment and Heritage

RE: Review of Office of Environment and Heritage (OEH) Draft "Conserving koalas in Wollondilly and Campbelltown LGAs – additional justifications"

I have been commissioned by OEH to review provide a scientific review and analysis of Conserving koalas in Wollondilly and Campbelltown LGAs – additional justifications relating to the following two key points:

1. To review and comment on the koala conservation report's key principles and recommendations to conserve the regional koala population, and
2. • To review and comment on the methods used to derive corridors for koalas and koala estimates included in OEH's koala conservation report.

I will first outline my experience and qualifications with koala research, comment on the documents provided and provide my recommendations.

I am an Associate Professor in wildlife ecology and evolution in the School of Life and Environmental Sciences at the University of Sydney. I have researched on koalas in NSW since 2006, including publishing over 10 scientific papers on koalas. I have also contributed to koala management by contributing to the NSW Koala Recovery Plan, and am a current expert advisory member on the NSW Save Our Species Koala Panel. I have a history of reviewing documents concerning koala management. My CV is attached.

In regards to the report's key principals and recommendations to conserve the regional koala population, the document appears sound. The areas considered by the report are being rapidly developed and hence threats to the regional koala population will increase. This does not even take into account the possible impacts of increased urbanisation interacting with the impacts of climate change, such as increased heatwaves and bushfires.

The report is correct in that development needs to be avoided in both core habitat and primary corridors. With increasing development in the area, these core habitat and

School of Life and Environmental Sciences
Faculty of Science
Room 225c, Heydon-Laurence Building
The University of Sydney
NSW 2006 Australia

T +61 2 9351 7661
F +61 2 9351 4119
E mathew.crowther@sydney.edu.au
sydney.edu.au/science/people/mathew.crowther.php

ABN 15 211 513 464
CRICOS 00026A

THE UNIVERSITY OF SYDNEY

corridor areas need protection. Cleared areas near the corridors also need protection, as koalas spend much of the time on the ground. When koalas are moving areas, they are particularly vulnerable to threats such as dog attack. Hence the recommendations of increasing corridor widths, and the use of barriers to separate koala habitat areas and corridors from residential areas are appropriate.

Habitat restoration and revegetation of cleared areas are essential. Many of the corridors depicted in the maps are very narrow and hence vulnerable to edge effects. Revegetation has to be well planned, and needs a mixture of local shelter trees (often non *Eucalyptus* species) and local feed species. Koalas use a large variety of *Eucalyptus* species in the area, and plantings must be appropriate for soil type. Tree planting is a long-term management action, as trees are not usable by koalas for many years. There are a number of research projects on tree use in this area, both published and unpublished reports and theses, and these need to be consulted for appropriate trees for planting.

The recommendations for mitigation of the impacts of widened roads and increased traffic, although correct, could be made stronger. Effective mitigation of the impacts of roads on koala populations is an expensive exercise, and needs a combination of fencing and underpasses. Signage, as reported, has been shown to be ineffective in mitigating against road deaths. Hence more details on the true cost of development in the area could be emphasised with more details on the fencing and underpasses.

Although briefly mentioned, I think there is more need for mitigation measures from chlamydia. The Campbelltown populations is currently free of chlamydia, while the Southern Highlands has chlamydia within its populations. Introduction of chlamydia to a population that was previously chlamydia-free can result in a rapidly increasing prevalence within a few years. Such a phenomenon was observed on the Liverpool Plains koala population, surrounding the town of Gunnedah, which had an extremely low, if not absent, prevalence of chlamydia a decade ago. There is a risk of corridors actually increasing the movements of chlamydia infected individuals into chlamydia-free areas. Possible mitigation measures for this would be increased veterinary checks of koalas in corridor areas, and possible barriers of certain corridors if they are problematic.

