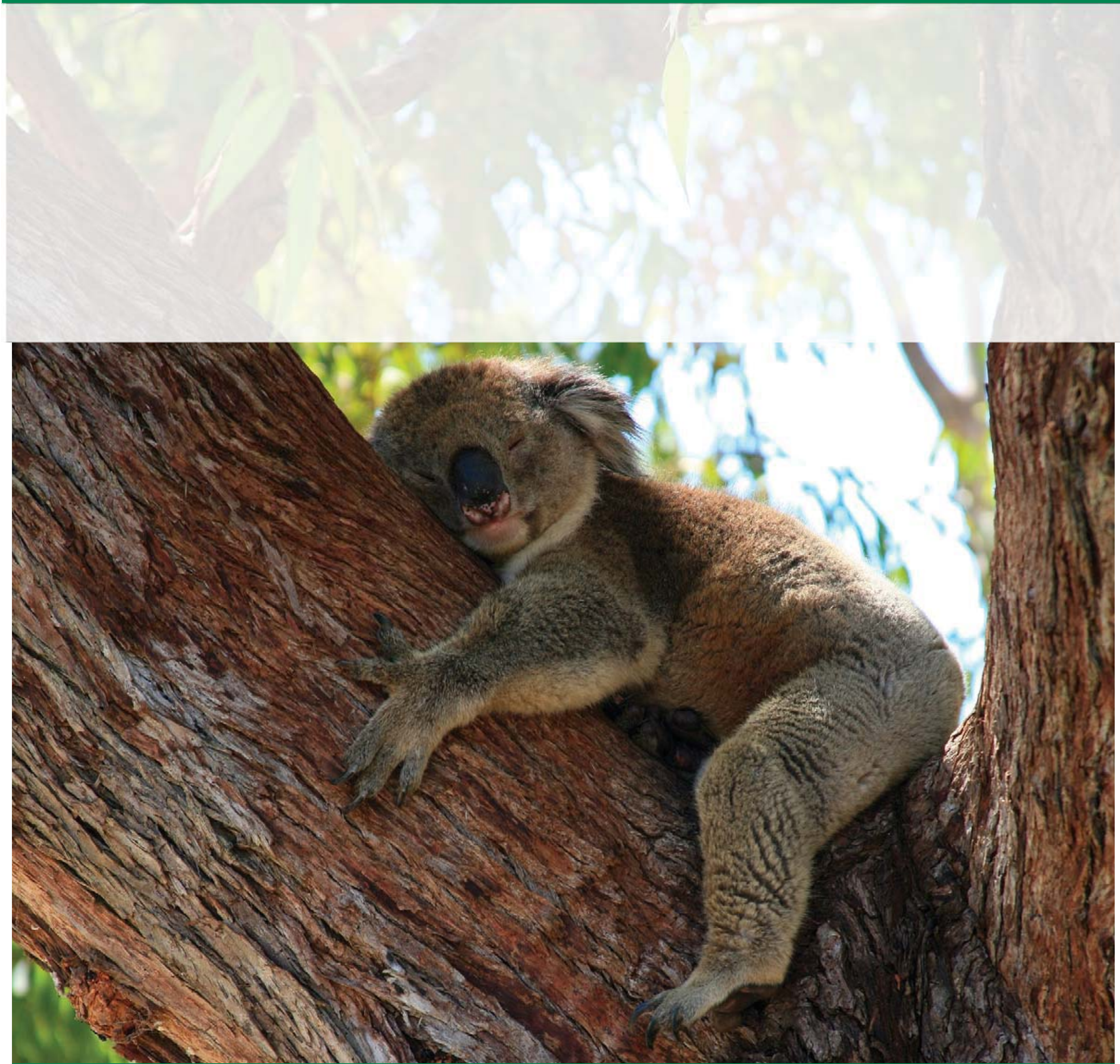
Appendix 1 – Ecosure/Biolink Report

ecosure

biolink



ecology / vegetation / wildlife / aquatic ecology / GIS

Executive summary

This report presents findings from assessments of the distribution, density and demographics of a koala population inhabiting a notional study area of approximately 8,250 hectares in the southeast of the Ballina Local Government Area on the far north coast of New South Wales. Approximately 2,152 hectares of preferred koala habitat occurs within the study area, ranging from high carrying capacity habitats of forest red gum on coastal floodplain to lower carrying capacity grassy blackbutt forests on the more elevated ranges. The work described herein arose from a need for specific information concerning the study area's koala population that would provide necessary baseline input parameters for Population Viability Analysis modelling to help evaluate the potential impacts on koalas of the conditionally-approved Woolgoolga to Ballina Pacific Highway Section 10 upgrade.

To assist the PVA process a demographic profile of the population was constructed from a subset of 51 koalas sampled from across the study area. The overall picture that emerged from this process was of a small and widely dispersed population that appeared to be primarily sourced from high carrying capacity red gum forests on the floodplains and swamp mahogany forests on coastal sands in the south of the study area. Tooth-wear/age class frequency data indicated a population that was at demographic equilibrium. A predominance of older animals in the north implied that birth rates in the north and recruitment levels from the west and south were not sufficient to offset mortalities. Six of the 51 koalas that were screened for purposes of demographic profiling were obtained as a direct consequence of vehicle-strike.

Despite the trend toward demographic equilibrium at the population level, a skewed sex-ratio evidenced by lower numbers of males implied a measure of male-biased mortality that was most notable amongst the sub-adult and older male tooth-wear classes. Reproductive output amongst adult female koalas was estimated to be approximately 43% annually across the population. Consistent with the trend towards older animals in the north, reproductive output by female koalas was higher in the south of the study area. Clinical expression of disease amongst male and female koalas was relatively low.

The annual mortality rate of koalas across all tooth-wear/age-frequency classes was estimated from the capture and screening program at approximately 10% of total population size. To better understand factors contributing to koala mortality, the detail of 472 koala-calls received by the Lismore-based Friends of the Koala over a 26-year period from 1989 to 2014 were examined. Two hundred and seventeen of the 472 records related to a koala mortality, 75% of which were from within the study area. Excluding instances where the reason for a given koala mortality was either not recorded or unknown, natural causes accounted for approximately 10% of known mortalities annually. In contrast, domestic dog attacks and vehicle-strikes accounted for more than 50% of all koala deaths annually, the latter involving significantly higher numbers of males than females and thus providing one explanation for the male biased mortality estimated by the capture and screening program. Mortalities (including euthanasia) due to disease were also high, the data over time notable for the presence of two peaks 15 – 17 years apart, the basis for which appears to be operating independently of other mortality drivers and factors such as climate.

Koala density across the study area was reassessed using direct count techniques at forty-six 250 metres x 40 metres (one hectare) transects, the majority of which were sites in which koalas were also counted in 2013 using a different sampling protocol. Eleven koalas were recorded during the transect searches, three of which were recorded within survey transects. The 2013 survey estimated koala density to be 0.12 koalas ha^{-1}, whereas the 2015 transect surveys returned a density estimate of 0. 07 koalas ha^{-1}. These data were pooled to create a refined density estimate of ~ 0.09 koalas ha^{-1}, thus enabling a more refined population estimate for the Important Population Focal Area of approximately 196 koalas to be derived.

Field surveys to better understand the distribution and extent of koala activity, as well as identifying areas of unoccupied habitat to inform potential translocation sites, involved assessment of 76 field sites at approximately 350 metre intervals, all of which were located in forested areas east of the conditionally-approved Section 10 upgrade alignment and west of the existing Pacific Highway. Subject to some qualifications, the resulting model indicated that the distribution of significant koala activity (and thus resident koala populations) was typically focused in areas of higher quality habitat. Koala density in this smaller study area was estimated at approximately 0.096 koalas ha^{-1} with an occupancy rate estimated to approximate 40% of available habitat. Areas of high carrying capacity but otherwise unoccupied habitat occurred in several areas. Potential impacts of road construction on the local koala population were accentuated by the locations of significant koala activity, the modelling serving to inform a conclusion that the home range areas of 10 – 14 koalas will be affected to varying degrees based on estimated koala densities within the forest areas that would be directly impacted by the road alignment; occupied habitat areas currently linking the eastern and western population cells in the area between Thurgate's Lane and Buckombil Mountain Road will also be impacted.

Based on an estimated population size of 196 koalas, an annual mortality rate of approximately 10% and that death due to vehicle-strike and attacks by domestic dogs collectively account for more than half of all koala mortality annually, a long-term, secure outlook for the study area's population appears uncertain. Given that the numbers of koalas killed on an annual basis by vehicle-strike is a function of population size (i.e. greater numbers of individual movements and more home range areas near roads when population numbers are higher), striving to offset the potential impacts of road construction by increasing population size alone will be largely ineffective if factors contributing to current mortality rates cannot be reduced substantively.

To enable forward projections relating to the potential impacts of the conditionally approved upgrade and associated issues of koala management to be objectively evaluated, population-specific baseline input parameters and other considerations relating to the PVA process were derived from the component studies comprising this report. The purpose of this information is to enable the current conservation status of the population to be objectively ascertained, as well as informing various management scenarios that may need to be developed and appraised if impacts are to be deemed 'acceptable' over the 50 year time frame specified by the Federal Government's consent condition.

Table of contents

List of figures

List of tables

Acknowledgements

Recognition and acknowledgement of individuals and/or organisations who helped us to carry out this project can be viewed at http://www.biolink.com.au/projects/koala-pva-project.

We also acknowledge field support from Maria Matthes, George Kordas, Bob Johnson, Emily Hatfield, Jim Dick, Cam Weetman, Karlee Taylor and Caitlin Weatherstone, as well as Chris Allen and Rob McKinnon from the Office of Environment and Heritage. We are especially grateful to Maria Matthes who not only assisted with locating, capturing and processing koalas (day and night), but also tirelessly collected and followed-up on koala sightings from the local community, and provided a devoted and inspirational role model for all who worked on the project. At the Ecosure end we also thank Marianne Donoghue, Beth Kramer, Noela Hamilton, Katherine Richardson, Phil Shaw, Jeff McKee and Matt Smyth.

We extend our sincere thanks to the Friends of the Koala (FoK) volunteers and leadership team and in particular Lorraine Vass, Pat Barnidge and Susannah Keogh for their 24-hour support and advice whenever (and at whatever time of the night) we encountered koalas with signs of disease. The FoK have a vital ongoing role in the management and recovery of koalas throughout the region.

We would like to acknowledge and thank the Nyangabul people and the Jali Local Aboriginal Land Council for their permission and support in accessing survey sites on Jali lands, and sincerely hope that burabi's will survive on these lands for future generations to enjoy and treasure.

The final report has also benefited from review comments from Associate Professor Jonathan Rhodes (UQ) and Dr. Rod Kavanagh (Niche Consulting), as well as feedback from Roads and Maritime personnel Bob Higgins, Scott Lawrence, Julie Ravallion and Simon Wilson.

PART 1
Introduction

1.1 Introduction

In May 2012, the koala was listed as a threatened species throughout Queensland (QLD), New South Wales (NSW) and the Australian Capital Territory (ACT) under the Commonwealth Government's *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999*. In NSW, koalas are listed as a Vulnerable species under the *Threatened Species Conservation* (TSC) *Act 1995*, with the viability of free-ranging koala populations decreasing in most areas due to a variety of threatening processes including ongoing habitat loss, modification and fragmentation, stress-related disease, bushfire, vehicle-strike and domestic dog attacks. While there is a substantive body of scientific literature informing this knowledge (Threatened Species Scientific Sub-committee 2012), there is yet no evidence demonstrating successful population recovery.

Since the mid-1990s the NSW Government has been committed to a progressive upgrade of the Pacific Highway to a safer dual carriageway standard between Newcastle and the QLD/NSW border. As a component of this commitment, NSW Roads and Maritime Services (Roads and Maritime) have been investigating a range of highway upgrade options in the area between Woolgoolga, to the north of Coffs Harbour and Ballina, south of Byron Bay. The proposed alignment (referred to as Section 10) of the existing Pacific Highway between the Richmond River and Ballina deviates from the existing highway via a new bridge over the Richmond River approximately six kilometres south of Wardell and traverses inland before re-joining the existing alignment three kilometres north of Wardell.

A koala habitat and population assessment across the entire Ballina Local Government Area (LGA) was completed in 2012/13 (Biolink 2013)[1], constituting the first comprehensive assessment of koalas and their habitat undertaken for the LGA. Amongst other things the BKS identified an area in the southeast of the LGA that was considered to support a nationally important population of koalas. This assertion was corroborated by historical records dating back over a century, together with indigenous knowledge and extensive areas of continuous occupancy by koalas over at least 40 – 50 years/six consecutive koala generations. The disparity between the habitat occupancy rate predicted by the historical analysis and the results of the field survey component implied a decrease in the extent of habitat supporting resident koala populations over recent years. This was supported by an overall low koala density estimate of 0.09 to 0.13 koalas ha^{-1}, the latter applying to areas wherein koala activity was known to occur. The envisaged Section 10 upgrade passes through the area occupied by the aforementioned population, the traverse directly impacting upon the eastern most population cell identified by the BKS, thus having the potential to displace a number of koalas.

The Woolgoolga to Ballina (W2B) Pacific Highway upgrade (including Section 10) was approved by the NSW Government in June 2014. In August 2014, the Federal Environment Minister similarly approved the W2B upgrade, albeit with a number of additional conditions including a need for further work to be undertaken on koala populations inhabiting the area to be traversed by Section 10. Specifically, the conditions required use of Population Viability Analyses (PVA) to be undertaken over a 50-year time frame in order to better understand long-term impacts (of road construction) on the area's resident koala populations. PVA was also to be utilised to examine the likely impacts of different management scenarios that might

[1] Hereafter referred to as the Ballina Koala Study (BKS)

be employed to reduce adverse consequences to a measure that was deemed ‘acceptable’.

The purpose of this report is to detail results from an examination of factors of relevance to koala population viability within the Important Population Focal Area[2].

Along with a separate genetic profiling study, the analyses and resulting outcomes from this examination are intended to inform specific components of the PVA process required by the Federal Environment Minister including:

a) the demographic structure of the koala population inhabiting the IPFA, including details of sex-ratios, reproductive output, age-class frequencies and associated mortality rates,
b) analyses of koala mortality data for the IPFA, including the extent of incidental harvests due to domestic dog attack and vehicle-strike,
c) a re-assessment of koala abundance (density) within the IPFA with a view to further refining estimates of population size previously obtained by the BKS, and
d) obtaining further knowledge of koala distribution east of the Section 10 alignment for the purpose of revising the extent and type of potential ameliorative measures, as well as informing possible population management programs such as translocation should the proposed upgrade proceed.