In regards to the determination of corridors for koalas, the methods seem to be sound. Generalised linear models and Geographical Information Systems are well-tested methods in determining habitat. The criteria in determining corridors was also appropriate and had a high overlap with the modelling approach. The details of the modelling and criteria are probably not as important as the quality of the data. The models and corridor criteria are based on very detailed and accurate vegetation mapping, and extensive koala spotlighting data. Hence, the models are likely to have a high predictive power.

Koalas have been VHF and GPS tracked in the local area for the last few years. Movements of some of these animals could be useful in determining koala corridor use, as well as the models and spotlighting data.

Determining densities and numbers of koalas is extremely difficult. Some reports have based density estimates on scat counts (usually using the SAT procedure), but these estimates are not universally accepted, and can be affected by decay rates and koala densities. The most accurate way of determining koala densities is distance-sampling, where the probability of detection is accounted for, with covariates of weather and habitat, as well as distance away from the observer. Estimates include confidence intervals, which can be quite large. The main issue with distance sampling is the sample size required to get reasonably accurate and precise estimates. These are a minimum of 75 koala observations per area, which is not feasible in some areas. Hence the method employed in this report, with a large number of systematic surveys (67), and being conservative in the area selection (i.e. leaving out cleared areas that koalas used), gives a reasonable minimum of koalas in the area.

In summary, the recommendations for protecting the koala core areas and habitat, as well as mitigating against future declines by roadkill are reasonable. The methods used in determining koala corridors and koala numbers are also reasonable. Future use of distance sampling, plus more details on disease surveillance, would help in providing more robust recommendations in the future.

Sincerely,

M Crowther

Associate Professor Mathew Crowther

10. Appendix 3

biolink
ecological consultants
PO Box 3196 Uki NSW 2484
T 02 6679 5593
F 02 6679 5523
www.biolink.com.au

NSW Office of Environment & Heritage
Attn: Liza Schaeper
Senior Team Leader
Ecosystems & Threatened Species
Greater Sydney Branch
PO Box 1967
Hurstville NSW 2220

30th January 2018

Re: Review of Revised Draft Report: Conserving koalas in Wollondilly and Campbelltown LGAs.

Dear Liza

Thanks for the opportunity to review and comment on more recent revisions to the draft report.

The revised document provides recommendations for koala conservation in Western Sydney, to which end it is clear that the majority of the areas identified as habitat are appropriately located and essential for koala survival. That the outcomes of the report remain conservative is also a positive aspect and because of this I am comfortable in offering qualified support for the report as it currently reads.

However, while I agree with the principles and application of science that has been used to inform the report, I do remain at odds with some aspects of the terminology and data analyses, especially that which relates to the identification of preferred trees. Consistent with my earlier feedback, I remain of the opinion that further work in this area will be valuable and reiterate my earlier offer of assistance with statistical analyses of the associated data.

The proposed mitigation measures of enclaving, fencing and underpasses are appropriate and reflect best practice measures. Because of the conservative approach that has been taken however, I remain concerned at the longer-term conservation implications of the report should the recommendations proceed without further expansion. Specifically, the recommendations insofar as they relate to the southern habitat areas need to be extended to the north as well (*i.e.* South Campbelltown / Macarthur PGA) where optimal levels of occupancy by koalas have been identified within identified linkage areas and there is an obvious need for east –west connectivity to be maintained, rather than discounted. Because of this I am strongly of the opinion that the report has yet to effectively accommodate the conservation needs of koalas in the Macarthur Priority Growth Area and that further work is required to effectively future-proof this important population. Hence the best-practice concepts articulated so well for the southern population need to be expanded into the northern area to which end measures such as fencing and the inferred lack of provision for connectivity will need to be reviewed.

I hope the preceding comments are of some value. Please don't hesitate to contact me if any of the matters I have raised require further clarification, to which end I am keen to offer any further assistance as may be required to resolve any of the issues that remain outstanding.

Yours Sincerely

Dr. Stephen Phillips
Managing Director / Principal Research Scientist.