1.1.1 The study area

The Ballina LGA covers approximately 49,200 ha on the far north coast of NSW between the Byron Shire to the north, Lismore City to the west and the Richmond Valley LGA to the south. Within this area, a notional boundary considered to support an ‘important population’ (i.e. the IPFA) for purposes of the EPBC Act was identified by the BKS. The ‘notional’ IPFA encapsulates an area of 8,247 ha in the southeast of Ballina LGA known locally as the Blackwall Range between Wardell and Alstonville, as well as associated lowland areas that include the localities of Meerschaum Vale, Pimlico, Wardell and Bagotville. Figure 1.1 illustrates the location of the IPFA in the context of the Ballina LGA.

[2] Herein referred to as IPFA

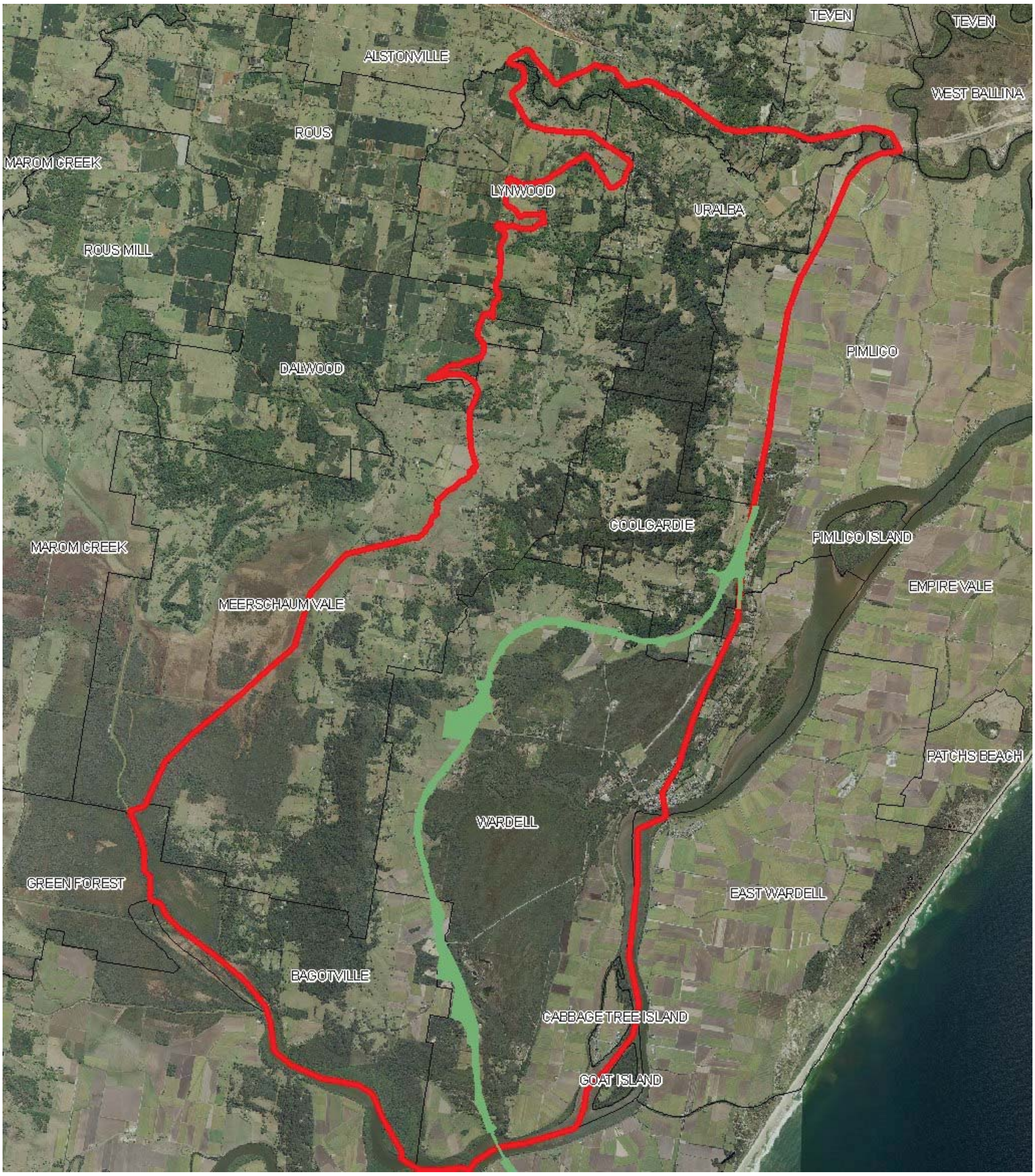


Figure 1.1 Location of the notional IPFA (red polygon) in the southeast of the Ballina LGA, including the envisaged alignment (green, linear polygon) of the conditionally approved Stage 10 W2B Pacific Highway upgrade

1.1.2 Extent of habitat and koala carrying capacity

Based on results of the BKS, suitable koala habitat within the IPFA is primarily determined on the basis of the distribution and abundance of the following preferred food tree species:

- tallowwood (*Eucalyptus microcorys*)
- swamp mahogany (*E. robusta*)
- forest red gum[3] (*E. tereticornis*).

Based on knowledge regarding the distribution and abundance of these three species, coupled with information regarding the influence of underlying soil landscapes on the palatability of preferred food tree species for koalas, approximately 2,152 ha of preferred koala habitat (PKH) has been mapped within the IPFA based on BKS koala habitat mapping (Table 1.1).

Table 1.1 . Estimated extent and carrying capacity of Preferred Koala Habitat classes within the IPFA. Carrying capacity estimates are based on mean values determined by other studies in comparable habitat types (Source: Phillips and Forsman 2005[4]; Phillips, Hopkins and Callaghan 2007[5]; Phillips and Allen 2012[6]; Phillips and Allen 2014[7])[8].

Koala habitat class	Area in IPFA (ha)	Carrying capacity
Primary Koala Habitat	96	0.63 koalas ha^{-1}
Secondary (Class A)	578	0.42 koalas ha^{-1}
Secondary (Class B)	808	0.23 koalas ha^{-1}
Secondary (Class C)	670	< 0.1 koalas ha^{-1}

The preceding data can be used to estimate a carrying capacity for the IPFA of ~ 556 koalas. However, a population of this size within the IPFA would be unsustainable and typified by evidence of over-browsing with nowhere for dispersing animals to colonise. Results from the aforementioned reports wherein populations were assessed as large (i.e. >350 koalas) and at demographic equilibrium imply that approximately 50% of available habitat (52.34% ± 5.15% - 95% CI) will be occupied at any one point (Phillips and Forsman 2005; Phillips, Hopkins and Callaghan 2007; Phillips and Allen 2014); this figure is now utilised as a sustainable management/recovery benchmark in most recently prepared Koala Plans of Management in NSW. Thus we consider the maximum number of koalas that could sustainably occur within the IPFA landscape for PVA purposes to be ~ 291 koalas (i.e. 556 x 0.5234).

[3] Includes the naturally occurring *E. robusta* x *E. tereticornis* hybrid.

[4] An ecological overview of koalas and their habitat on the Innes Peninsula, Port Macquarie NSW.

[5] Koala habitat and population assessment for Gold Coast City LGA.

[6] Koala conservation in the south-east forests: assessment of the need for and feasibility of a population augmentation program.

[7] Strzelecki Ranges Koala Survey.

[8] Copies of these reports can be provided if required.

1.1.3 Stochastic considerations

(i) Drought

Archival Drought Statements prepared by the Bureau of Meteorology's National Climate Centre (http://www.bom.gov.au/climate/drought/) indicate that the far north coast of NSW (including the IPFA) experienced several periods of serious rainfall deficiency between 1990 and 2014. Rainfall is considered to be deficient if it is within the lowest 10% of historical totals (well below average) for any given period of three months or more. Protracted serious to severe rainfall deficiencies were recorded for the IPFA between December 2001 and January 2004, and again from December 2013 to November 2014. These data indicate that serious local rainfall deficit conditions have occurred over at least three of the last 14 years thus enabling an estimate of the annual probability of occurrence of a drought episode to be ~ 21%.

Drought conditions impact upon tree health and habitat quality, koala morbidity and reproductive output within the IPFA. Impacts on koalas and their habitat during local drought conditions are likely to be greatest in elevated ridge areas, particularly those on less structured, shallower soil profiles with relatively low moisture-holding capacity where trees have less access to ground moisture reserves. Based on our observations from a number of local government areas, we hypothesise that the impact of such conditions within the IPFA may equate to failure in successful reproductive output in ~ 10% of breeding females over ~ 32% of available habitat (i.e. 700[9] ha of ridgeline habitat out of 2,152 ha) during serious rainfall deficit years. The impacts on reproduction and survival are expected to be small with proportional estimates of 0.1 and zero respectively. Our observations within the IPFA and in other areas suggest that these effects are restricted to ridge tops, populations during drought conditions faring better in low-lying areas on alluvial deposits and quaternary sand sheets. This could arguably be one of several contributing factors already affecting the current distribution and conservation status of the koala population across the IPFA.

(ii) Fire

Fire history is not well documented within the IPFA, oral history recalling a single, wildfire event in the Ngunya Jargoon IPA approximately 35 - 40 years ago (Marcus Ferguson pers comm), while NSW NPWS records describe a localised wildfire near Uralba in the northern parts of the Blackwall Range during the 1970s.

While the preceding information implies a relatively low frequency/probability of occurrence of ~ 3%, the impacts of such an event will vary depending on exactly where the wildfire occurs. Within the Ngunya Jargoon IPA for example, it is likely that the greater proportion of the habitat would be impacted with a correspondingly high impact on koala survival and reproduction. In contrast, a wildfire event in the Uralba – Coolgardie area would likely remain quite localised with a lesser impact. In consideration of such extremes we speculate that on average such a wildfire would likely affect no more than 10% of the IPFA in a single event, with associated impacts on reproduction and survival for PVA purposes estimated as severe to moderate (proportional estimates of 0.85 and 0.6 respectively).

[9] Estimated on basis of 100 m wide area of influence along ~ 35 km of ridgeline in elevated areas of IPFA.

1.1.4 Burabi and the Nyangabul people

The study area is located within the boundaries of the Nyangabul people of the Bundjalung Nation. The Nyangabul people have a long association with and connection to the koala, which they know as burabi and have traditional customs and stories associated with this connection that go back generations. Jali Local Aboriginal Land Council own and manage the greater proportion of land within the area to be impacted, while the associated Ngunya Jargoon Indigenous Protected Area supports the bulk of suitable koala habitat to the east of the conditionally approved Section 10 alignment.

PART 2
Population demographics

2.1 Objective

Detailed information on population structure, reproductive rates and other parameters influencing population dynamics and viability are fundamentally important components of the PVA process.

The primary objective of this part of the study was to obtain data on the current demographic structure of the IPFA koala population, including the distribution and proportional representation of age-classes, associated mortality rates, sex-ratio and numbers of reproducing females.

.

2.2 Methods

2.2.1 Koala capture, processing & data collection

A 2.5 km x 2.5 km grid-base overlay was used to guide the capture and screening program to ensure to the maximum extent possible that a uniformly distributed survey and capture effort was achieved by ideally restricting the number of captures to no more than five – seven koalas per grid cell. Subject to landowner approvals, koalas were captured by both pole and flag or by trap (Phillips 2011)[10], anaesthetised and clinically assessed. During each assessment, the koala's sex, weight and body condition score were determined, clinical signs of disease recorded and samples collected for later analysis (see below). While the presence of pouch or dependent back-young was recorded, juvenile koalas were not included in the screening program.

2.2.2 Age-classing

Tooth-wear classes (TWCs) of Gordon (1991)[11] were used to allocate individual koalas to a population cohort. To assist PVA considerations we adapted the upper 95% confidence interval from Table 2 of Gordon (1991) to define the maximum age in years for each TWC; when rounded to the nearest whole number this approach enables partitioning into annual age increments as outlined in Table 2.1.

Table 2.1 Partitioning of koala tooth-wear classes (TWC) and corresponding stages (TWS) into annual age increments. Max. age = maximum age (in years) as indicated by the upper 95% confidence interval in Table 2 of Gordon (1991).

TWC	TWS	Max. age	Age in years
1	P4A	-	1
2	P4B	2	2
3	P4C	3	3
4	P4D	5	4 - 5
5	P4E	7	6 - 7
6	P4F, M1f-h	10	8 - 10
7	P4F, M1F, M2g-i	-	10+

[10] Development of a lightweight, portable trap for capturing free-ranging Koalas *Phascolarctos cinereus*. *Australian Zoologist* **35(3)**, 747 – 749.

[11] Estimation of the age of the koala *Phascolarctos cinereus* (Goldfuss) (Marsupialia Phascolarctidae) from tooth-wear and growth. *Australian Mammology* **14**, 5 -12.

2.2.3 Female reproductive status

The reproductive status of females was ascertained using a four-tiered assessment as follows:

(i) No pouch young present nor evidence of recent occupancy or lactation,

(ii) Pouch-young present,

(iii) Back-young present, or

(iv) Neither pouch-young nor back-young present, but evidence of recent/ongoing lactation (functioning mammary gland and elongated teat).

2.2.4 Koala health & welfare

In addition to physical examination and visual assessments of disease status and health, ocular and urogenital swabs were also taken to assist ongoing koala *Chlamydia* research programs, fur samples for a toxicology study, and ear tissue samples for Koala Retro-virus (KoRV) analysis and genetic profiling. Where appropriate, each koala was micro-chipped and/or identified with individually numbered Wireless Identification Device (WID)[12] or FoK ear-tags to assist sample referencing and longer-term monitoring. Once fully recovered from the anaesthetic, each koala was released back into the tree from which they had been captured or an adjacent smaller tree.

In instances where a koala was either determined upon capture to be moribund, assessed as being in poor health or otherwise expressing chronic disease symptoms, it was transported to the FoK Care Centre at Lismore. Access to some koalas was also facilitated through the FoK hotline/network; koalas killed by domestic dogs or motor vehicles in the study area were considered to be part of an incidental harvest resulting in demographic data and tissue samples that could be included in the data collection/screening program.

2.2.5 Central tendency measures

The majority of data associated with the capture and screening program were enumerative. Hence data were assumed to follow a binomial/poisson distribution and unless otherwise specified, the Standard Deviation was estimated using the following term:

$$\sigma = \sqrt{pq/n} \qquad \text{(Eqn 1)}$$

Where:

σ = standard deviation of the sample

p = the sample proportion

q = 1 – p

n = total sample size

12 Optionally fitted to koalas captured within 500m of a site initially considered for a land bridge at a location between Old Bagotville Road and Richmond River.

2.2.6 Mortality rates

Mortality rates for male and female cohorts were estimated from age frequency data using the basal formula of Heincke (1913) modified for koalas by dividing the initial mortality rate estimate for each Tooth Wear Class (TWC) by the maximum age (Table 2.1 refers) as follows:

$M_i = (\Sigma N_{(i...)} - N_i/\Sigma N_{(i...)})/A_{max}$[13] (Eqn 2)

Where:

M_i = mortality rate for TWC "i"

ΣN = total number of koalas in TWC (i…) for each gender cohort

N_i = number of koalas in cohort "i"

A_{max} = maximum age represented by the upper 95% confidence interval estimate for the corresponding TWC in Table 2 of Gordon (1991).

Estimates of the Standard Deviation associated with environmental variation (SD_{EV}) for each cohort-based mortality rate (*M*) were derived by multiplying *M* by the Coefficient of Variation (CV) associated with the mean numbers of deceased koalas documented by the FoK over the 26 year period 1989 – 2014 (Part 3 refers).

[**Note:** there are several assumptions inherent in the calculation of mortality estimates that rely upon age-frequency data, not all of which (e.g. a stationary population with stable age structure) might hold for a given population, thus limiting the reliability of the associated estimates. Other techniques are also available, all of which share similar assumptions or require other types of data not collected by this study. Despite its relative straight-forward and intuitive nature, the approach adopted herein is one of the better approximations we have examined in terms of mirroring actual mortality rates in free-ranging koala populations.]

[13] The use of the maximum age is required to accurately enable annual mortality estimates to be calculated given that each of the TWC groupings in Gordon's 1991 approach encompass more than one year.

2.3 Results

Subject to property access restrictions, the majority of forested habitat within the IPFA was searched for koalas. There were several instances (e.g. Coolgardie through to Uralba) where koalas were sighted, but either land-owners did not approve of their capture or the animals were not catchable due to forest structure and topography.

Data from 51 koalas including one skull were obtained over the period from early December 2014 through to mid - June 2015. Of these, three koalas were the victim of domestic dog/fox attack, six the result of vehicle-strike, two captured by hand when observed crossing open ground and the remainder captured using pole and flag or trapping techniques. The distribution of captures ranged across the IPFA from Lynwood and the Bruxner Highway in the north to Pimlico, Wardell and Bagotville in the south (Figure 2.1). Despite extensive searches only two koalas, both males, were located and captured within 500 m of the initially considered location for a land bridge at a site between Old Bagotville Road and the Richmond River. Three of the captured koalas had been previously ear-tagged by FoK. Only one of the 51 specimens could not be aged, this being a female koala killed by vehicle-strike and whose skull was crushed as a consequence. A summary of the capture data is provided in Appendix 1.

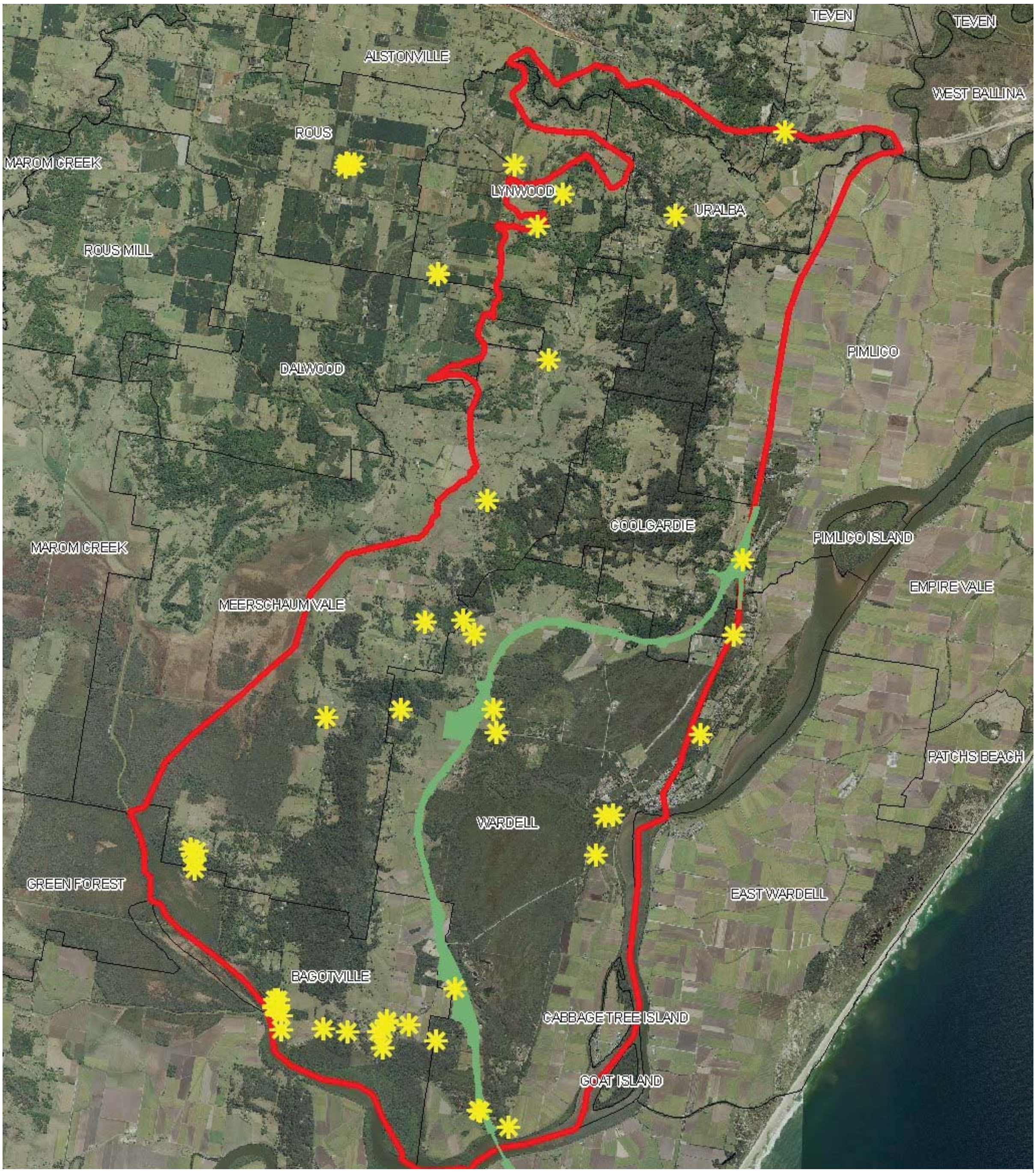


Figure 2.1 Localities of 51 koalas (yellow highlighted asterisks) informing the demographic profile for the IPFA. Further details for each sample are provided in Appendix 1.

2.3.1 Population structure and composition

Six TWCs (2-7) were represented amongst the captured koalas, the frequencies of which are illustrated in Figure 2.2. We estimated the ecological window represented by the samples to cover a minimum period of 10 years, this being the difference between the oldest animal in the sample (10+) and the youngest (small, unfurred pouch young no more than several weeks of age) observed during the screening program. The aggregated data-set implies a population trending towards a predominance of older age-classes. This pattern was most notable in the north of the IPFA where older age-class animals formed the more commonly-captured cohort.

Figure 2.2 Tooth-wear/age-class frequency distribution of IPFA koalas.

The gender ratio at population level was strongly female-biased with female koalas being almost twice as common as males (Ratio: 1.68 females for every male). Figures 2.3 and 2.4 illustrate the age-frequency histograms for male and female koalas, both of which imply approximately normal distributions.

2.3.2 Reproductive output

Evidence of reproduction was recorded in 13 of the 29 adult females represented in TWCs 3 – 7, this outcome enabling an estimate of 44.83% ± 9.27% (SD) of adult female koalas breeding annually. Reproductive activity in females was restricted to TWCs 3 – 5. Joey ages ranged from pouch young that were a few weeks of age up to advanced back young. As a subset for female koalas generally, breeding female koalas were more commonly recorded in the south of the IPFA (Figure 2.5).

Figure 2.3 Tooth-wear//age-class frequency distribution of female koalas within the IPFA.

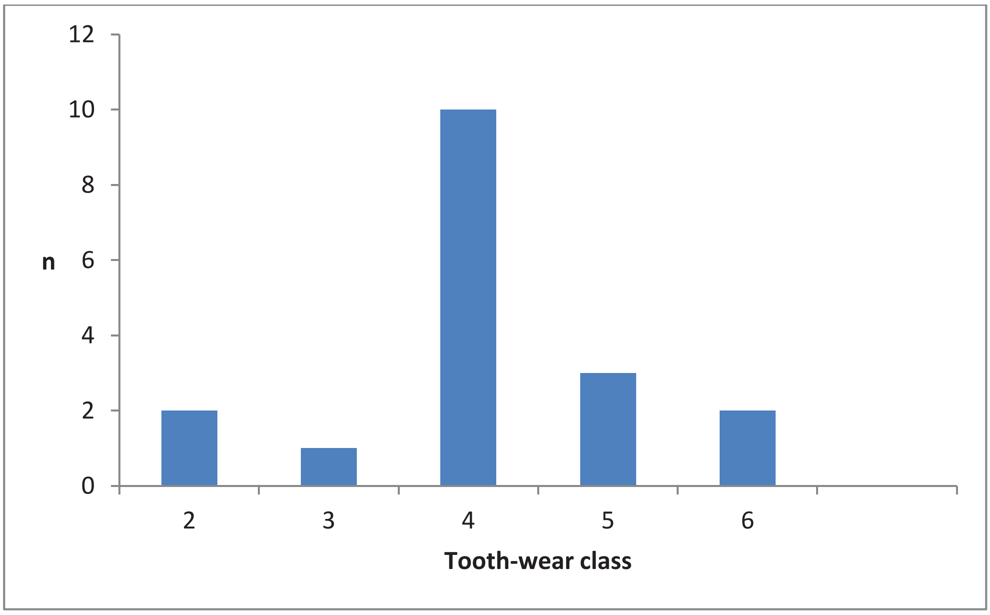


Figure 2.4 Tooth-wear/age- class frequency distribution of male koalas within the IPFA.

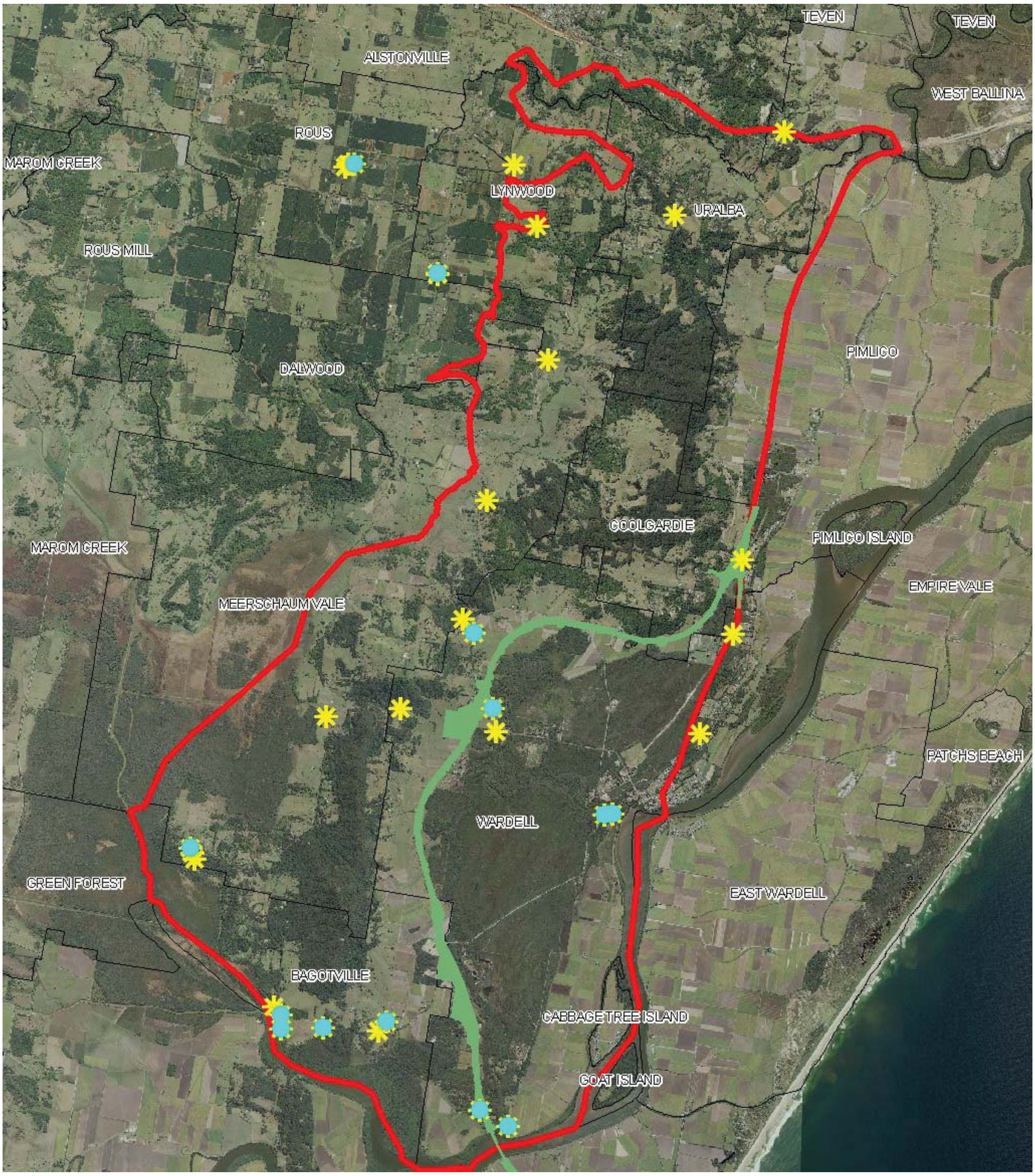


Figure 2.5 Locations of 13 breeding female koalas (blue highlighted asterisks) as a subset of all adult female koalas (n = 30) captured and screened within the IPFA.

2.3.3 Mortality rates

When averaged across all cohorts, annual mortality within the IPFA population was estimated at 9.94% ± 8.91% (SD). Table 2.2 provides a breakdown of the IPFA mortality estimates by gender-based cohort.

Table 2.2 Estimated mortality rates (M) for each of the six TWC cohorts represented in the IPFA koala population. Estimates are based on a sample of 32 female and 18 male koalas. Information in columns TWC and TWS reflect corresponding tooth-wear classes and associated scores of Gordon (1991) respectively. SD_{EV} is an estimate of the standard deviation of the mortality estimate due to environmental variation.

Age (years)	TWC	TWS	M(%)	SD_{EV}
Females				
1	1	P4A	19.7	11.63
2	2	P4B	19.7	11.63
3	3	P4C	26.21	15.48
4	4	P4D	7.34	4.33
5		P4D	7.34	4.33
6	5	P4E	5.37	3.17
7		P4E	5.37	3.17
8	6	P4F	2.76	1.63
9		P4F	2.76	1.63
10		P4F	2.76	1.63
Males				
1	1	P4A	19.45	11.49
2	2	P4B	19.45	11.49
3	3	P4C	30.56	18.05
4	4	P4D	4.3	2.54
5		P4D	4.3	2.54
6	5	P4E	6.29	3.71
7		P4E	6.29	3.71
8	6	P4F	2.92	1.73
9		P4F	2.92	1.73
10		P4F	2.92	1.73

2.3.4 General observations

Notwithstanding a low koala encounter rate over the greater proportion of the IPFA, in general terms captured koalas were in good condition, while chronic clinical expression of disease appeared to be primarily restricted to localities between Meerschaum Vale and Lynwood in the northern half of the IPFA. Of nine koalas taken to the FoK Care Centre during the course of the capture and screening program, four were euthanized on humanitarian grounds because of the extent of wasting/trauma/disease. Of the remaining five, two died upon arrival and were subsequently assessed as the consequence of an earlier vehicle-strike and sepsis respectively, while the remaining three (one adult and two sub-adults) were admitted for treatment at the Care Centre.

Evidence from the literature indicates that inbreeding depression and associated loss of genetic diversity will reduce resilience and evolutionary capacity, lower fitness and so increase the risks of extinction. Few morphological indications of potential inbreeding such as micro-cephaly, reduced body size/weights and/or other anomalies (e.g. undescended testicles) were observed amongst captured koalas. On this basis it is not considered likely that inbreeding depression will be a significant factor impacting on current baseline input parameters. Nonetheless, this parameter should be reappraised once the genetic analysis has been completed and may also need to be considered in conjunction with scenario modelling to accommodate potential future isolation effects associated with the conditionally-approved Section 10 upgrade.

Data from nine of the 51 koalas were obtained as a direct consequence of incidental mortalities due to domestic dog/fox attack (*n* = 3) and vehicle strike (*n* = 6) respectively. While it is acknowledged that the numbers of koalas killed by these two processes are grossly under-reported, an estimation of the actual numbers involved would assist the PVA modelling process. While some indication of the extent to which vehicle-strikes are under-reported is provided in Part 3, it is noteworthy that in terms of attacks by domestic dogs, local landholders in the Lynwood area have also advised of at least five unreported mortalities of sub-adult and adult koalas (including breeding females) over the five-year period 2010 – 2014, none of which are recorded in the publicly available databases.

2.3.5 Key outcomes

Demographic data was obtained from a subset of 51 koalas from the population inhabiting the IPFA, with koalas killed by vehicle-strike comprising almost 12% of those animals sampled over the course of the study. The population profile that emerges is of a relatively small and widely dispersed population primarily sourced from high density/carrying capacity red gum forests on the floodplains and swamp mahogany forests on coastal sands in the south-southwest of the study area.

The capture data indicates a population that is characterised by an approximately normal age-class distribution. Despite this, older animals were more commonly encountered in the north of the IPFA, implying that recruitment levels from the west and the south may not be sufficient to offset mortalities.

The female bias in the population is atypical compared to other populations we have assessed. The reasons for this are unclear, however given the results outlined in Part 3, we consider that this may be a reflection of male-biased mortality amongst sub-adult and older male cohorts. Clinical expression of disease was relatively low, constrained primarily to a small number of koalas in the north of the IPFA, while reproductive output by female koalas was higher in the south.

The average annual mortality rate across all cohorts was estimated at 9.94% ± 8.91% (SD) of the total population size.

PART 3
Analysis of FoK mortality data

3.1 Objectives

Understanding the factors that contribute to koala mortalities and so influence distribution, abundance and population trends over time is important if long-term, sustainable management outcomes are to be realised. The preceding demographic profile revealed a koala population with an average annual mortality rate of approximately 10% of total population size, the results implying amongst other things a high measure of male-biased mortality. The objective of this Part is to further investigate mortality data for the IPFA through analysis of records maintained by the FoK.

3.2 Methods

3.2.1 Data collection and partitioning

Records related to 'koala-calls' received by the Lismore-based FoK 24-hour rescue hotline for the Ballina LGA were provided for analyses. Amongst other things, attributes associated with each of these records include the date, location and underlying reason for the call, as well as the outcome, typically reported as either advice/record only, in-care, released, relocated or dead (including euthanasia).

At the LGA level, records were examined in order to describe general trends over time, followed by a partitioning and analyses of koala mortality data and the localities/contexts with which such data was associated. Because mortality data was of specific interest to the intended outcomes of this report, records that related to dead koalas were partitioned into four primary categories as detailed below. In instances where uncertainty relating to the cause of death was reflected in the mortality being attributed to more than one category, the score was partitioned accordingly (i.e. a cause of death may have been listed as 'dog attack/road-kill' in which case both categories of incidental mortality received a score of 0.5 each).

Further details for each of the four primary mortality categories are as follows:

A **natural** mortality was attributed to those records of koalas that were identified as having died from causes such as being aged and/or wasted (including instances of age and/or wasting associated with expression of disease). Juvenile koalas found dead on the ground or at the base of trees were also considered to have died from natural causes, as were those predated upon by a native animal or presumed to have died from misadventure such as falling from a tree.

A **symptomatic** mortality was assigned to deaths described as due to wet-bottom, conjunctivitis and/or blindness, organ failure and cancer/lympho-sarcoma, all of which tend to be typically associated with Chlamydiosis or Koala Retro-virus (KoRV) and generally considered attributable to stressors from anthropogenic related factors such as historical habitat loss or modification and/or genetic factors such as inbreeding.

An **incidental** mortality was one caused by vehicle-strike or domestic dog attack, or where injuries would suggest that either of these was the most probable cause of death (e.g. presence of a broken jaw, puncture marks).

A mortality due to **unknown** causes was attributed to records where the associated information in the database was generally insufficient to unambiguously identify a direct cause of death. Such records were subsequently discarded for the purposes of most of the analyses reported herein.

3.2.2 Data analysis

3.2.2.1 Koala-calls

Unless otherwise alluded to by the results herein, the majority of the derived data associated with callouts were enumerative. Because of this, most data were assumed to follow a poisson distribution. Hence, unless otherwise specified, the Standard Deviation was estimated using the formula previously detailed in Part 2.

Frequency histograms were used to show trends in the number of koala-calls over time, between months and by season, with regression analysis utilised to examine any potential relationships between time and the number of koala-calls that were received.

3.2.2.2 Mortality data

Mortality data was initially partitioned in terms of whether the record occurred within the IPFA or elsewhere in the LGA, a *t*-test was used to examine differences in the annual numbers of dead koalas between the two areas. Chi-square analyses were then used to examine differences in mortality frequencies for each of the primary categories between the two constituent parts of the LGA. Thereafter analyses were restricted to only those records that occurred within the IPFA. Frequency histograms were again used to show trends in the mortality data over time.

Amongst other things, a requirement of koala population management is knowledge regarding the extent to which mortalities beyond those that occur naturally in the population will influence population trends over time. Such knowledge is especially important where mortalities may be a direct result of human activity in the form of either vehicle-strike or domestic dog attack. An estimate for the number of koala deaths due to vehicle-strike that are not reported can be derived from data collected by Phillips and Fitzgerald (2014)[14] whereby 12 of the 27 records compiled for a 50 km length of the Pacific Highway between Chinderah and Ewingsdale in Byron and Tweed LGAs were not otherwise included in publicly available databases. Such knowledge enables an estimate of the number of unreported koala road-kills of 44.44% ± 18.74% (95% Confidence Interval). At least six koalas were killed by vehicle-strike in the IPFA during the course of the demographic study; while numbers of previously unreported domestic dog attacks were also obtained (Part 2 refers).

In addition to incidental harvests of koalas due to vehicle-strike and domestic dog attack, increased mortalities may also result from elevated disease levels in areas where individual animals and populations are subject to traumas or where populations remain isolated from each other through historical and ongoing processes of habitat fragmentation. In such cases, inbreeding arising from a long period (i.e. many koala generations) of isolation may also have some bearing on both the stress response and incidence of disease and associated mortality levels. However, depressed fecundity and/or an increase in mortalities due to disease may also be a part of a naturally occurring, density–dependent phenomenon that enables population regulation.

---

[14] A review of koala road-kill data and issues relating to underpass use by koalas: Pacific Highway upgrades from Clothier's Creek to Ewingsdale, NSW. Final report to NSW Roads and Maritime.

3.2.3 Standardising road-kill

Within the IPFA road-kill data were standardised across Council and State-managed roads in terms of the minimum number of koalas being killed per kilometre per year; this was done by initially defining the distance of the road traverse along which the road-kill records were distributed and then averaging the number of koalas killed per kilometre along these sections of road annually over the time period for which records were available. Any additional NSW Wildlife Atlas koala road-kill records along these roads for the same time span as that covered by the FoK records were also considered in these calculations.

In order to investigate for potential correlations between any peaks in disease-related mortality and climatic fluctuations, rainfall data was obtained from historical records available through the Australian Government's Bureau of Meteorology website. Rainfall over the period to which the records related was estimated by averaging annual rainfall figures from up to nine weather stations; Ballina Airport, Meerschaum Vale (Bardon), Meerschaum Vale (jbd), Coraki, Woodburn, Evans Head (bombing range), New Italy, Lismore Airport and MacLean's Ridges.

3.3 Results

3.3.1 Koala-calls

The FoK database contained details of 472 koala calls that were received over a 26-year period from 1989 to 2014, the frequency of calls over this time period (Figure 3.1) averaged approximately 18 annum^{-1} (Mean no of calls: 18.15 ± 9.72 (SD), range 4 - 38), increasing significantly over time ($r^2 = 0.411$, $F = 16.75$, $P < 0.001$). For each of the key mortality drivers of domestic dog attack, vehicle-strike and symptomatic disease, the annual proportion of koala-calls related to these categories did not vary significantly over the 26-year period to which the records relate (dog attack: $r^2 = 0.008$, $F = 0.1134$, $P = 0.7413$; vehicle-strike: $r^2 = 0.0106$, $F = 0.2029$, $P = 0.6575$; disease: $r^2 = 0.0034$, $F = 0.0752$, $P = 0.7865$).

Rainfall over the 26-year period to which the records relate averaged 1,588 mm annum^{-1} (Standard deviation: ± 414 mm; Range: 1035 – 2808 mm), the driest years occurring in 1992 and 2002, the wettest in 1999, 2008 and 2010 (Figure 3.2).

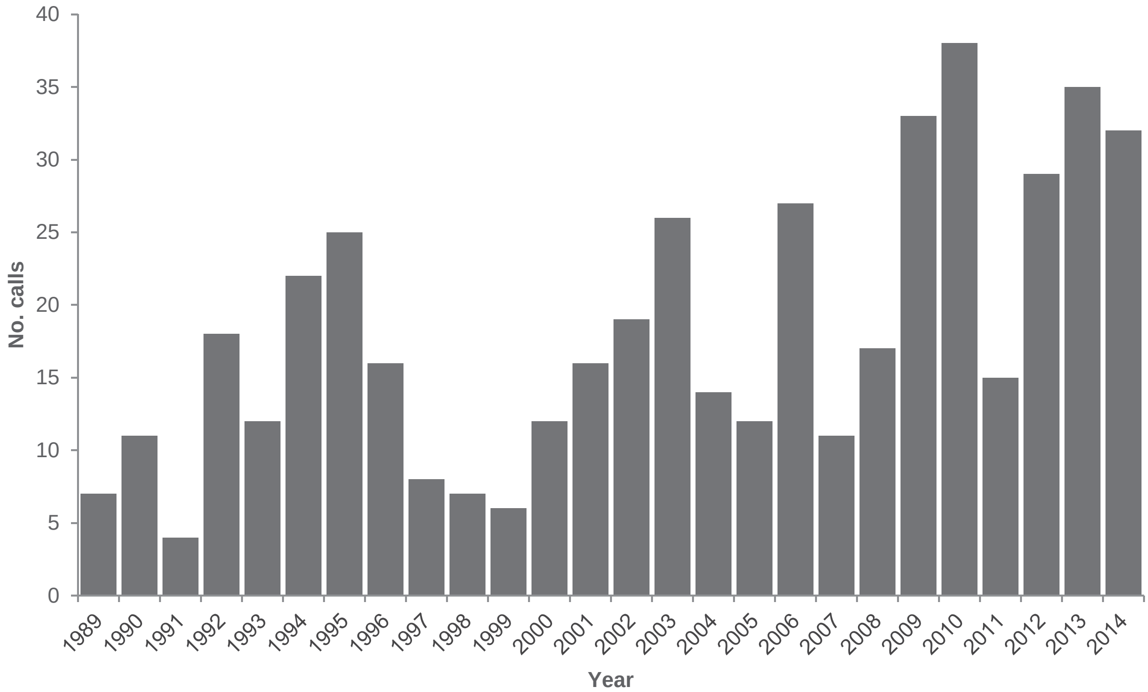


Figure 3.1 Numbers (n) of koala-calls received by FoK from across the Ballina LGA between 1989 and 2014.

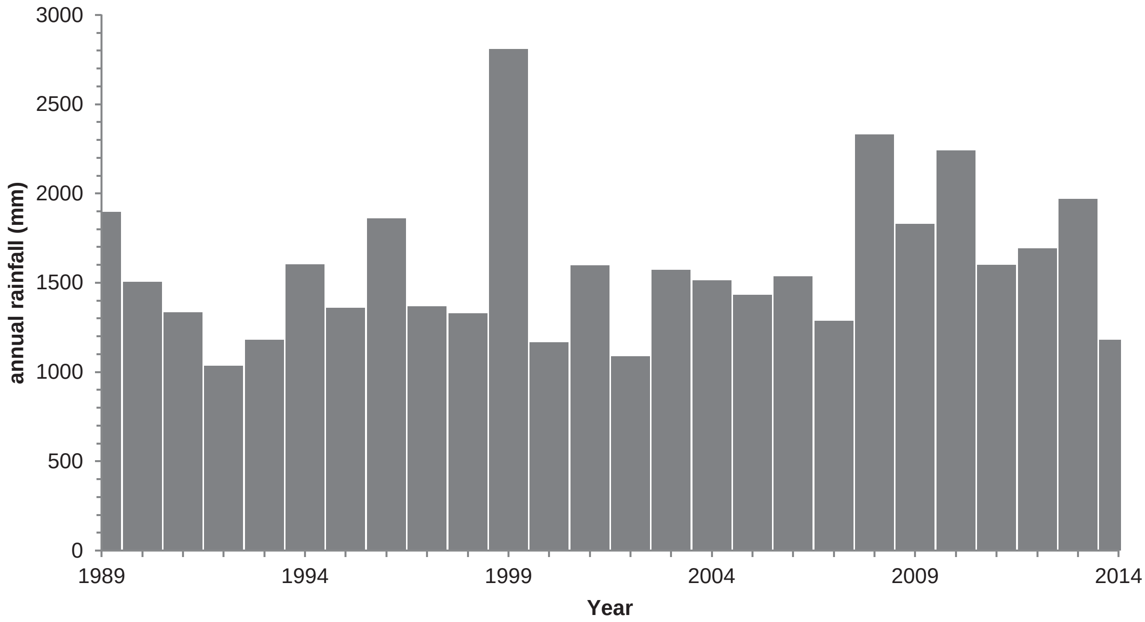


Figure 3.2 Annual averaged rainfall totals for the area covering the IPFA over the period 1989 – 2014 (Source Australian Bureau of Meteorology). Totals have been estimated from a series of up to nine weather stations in and immediately adjoining the study area.

Koala-calls were most frequently received between the months of July and January, peaking over Spring. All cohorts were represented in the call-out records, including orphaned joeys, females with pouch or back-young and aged koalas. Male koalas were more likely to be the subject of a koala call than were female koalas (X^2 = 23.273, 1_{df}, $P < 0.001$). Figure 3.3 illustrates trends in the frequency of koala calls by month and season.

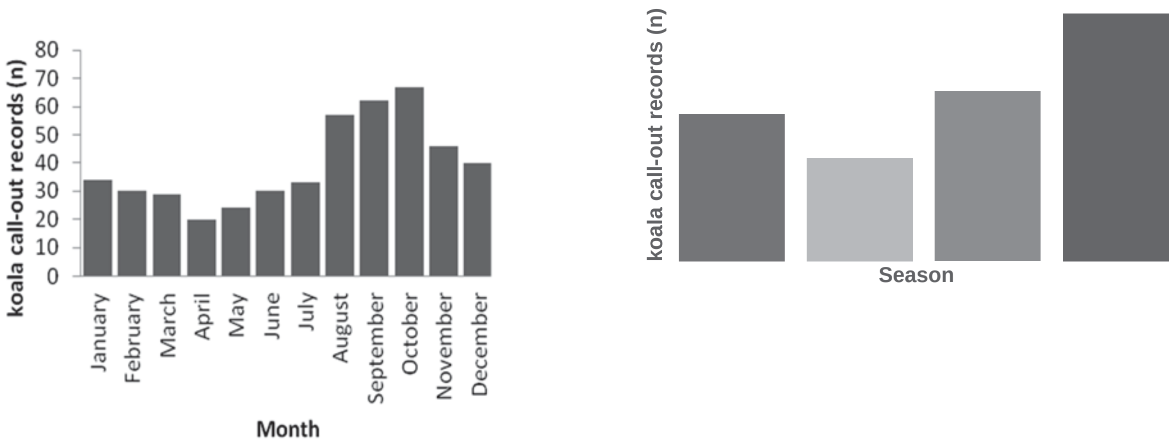


Figure 3.3 Monthly and derived seasonal trends in FoK koala-calls from across the Ballina LGA between 1989 and 2014.

3.3.2 Mortalities across the LGA

Of the 472 calls responded to by FoK, approximately 46% (*n* = 217) resulted in the death of the koala. Across the LGA, known mortalities averaged approximately 8 koalas a year [Mean = 8.34 ± 4.45 (SD), the numbers of which while trending upwards over time appear to have remained relatively stable (r^2 = 0.0406, *F* = 1.0145, *P* = 0.3239). Approximately 75% of all known mortalities (162/217) were from within the IPFA, the mean number of known annual mortalities therein (Mean = 6.23 ± 3.68 (SD) significantly higher than elsewhere in the LGA (6.23 *vs* 2.12 known mortalities annum^{-1}; Levene's Test: *F* = 3.364, 25_{df}, P < 0.01; *t* = 5.006, 39_{df}, P < 0.001).

Excluding 68 mortalities where the primary cause of death was recorded as 'unknown', the major contributors to koala mortality across the Ballina LGA were disease and vehicle-strike respectively, both of which collectively accounted for 69% of cause-known koala mortalities. Attacks on koalas by domestic dogs accounted for a further 20% of known mortalities, the remaining 11% recorded as being due to natural causes. Significantly, incidental mortalities due to vehicle-strike and domestic dog attack collectively comprised more than 50% of all cause-known koala mortalities annually. Table 3.1 further partitions the primary causes for koala mortalities in terms of the IPFA and the remainder of the LGA.

Table 3.1 . Numbers of known koala mortalities and attributed causes across the Ballina LGA from 1989 – 2014, partitioned in terms of occurrence either within the IPFA or elsewhere in the LGA. Numbers of mortalities attributable to unknown causes are provided in brackets but are not included in totals.

Area/Cause	Dog Attack	Road	Natural	Disease	Unknown	Totals
BLGA (part)	3	19.5	5	12.5	(15)	**40**
IPFA	22	35	12	40	(53)	**109**
BLGA (all)	**25**	**54.5**	**17**	**52.5**	(68)	**149**

With the exception of attacks on koalas by domestic dogs which were significantly higher in the IPFA when compared to the rest of the LGA, there were no significant differences between the IPFA and the remainder of the LGA in terms of the frequencies of mortalities attributable to other causes (Vehicle-strike: X^2 = 2.999, *P* = 0.083; Natural: X^2 = 0.064, *P* = 0.8 and Disease: X^2 = 0.578, *P* = 0.447).

3.3.3 IPFA mortalities

3.3.3.1 Natural causes

Database records for the IPFA contained 12 records where the cause of death was considered to be due to natural causes, this category comprising 11.01% ± 3.0% (SD) of all mortalities where cause of death was known.

3.3.3.2 Incidental causes

Domestic dog attacks

Database records for the IPFA contained 22 records of known koala mortalities where the cause of death was assessed as being due to an attack by a domestic dog, this category comprising approximately 20.18% $\pm$ 3.85% (SD) of all incidental mortalities within the IPFA where the cause of death was known. Despite what otherwise appears to be a downward trend in the number of fatal domestic dog attacks on koalas being reported over the last decade (Figure 3.4), regression analysis did not attribute a measure of significance to the trend at this point in time (r^2 = 0.0076, F = 0.084, P = 0.7769).

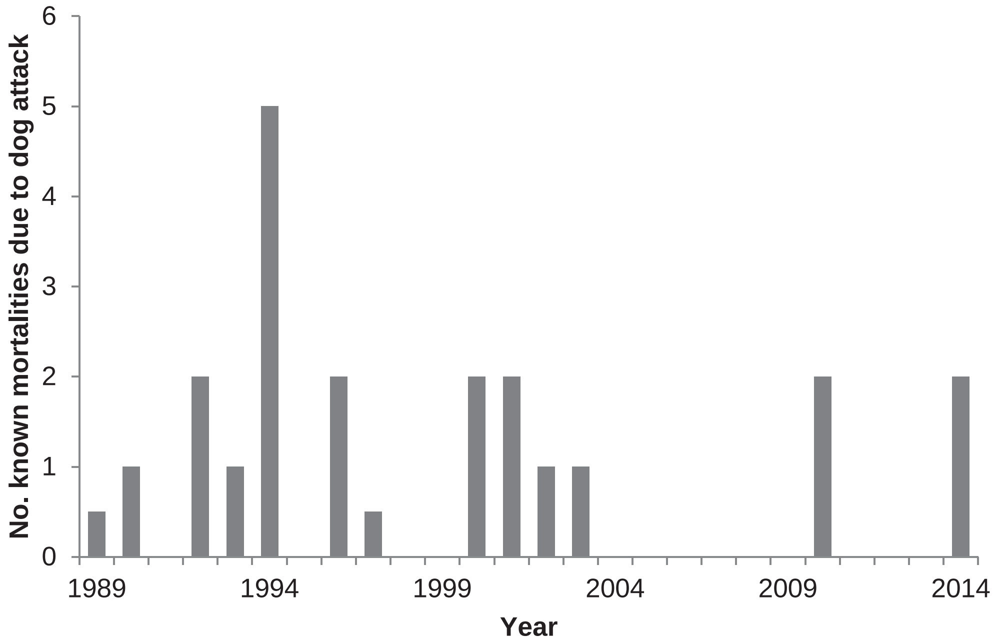


Figure 3.4 Numbers of known koala mortalities across the IPFA that were attributed to attacks by domestic dogs over the time period 1989 – 2014.

Attacks on koalas by domestic dogs were most commonly reported from the Meerschaum Vale area (36%) followed by Coolgardie (18%), Wardell (14%), Bagotville (14%) and thereafter other localities including Uralba, Lynwood and Cabbage Tree Island. Based on the raw data there did not appear to be a significant difference in the frequencies of male (n = 10) and female koalas (n = 12) that were known to have died as a consequence of domestic dog attack.

The <u>minimum</u> number of annual koala mortalities within the IPFA that can be estimated as directly attributable to attack by domestic dogs was 1.64 ± 0.33 (SD) koalas annum^{-1}.

Vehicle-strike

Following disease, vehicle-strike was the second largest contributor to koala mortality within the IPFA, responsible for 32.11% ± 4.47% (SD) (n = 35/109) of all cause-known koala deaths between 1989 and 2014. Death from vehicle-strike was most commonly recorded from the localities of Meerschaum Vale (34%), Wardell (26%) and Alstonville (26%). The roads in these areas where vehicle strike was most commonly recorded include the Bruxner Highway to the east of Alstonville down to the intersection with the Pacific Highway (23%), Bagotville and Wardell Roads (21% and 13% respectively) and the Pacific Highway between Wardell and the Bruxner Highway intersection (11%). Remaining vehicle strikes were recorded from several minor roads elsewhere in the IPFA. None of the aforementioned roads have dedicated mitigation structures in place.

Figure 3.5 illustrates trends in the reported numbers of koalas being killed by vehicle-strike over the 26-year period to which the records relate, the number of known mortalities not appearing to have varied significantly over time (r^2 = 0.044, F = 0.7835, P = 0.3884). However, male koalas were nearly twice as likely to be the victim of vehicle-strike than were female koalas (Ratio: 1.80: 1.00; X^2 = 4.571, P = 0.033).

The minimum number of annual koala mortalities attributable to vehicle-strike is 2.00 ± 0.30 (SD) koalas annum^{-1}.

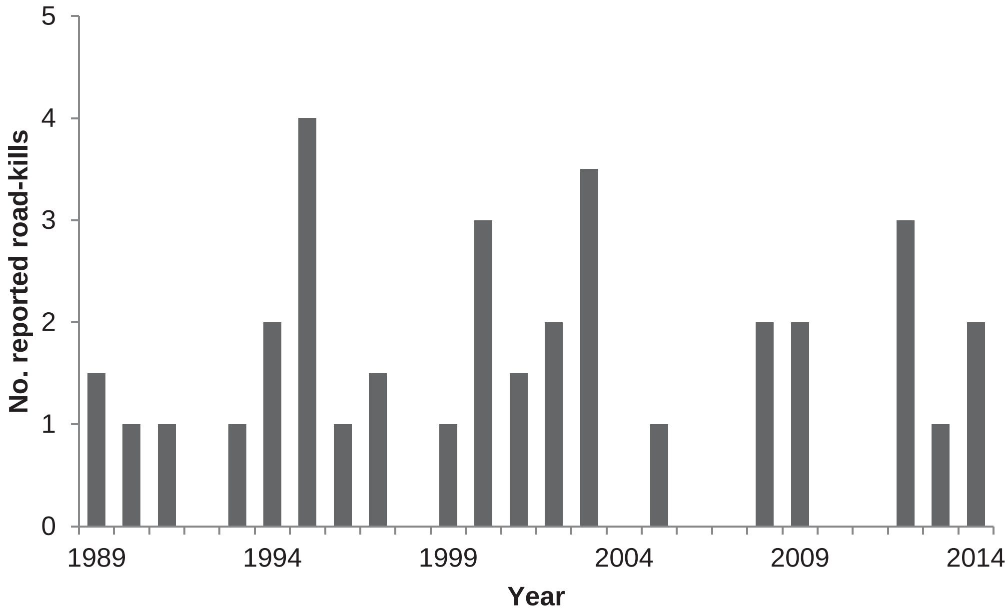


Figure 3.5 Numbers of known koala mortalities across the IPFA attributable to vehicle-strike over the time period 1989 – 2014.

Standardized in terms of the number of koalas kilometre^{-1} annum^{-1}, Table 3.2 further partitions vehicle-strike data to identify those roads within the IPFA where mortalities were most commonly reported. This approach identified the section of the Bruxner Highway to the east of Alstonville down to the intersection with the Pacific Highway as making the highest contribution to vehicle-strike mortalities within the IPFA (Table 3.2).

Table 3.2 Standardised koala vehicle-strike data for major roads within the IPFA. Numbers in brackets represent additional (i.e. non-FoK) records from NSW Wildlife Atlas that have been included in the "n" value being used. The values in the "Average" column were calculated by dividing "n" by the number of years (26) to which the data relate.

Road	*n*	Average	km	no. koalas km^{-1} $annum^{-1}$
Pacific Highway	7(3)	0.269	10.5	0.026
Bruxner Highway	8	0.308	5	0.062
Wardell Road	9.5(5)	0.365	9	0.041
Bagotville Road	7.5	0.288	8.5	0.034

Disease

Disease-related deaths were the single biggest contributor to koala mortality across the IPFA, responsible for approximately 36.7% ± 4.62% (SD) (n = 40/109) of all cause-known koala deaths between 1989 and 2014, the most commonly recorded cause being "Conjunctivitis/Cystitis". Diseased koalas were most commonly reported from the Alstonville/Uralba and Meerschaum Vale localities (33% and 30% respectively).

Changes in the numbers of koalas known to have died from disease over the period 1989 – 2014 are illustrated in Figure 3.6 and arguably infer the presence of a cyclical phenomenon occurring across the IPFA landscape with peaks over 15 – 17 year time frames. Similar apparent cycles have been detected recently for the Richmond Valley Council area by Phillips and Weatherspoon (2015)[15]. It is noteworthy that the two peaks illustrated in Figure 3.6 do not arise in the same areas (and thus in a spatial sense are mutually exclusive), that for the period 1994 – 96 associated with the Meerschaum Vale and Wardell localities while that for 2007 – 2009 appears to be primarily associated with the localities of Coolgardie and Uralba. Equal numbers of male and female koalas were recorded as dying from disease.

[15] Koala Habitat & Population Assessment: Richmond Valley Council LGA. Final Report to Richmond Valley Council. Biolink Ecological Consultants, Uki NSW.

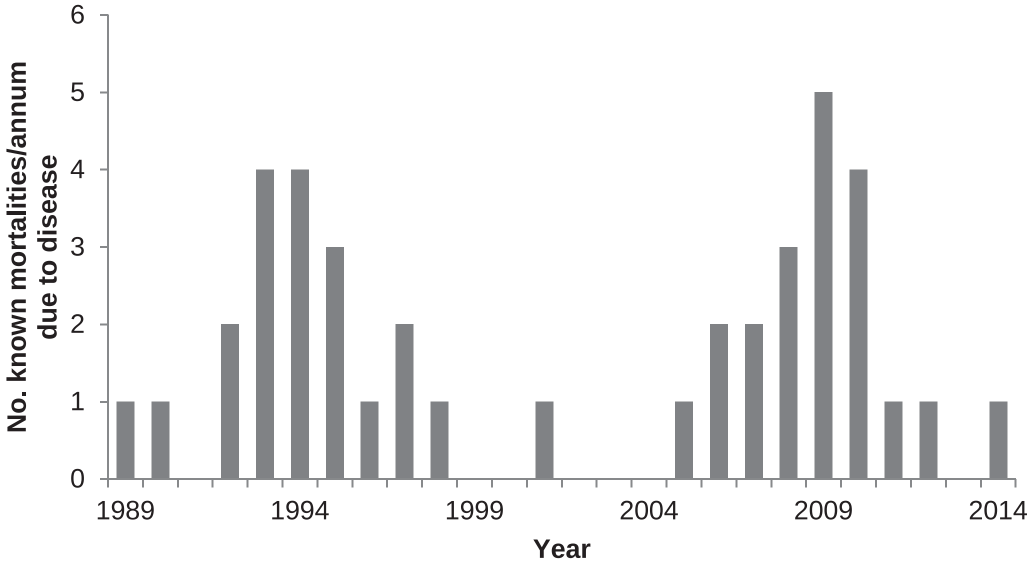


Figure 3.6 Numbers of known koala mortalities attributable to disease within the IPFA over the time period 1989 – 2014.

3.4 Key outcomes

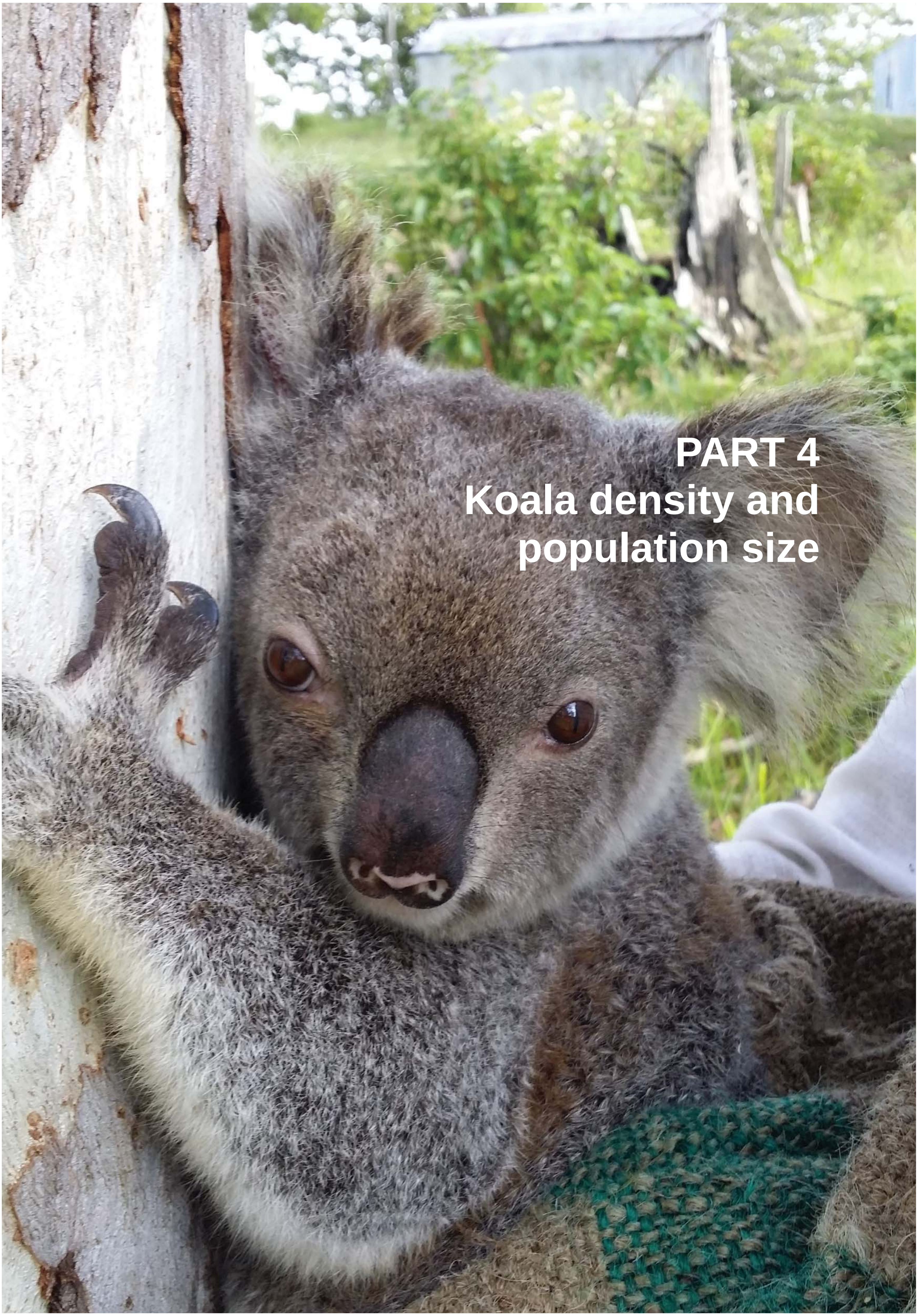
Koala call-out data provided by FoK for the Ballina LGA was available for the 26-year time period between 1989 and 2014. The majority of koala call-outs and associated mortality data across the Ballina LGA were derived from the IPFA, *defacto* confirming the latter area as a significant population centre for koalas in the LGA.

Incidental mortalities due to domestic dog attack and vehicle strike comprise more than 50% of all known koala mortalities on an annual basis. Concordant with the male-biased mortality earlier alluded to by the results obtained in Part 2 of this report, significantly greater numbers of male koalas are being killed within the IPFA by vehicle strike than are female koalas. The six koalas known to have been killed by vehicle-strike within the six-month period of the demographic study exceeds the maximum number of koalas known to have been killed annually by motor vehicles over the 26 year period to which the FoK records relate.

Changes in the numbers of koalas known to have died from disease over the period 1989 – 2014 implies the presence of a cyclical phenomenon occurring at a landscape scale with two peaks 15 – 17 years apart. Based on the information contained in this section, the peaks appear to be independent of climatic considerations such as low rainfall cycles, while levels of incidental harvest have remained relatively constant over the time period between the two peaks. In the absence of other data, this outcome potentially points to a largely unrecognized role of disease as a primary regulator of koala abundance across the IPFA. The extent to which anthropogenic-related causes such as habitat loss and/or modification may contribute to this mortality cycle remain speculative and problematical to differentiate.

Standardising the road-kill data clearly enables koala black spots to be better identified and (if required) prioritized for remedial action. The variable '*no. koalas killed* km^{-1} *annum*$^{-1}$' enables koala black spots to be prioritized for remediation while also having utility for PVA purposes by enabling adjustment of road-kill potential along areas affected by the conditionally approved Section 10 upgrade. Based on data collected from roads to the north and observations from this study, a multiplication factor of between 2 (minimum) and 3 (precautionary) would appear necessary if any meaningful estimation of the real numbers of koalas being killed annually by vehicle strike is required.

Key anthropogenic drivers of koala mortalities such as vehicle-strike are typically density-dependent harvesting mechanisms that operate at population level. While the downward trend in fatalities due to domestic dog attack was not statistically significant, it may also reflect an increasing absence of koalas in areas where domestic dog densities are high and dog ownership is long standing. In contrast, the lack of any significant change in the numbers of koalas being killed by vehicle strike over the 26 years to which the records relate may imply little change in the numbers of koalas inhabiting the IPFA over this period.



PART 4
Koala density and population size

4.1 Objective

To refine the previous koala density and population estimate arising from the BKS in order to derive a better understanding of the size of the koala population inhabiting the IPFA. This estimate provides a key input parameter (i.e. initial population size) for the PVA modelling process.

4.2 Methods

4.2.1 Site selection

Seventy-two locations within the IPFA were identified as potential field survey sites. Forty two of these sites were originally sampled for purposes of the BKS, while a further 30 higher resolution sites focused specifically on the proposed Section 10 alignment for the additional survey work reported by Ecosure (2014)[16]. Direct counts of koalas within a 25 m fixed radius (0.196 ha) at each field site had been undertaken as a component of the BKS survey program. This work provided an initial density estimate ($Ø_1$) of 0.12 ± 0.05 (SD) koalas ha^{-1} within the IPFA.

4.2.2 Field survey

The group of 72 potential survey sites was reduced to 59 by excluding sites located in areas of dry rainforest and camphor laurel. At these latter locations, direct counts of koalas were undertaken along transects that were 250 m in length and 40 m in width to cover a total area of approximately one ha. Direct counts of koalas at each transect site involved three observers walking ~ 20 m apart, one on the centre line and one on either side. Transects were generally oriented north-south (on flat to undulating terrain) or along the contour (on steeper terrain) and were generally commenced 125 m from the site co-ordinates, continuing for a further 125 m past this location.

4.2.3 Koala density/population estimate

Because of the larger area being searched when compared to the 25 m radius searches that were undertaken for purposes of the BKS, it was envisaged that a second and more refined koala density estimate ($Ø_2$) for the IPFA would be obtained by dividing the theoretically greater number of koalas counted during transect searches by the pooled search area of all transects. The resulting density data could then be extrapolated across the total area of preferred koala habitat (2,152 ha) mapped within the IPFA (see Part 1) in order to derive a population estimate.

[16] *Woolgoolga to Ballina koala preconstruction surveys - final report*, Report to Roads and Maritime Services, West Burleigh

4.3 Results

4.3.1 Survey effort

Forty-six field sites were surveyed between 13 April and 24 April 2015 covering a total search area of 45.34 ha. Thirteen of the 59 targeted sites could not be accessed due to either inundation of low-lying coastal sections of the IPFA or retraction of earlier consents from land owners on whose properties the sites were located.

4.3.2 Koala sightings

Eleven koalas were sighted during the course of the surveys, three of which were recorded within the 45.34 ha covered by the transect searches, the remainder elsewhere within the IPFA while traversing between survey sites. Three of the koalas that were observed, including one from the transect surveys, had been previously captured as part of the demographic profiling component of this project (Part 2 refers).

The distribution of survey sites and the location of koala sightings are illustrated in Figure 4. 1. with individual site coordinates and further details provided in Appendix 2

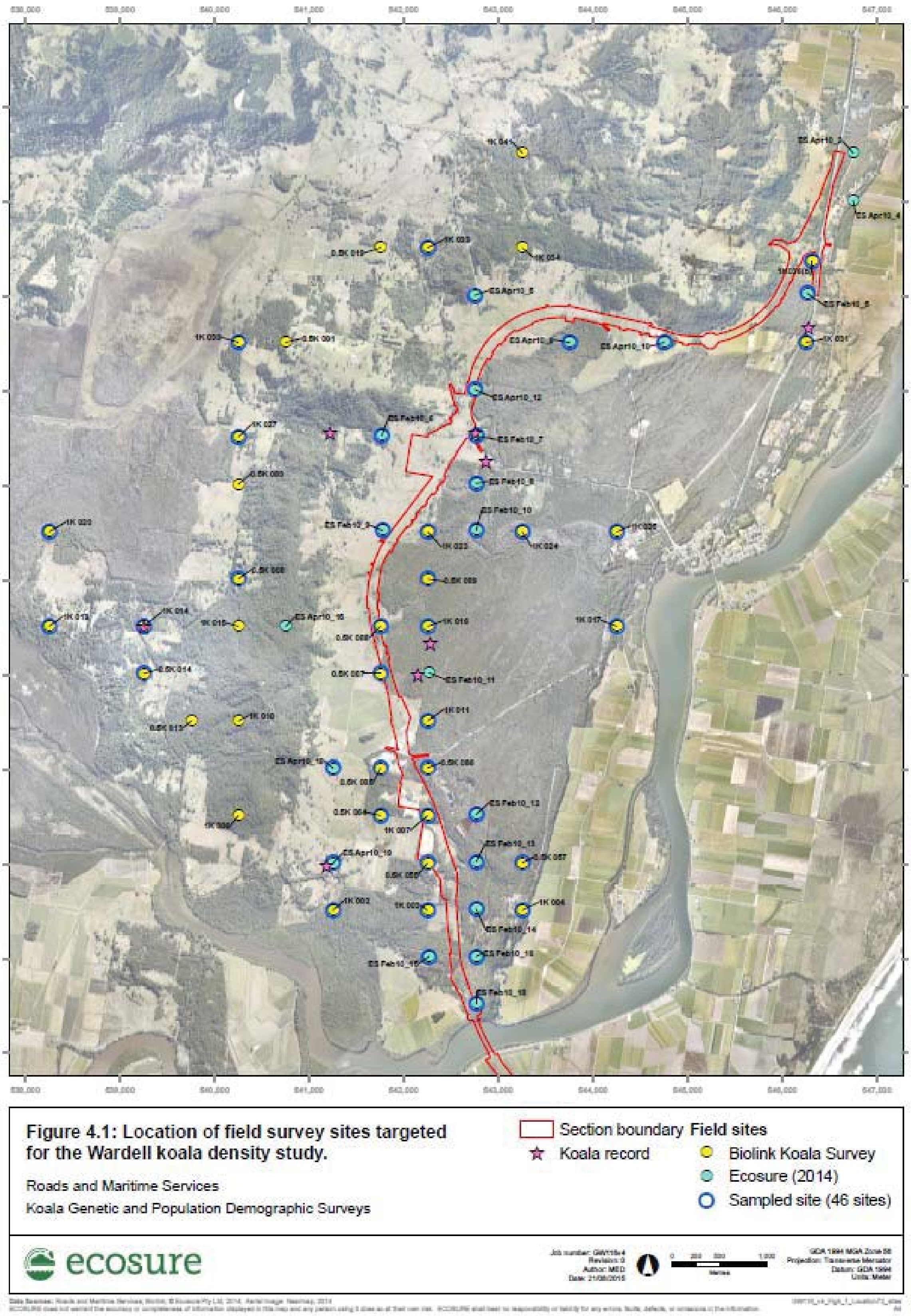


Figure 4.1 Location of 72 field survey sites targeted for the Wardell koala density study. Blue sites represent sites from Ecosure (2014) and yellow represent sites from the BKS.

4.3.3 Koala density/population estimate

Based on the presence of three koalas within the 45.34 ha covered by the transect searches, koala density ($Ø_2$) was estimated at 0.066 ± 0.037 (SD) koalas ha^{-1}. When this density estimate was extrapolated across the 2,152 ha of preferred koala habitat within the IPFA a population estimate of 142 ± 80 (SD) koalas resulted which was lower than the original estimate of 259 ± 107 (SD) derived from the BKS data. In order to lessen the uncertainty around these estimates and guided by the work of Roberts and Binder (2009)[17] we pooled survey outcomes arising from the BKS field surveys with those of this survey to obtain a refined density estimate ($Ø_3$) as follows:

$$Ø_3 = (n_1Ø_1 + n_2Ø_2)/(n_1 + n_2) \quad \text{(Eqn 3)}$$

Where:

$Ø_3$ = refined koala density estimate

$Ø_1$ = density estimate from previous work; 0.12 ± 0.05 (SD) koalas ha^{-1}

$Ø_2$ = density estimate from this study; 0.07 ± 0.04 (SD) koalas ha^{-1}

n_1 = number of survey sites associated with $Ø_1$

n_2 = number of survey sites associated with $Ø_2$

with a Standard Deviation of:

$$\sigma = \surd(Ø_{3*}(1-Ø_3)/(n_1 -1 + n_2 -1) \quad \text{(Eqn 4)}$$

Where:

σ = standard deviation of the refined estimate

$Ø_3$ = refined koala density estimate

n_1 = number of survey sites associated with $Ø_1$

n_2 = number of survey sites associated with $Ø_2$

This approach yielded a refined density estimate of 0.091 ± 0.03 (SD) koalas ha^{-1} and a corresponding population estimate for the IPFA of 196 ± 65 (SD) koalas

[17] Analyses based on combining similar information from multiple surveys. *Journal of Statistical Mechanics*. 2138 – 2147.

4.4 Key outcomes

Previous survey work undertaken for the BKS by way of 25 m fixed radius searches for koalas at 42 field sites across the IPFA yielded a koala density estimate of 0.12 ± 0.05 (SD) koalas ha^{-1} and a consequent population estimate of 259 ± 107 (SD) koalas.

Direct counts of koala numbers were undertaken in 46 x 1 ha transects uniformly distributed across the IPFA. Eleven koalas were sighted, three of which were recorded in the 45.34 ha covered by the transect searches to provide a density estimate of 0.07 koalas ha^{-1}, with a corresponding population estimate for the IPFA of 142 koalas. Three of the 11 koalas that were sighted during the survey program had previously been captured for purposes of the demographic study reported elsewhere (Part 2 refers).

Despite a low koala encounter rate in both survey events, pooling of survey results from both the BKS and this assessment enabled a more refined density estimate to be derived resulting in a population estimate of 196 ± 65 (SD) koalas across the IPFA.

PART 5
Koala metapopulation distribution east of the proposed section 10 upgrade

5.1 Objectives

Accurately determining the distribution of koala populations across a given landscape is essential for koala population conservation and management planning. This component of the overall project was focussed on the following objectives:

(i) To further refine/improve knowledge about the location and extent of areas currently occupied by resident koala populations to the east of the conditionally-approved highway alignment; and

(ii) To identify areas of suitable habitat that are currently unoccupied or that appear to currently support transient use by koalas that may be suitable for consideration as potential translocation sites if required.

5.2 Methods

5.2.1 Survey area

The survey was restricted to an area of approximately 1,750 ha north of the Richmond River, west of the existing Pacific Highway alignment and associated urban environment of Wardell and east of the conditionally-approved alignment for the Section 10 upgrade (Figure 1 refers). With the exception of some elevated lands in the southwest, the majority of koala habitat in the survey area is comprised of low-lying swamp and dry sclerophyll woodlands and forests and heathlands on coastal sandplains and alluvial deposits. As detailed by the BKS, koala habitat in the lower-lying areas is determined by the localised presence of swamp mahogany *E. robusta*, forest red gum *E. tereticornis* and the naturally-occurring hybrid between these two species (sometimes referred to as *E. patentinervis*) while in more elevated sections of the survey area, tallowwood *E. microcorys* is typically the most important koala food tree species.

5.2.2 Survey design

A 350 m point-based grid overlay anchored to the original 500 m BKS grid was initially utilised to sample koala activity/density, with primary field sites located wherever grid intersections occurred in areas of native vegetation containing eucalypts. Supplementary field sites were subsequently included at intermediate intervals between high or medium use and low use sites[18] in order to further inform the modelling process by more precisely delineating areas of significant koala activity. Coordinates for each site were uploaded into hand-held GPS receivers (GDA94 datum) in order to assist navigation in the field. Where necessary the precise location of sites was adjusted in the field to avoid areas of temporary inundation and/or to incorporate eucalypts within the sample. Landowners were contacted to seek permission before entering private properties that contained survey sites.

5.2.3 Site assessment

Once located, each site was sampled using the Spot Assessment Technique (SAT) of Phillips and Callaghan (2011)[19]. A default high use activity level was applied as soon as ten trees scored positive for koala faecal pellets at any site, thus surpassing the minimum threshold for classification as high use. Conversely, if the first 25 trees scored negative for faecal pellets, a default low use activity level was applied as this outcome would not change regardless of the score for the remaining five trees at the site.

In accordance with the SAT, the results of field survey are described in terms of 'active sites' and 'koala activity'. An active site is any site where one or more koala faecal pellets were recorded in the search catchment around the base of one or more of the sampled trees, while the associated koala activity level is calculated as the percentage of surveyed trees that

[18] As defined by: Phillips, S. and Callaghan, J. 2011.

[19] The Spot Assessment Technique: a tool for determining localised levels of habitat use by Koalas. *Australian Zoologist*. **35(3)**: 774-80.

scored positive for the presence of koala faecal pellets (Eqn 5 refers).

$$\text{Activity Level} = \frac{\text{Number of trees with faecal pellets}}{\text{Number of surveyed trees}} \times 100 \qquad \text{(Eqn 5)}$$

5.2.4 Koala activity modelling

Koala activity data from all sampled field sites were interpolated across the study area using regularised, thin-plate splining techniques through the spatial analyst extension in ArcGIS 9.3. To assist this process null points were incorporated into the modelling process at regular intervals (~ 100 m) in order to (i) delineate major distributional and/or dispersal barriers such as the Richmond River, and (ii) constrain the modelling process to areas east of the conditionally-approved highway alignment. The general approach is explained in more detail within Phillips *et al.* (submitted)[20].

The output from the splining process was then utilised to produce an activity contour model to delineate areas occupied by resident koala populations by identifying those contours concordant with the 10%[21], 23% and 33% significant activity thresholds of Phillips and Callaghan (2011) as detailed in Table 5.1. Additional contours were included in the activity model as required to assist with interpretation of connectivity.

Table 5.1 Categorisation of koala activity based on use of mean activity level ± 99% confidence intervals for each of three area/population density categories. Activity levels in the Medium (normal) and High use range indicates occupancy by resident koala populations (Source: modified from Phillips and Callaghan 2011).

Activity Category	Low use	Medium (normal) use	High use
Area (koala density)			
East Coast (low)	-	≥ 9.99% but ≤ 12.59%	> 12.59%
East Coast (med-high)	< 22.52%	≥ 22.52% but ≤ 32.84%	> 32.84%

5.2.5 Koala density estimates

Independent of the transect searches reported in Part 4, a 25 m fixed-radius (0.196 ha) search for koalas was undertaken around the centre tree at each SAT survey site irrespective of the resulting activity level. A koala density estimate could then be derived by dividing the total number of koalas recorded in the 25 m fixed-radius searches associated with each primary field site, by the sum of the areas searched using this method. Supplementary field sites were not included in this assessment.

[20] Modelling koala population structure across the landscape in order to provide greater certainty for conservation and management purposes. *Landscape and Urban Planning.*

[21] Applies only to low nutrient elevated sites in the extreme south of the survey area.

5.3 Results

5.3.1 Koala activity

Surveys were undertaken between 27 April and 22 June 2015, during which time 53 primary and 23 supplementary field sites were assessed. Preferred koala food trees were present in 22 of the 53 primary field sites that were sampled (41.51%).

Evidence of koala activity (i.e. koala faecal pellets recorded beneath at least one tree within a given field site) was detected at approximately 55% (29/53) of the primary field sites wherein koala activity levels ranged from 3.33% to 100% (mean activity level (active sites only): 19.42% ± 7.48% [SD]). Nine of the primary field sites returned significant (i.e. medium or high) koala activity levels (i.e. >22.52% activity for med-high population density sites on coastal lowlands, plus one >9.99% low-density site on elevated erosional soils in the south) consistent with the presence of resident koala populations. When considered in the context of the total number of primary field sites that contained preferred koala food trees (*n* = 22) these data enable an occupancy estimate of 40.91% ± 10.73% (SD) across the area covered by the survey program. As with the density survey detailed in Part 4 of this report, heavy rainfall and inundation of low-lying areas in the week preceding the commencement of surveys impeded access to a number of low-lying, swamp forest sites in central parts of the survey area.

The distribution of survey effort across the survey area is illustrated in Figure 5.1, while the associated site coordinates and resulting activity levels are detailed in Appendix 3.

Figure 5.1 Location of 53 field survey sites used for the Wardell koala meta-population study. Surveyed primary field sites are shown as large green dots, those that returned significant activity levels highlighted in blue, supplementary sites are shown as small green dots

5.3.2 Koala density

One koala was recorded within the 10.39 ha of habitat collectively sampled by the 53 x 25 m radial koala searches undertaken at primary field sites. This data translates to a koala density estimate within the area surveyed by this study of approximately 0.096 ± 0.08 (SD) koalas ha^{-1}.

5.3.3 Activity modelling

Koala activity was discretely clustered around suitable habitat areas predominantly located around the periphery of the survey area. The resulting koala population distribution model based on the koala activity is provided in Figure 5.2.

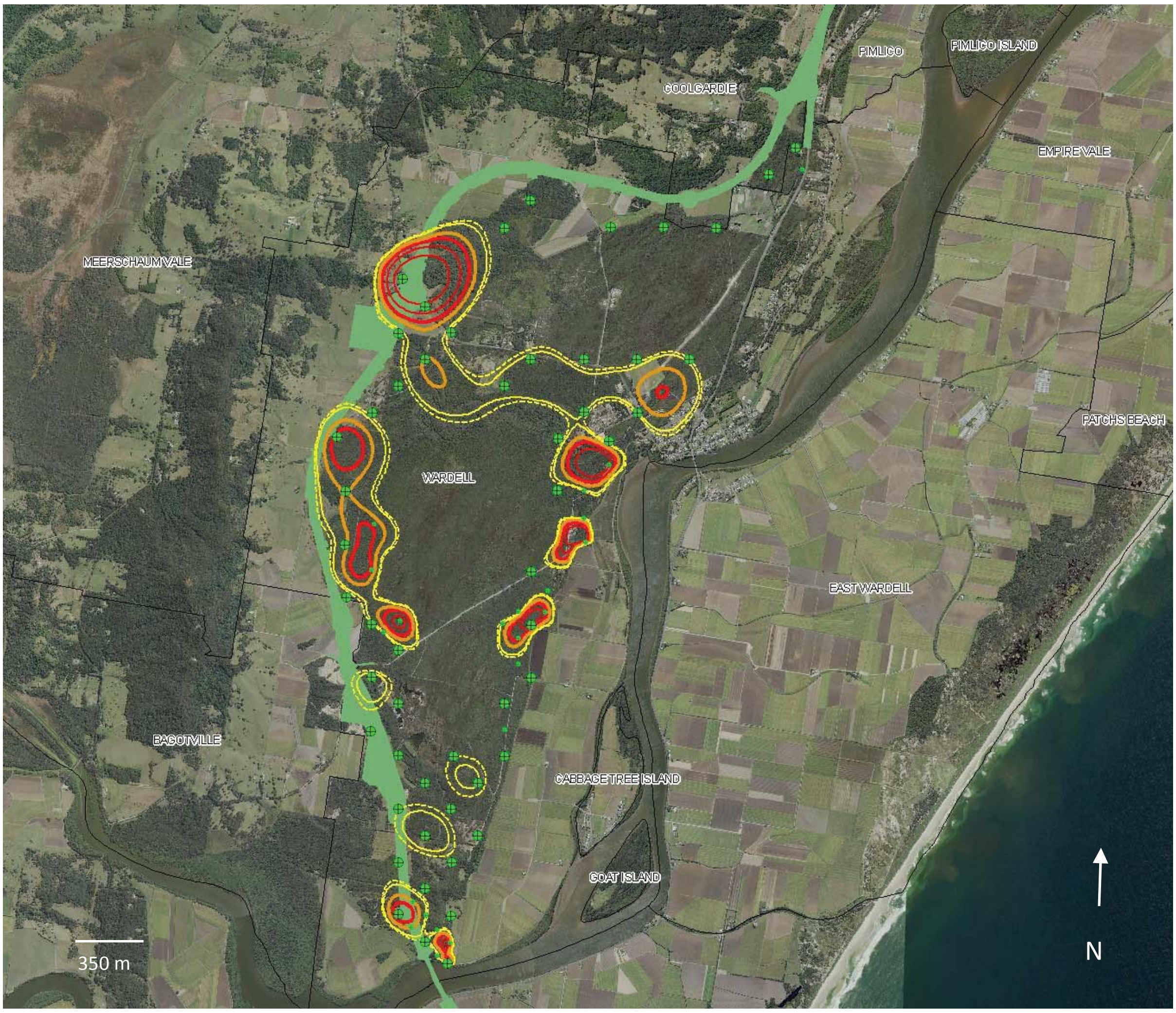


Figure 5.2 Koala activity model for the Wardell meta-population study area. Surveyed primary field sites are shown as large green dots, supplementary sites are shown as small green dots. Dotted yellow lines represent the 7% activity contour, solid yellow lines = 10% activity, thick orange lines = 23% activity (i.e. medium use), thick red lines = 33% activity (i.e. high use), additional narrow red lines = 50% and 75% activity respectively.

The model identifies cells of significant (i.e. medium to high) koala activity in the central west, northwest, northeast and central east, and far south sections of the surveyed area. These cells generally coincide with locations supporting vegetation types that include preferred koala food tree species and also coincide with locations where the majority of koala sightings were recorded during the field survey program. The localities where the cells have been identified are shown in Figure 5.2 and are described briefly as follows:

- Locality 1 (Bingle Creek) – areas with scattered clumps of swamp mahogany woodland associated with drainage lines amongst shrubland communities on Jali lands on the western fringe of Wardell. This cell is ~ 19 ha in size.
- Locality 2 (Bingle Creek) – swamp mahogany and forest red gum dominated forest and woodland areas on Jali lands adjoining Bingle Creek near the southwestern edge of Wardell. This cell is ~ 21 ha in size.
- Locality 3 (Old Bagotville Road East) – swamp mahogany and forest red gum dominated forest and woodland areas on Jali lands that adjoin cane farming lands to the southeast. This cell is ~ 11 ha in size.

- Locality 4 (Old Bagotville Road South) – swamp mahogany dominated forest and woodland areas on Jali lands to the south of Bagotville Road, extending along the interface with the cane farming lands to the east. This cell is ~ 8 ha in size.
- Locality 5 (Back Channel Road) – forest and woodland areas containing forest red gum and tallowwood on foot-slopes and low ridges on private property in the southern extent of the study area, running northwards from the Richmond River. This locality consists of two linked cells totaling ~ 20 ha in size that will be directly impacted by the conditionally-approved upgrade. Based on the estimated carrying capacity for secondary (class B) habitat (as detailed in Table 1.1 in Part 1) of ~ 0.23 koalas ha^{-1} multiplied by the overall size of the cell (~ 20 ha) and allowing for a difference of one koala either side of the product, we estimate the number of koalas to be impacted in this area as four to six individuals.
- Locality 6 (Western Jali Lands) – forest and woodland areas containing swamp mahogany. This locality comprises three linked cells totaling ~ 80 ha in size, the northern-most of which is peripherally impacted by the upgrade alignment. Based on the carrying capacity for secondary (class A) habitat (as detailed in Table 1.1 in Part 1) of ~ 0.42 koala ha^{-1} multiplied by a disturbance area of ~ 3 ha, we estimate the number of koalas to be impacted by clearing activities in this area as likely to be no more than two individuals.
- Locality 7 (Thurgates Lane to Buckombil) – slightly elevated forest and woodland areas containing tallowwood and low-lying areas containing forest red gum on private property in the eastern section of Thurgates Lane extending across Wardell Road to the north. This locality comprises two linked cells totaling ~ 60 ha in size that will be directly impacted by the conditionally-approved upgrade. Based on the carrying capacity of secondary (class A) habitat (as detailed in Table 1.1 in Part 1) of ~ 0.42 koalas ha^{-1} multiplied by an estimated area of direct impact associated with the road alignment of ~ 10 ha, we estimate the number of koalas to be impacted in this area as four to six individuals.

The preceding outcomes remain qualified by the fact that we were unable to access all areas due to heavy rainfall and inundation of some low-lying swamp forest sites. Because of this we cannot exclude the possible occurrence of additional activity cells within the swamp forest areas to the immediate south of Thurgates Lane, Wardell Road and Bingle Creek generally. Regardless, when overlain with koala habitat mapping and subject to the aforementioned qualification, the model enables identification of two relatively large and currently unoccupied or under-utilised areas of preferred koala habitat (see Figure 5.3) as follows:

- Site 1 (Central Jali lands) - areas dominated by swamp mahogany extending southwards between occupied localities 3 (Old Bagotville Road South) and 4 (Back Channel Road) in the south-eastern section of the study area. This site is bordered in the west by dry heathland and woodlands that are largely devoid of preferred koala food trees with the exception of dune swale areas, but which support supplementary food and shelter resources. This site is ~ 30 ha in area and is estimated to be potentially capable of sustaining a small population cell of up to ~ 12 additional koalas.

- Site 2 (Lumley's Lane Jali Lands and adjoining areas of private property) – areas dominated or co-dominated by swamp mahogany in the north of the study area off Lumley's Lane to the south and between Lumley's Lane and the current Pacific Highway alignment. This site consists of fringing habitat patches bordered primarily by eucalypt woodlands, swamp forests, heathlands and shrublands on sandy substrates. It is estimated that these sites would collectively total ~ 15 to 20 ha and could potentially sustain ~ six to nine additional koalas.

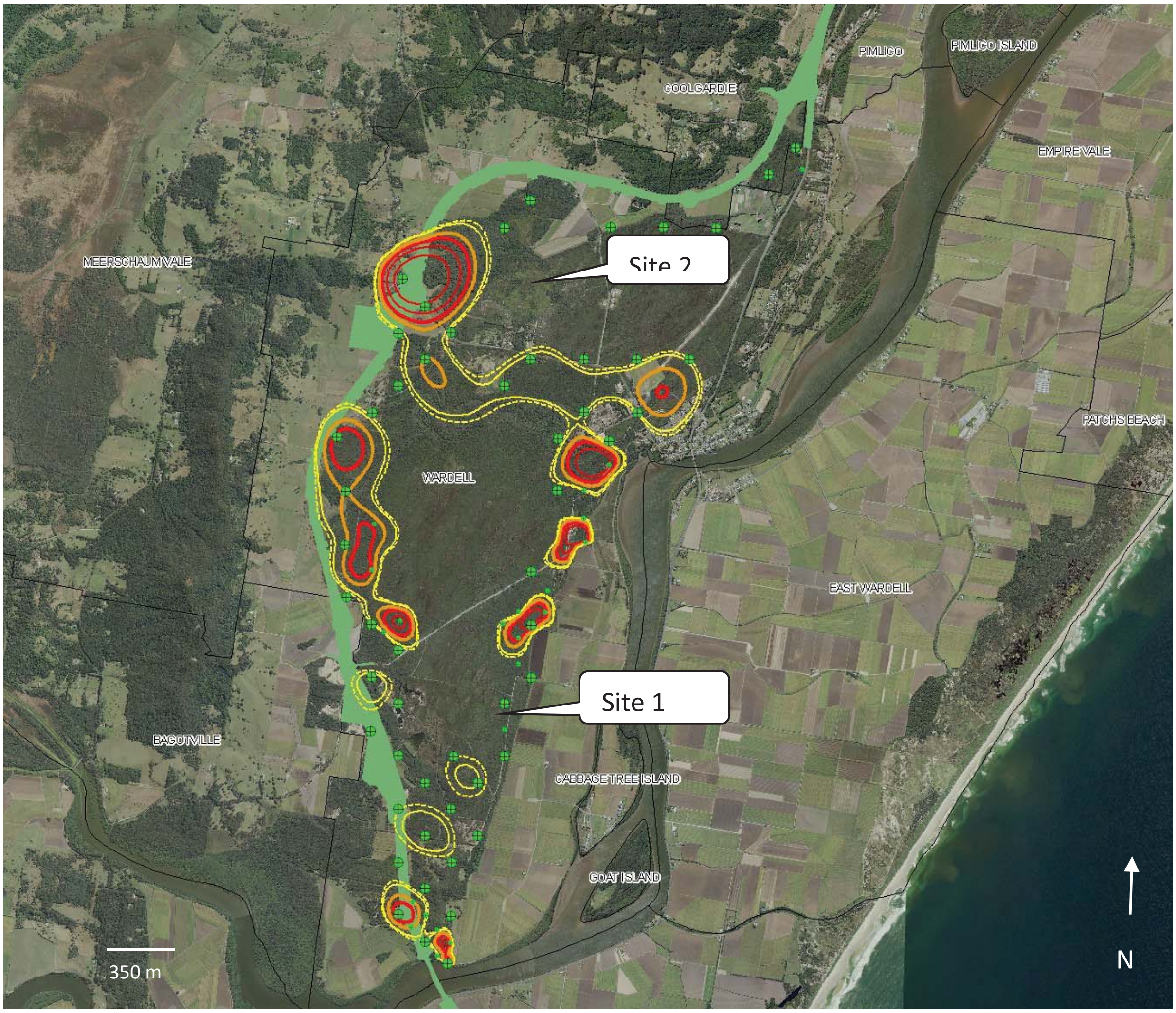


Figure 5.3 Locations of currently unoccupied and/or under-utilised areas of high carrying capacity preferred koala habitat.

5.4 Key outcomes

SAT surveys were undertaken at a total of 76 sites (53 primary sites and 23 supplementary sites) across forested parts of the study area to the east of the conditionally-approved Section 10 highway alignment.

The potential impacts on the local koala population associated with the conditionally-approved Section 10 upgrade are accentuated by the focus of koala activity and distribution in areas that overlap or adjoin preferred koala habitat in the west.

Whilst the activity model was confined to the area to the east of the conditionally-approved Section 10 alignment, it is apparent that koala activity links across the upgrade alignment at two localities, the most important of which occurs at Locality 7 (Thurgate's Lane to Buckombil Mountain Road). In contrast, and informed by the field surveys undertaken for this Part, there is no evidence of continuity of significant koala activity in the vicinity of Chainage 147600, a locality previously identified for a fauna land bridge.

A density estimate of approximately 0.096 ± 0.08 (SD) koalas ha^{-1} was derived for suitable habitat within the meta-population study area. This density estimate is in accord with that estimated by the BKS and the transect surveys detailed in Part 4 of this report.

Unless properly managed, it is estimated that the impact of constructing the conditionally-approved Section 10 highway alignment has the potential to result in the displacement of ~ 10 to 14 koalas.

Two areas (Figure 5.3) containing preferred koala habitat were identified by the metapopulation study with expected high carrying capacity that do not appear to currently support resident koalas.

The activity model can be overlain with the road footprint for an enhanced understanding of potential future impacts upon the resident koala population as a result of the conditionally-approved highway alignment and associated changes to local road traffic volumes.

PART 6
Population status & derived PVA baseline input parameters

6.1 Objective

The purpose of this Part is to detail specific recommendations arising from Parts 1 – 5 of this report insofar as they relate to the baseline input parameters required to inform the PVA process.

6.2 Population status

The preceding parts of this report have revealed the presence of a relatively small and widely dispersed koala population. Based on the average annual mortality rate of approximately 10% and the information detailed in Parts 2 and 3, incidental mortalities due to vehicle-strike and attacks by domestic dogs account for more than half of all koala deaths annually. Because of this, striving to increase population size and/or carrying capacity will arguably be ineffective if incidental mortality rates cannot be reduced. Indeed, based on the premise that the mortalities due to domestic dog attack and vehicle-strike are the primary drivers of population decline in the population, we speculate that a reduction in the cohort-based mortality rates of approximately 50% will likely be required in order to place the population on a more sustainable footing.

6.3 Parameters of acceptable impact

In approving the W2B Pacific Highway upgrade and with particular regard to koalas occupying the IPFA, amongst other matters, the following condition was specified:

"*The (Federal Environment) Minister will only approve the plan and the commencement of Section 10 of the action if the impacts to the Ballina Koala population are demonstrated to be acceptable within the Ballina Koala Plan*."

The authors propose the following principle as a basis for addressing this key condition through the PVA and koala planning process:

"The PVA-modelled measures of population status (e.g. rate of decline, mean population size) and the associated Probability of Extinction (PE) of the koala population inhabiting the IPFA in a post-construction Section 10 highway upgrade scenario, must at the very least not be worsened but ideally improved from the pre-construction baseline PVA-modelled outputs."

6.4 Baseline input parameters

(i) Single or multiple populations?

The BKS identified four clusters of koala activity within the IPFA. These four clusters have been loosely referred to as the eastern and western cells, the former relating to areas occupied by resident koala populations of the Ngunya Jargoon IPA and adjoining localities, the western cell comprising populations extending northwards from Bagotville through Meerschaum Vale and Buckombil Mountain and thereafter northwards to Coolgardie – Uralba. Based on knowledge gained during the work detailed herein, we consider the western and eastern population cells in the current landscape configuration to be demonstrably in contact in two localities. Thus for baseline PVA modelling purposes, but conditional upon results from the genetic analysis, we propose that the IPFA population be regarded as a **single** population.

Based on the requirements of Vortex Version 9.99 the following baseline input parameters are proposed:

(ii) Scenario settings

We propose a minimum of **500** iterations over a **50-year** time frame with extinction defined as only **one sex remaining**.

(iii) Species description

Inbreeding depression

Based on the observations reported in Part 2 (Demographic Profile) but subject to additional information that might be forthcoming from the genetic study, we do not consider that any potential exists that would warrant inbreeding depression being incorporated for baseline PVA modelling purposes.

Environmental Variance (EV) concordance

We propose that EV concordance be confirmed.

Number of types of Catastrophes

Information supplied in Part 1 (Introduction) supports the incorporation of **two** potential catastrophes as baseline PVA input parameters (further details are provided in section *vii* below).

(iv) Dispersal among populations

Not required for baseline PVA input parameter purposes.

(v) Reproductive system

The koala's reproductive system/life history strategy is **polygynous**.

- Age of first offspring for Females: **2**
- Age of first offspring for Males: **4**
- Maximum age of reproduction: **8**[22]
- Maximum number of broods year^{-1}: **1**
- Maximum number of progeny brood^{-1}: **1**
- Sex ratio at birth in % males*:* **50**

Density Dependent Reproduction

Should this data be required for subsequent PVA modelling but otherwise based on data in Part 2 (Population demographics) we estimate the percent of females to be reproducing at low density **P(0)** to be ~ **65%** and the percent of females to be reproducing at high density **P(K)** to be ~ **30%**.

(vi) Reproductive rates

% Adult females breeding

Based on the information provided in Part 2 (Population demographics) we estimate a value of **44.83% ± 9.27% (SD)** as indicative of the numbers of adult females breeding on an annual basis.

Distribution of broods per year

As applicable to a single population.

Specify the distribution of number of offspring per female per brood

As applicable to a single population.

(vii) Mortality Rates

Based on the outcomes arising from Part 2 (Population Demographics), we advise the following baseline mortality rates as detailed in Table 6. 1, the associated Deviations due to Environmental Variation (D/EVs) estimated on the basis of the Coefficient of Variation of **59.06%** determined in Part 3 (FoK Mortality Data) as applying to the mean number of dead koalas being reported annually across the IPFA. For PVA purposes the percentage representation of the number of koalas in each TWC cohort as a function of estimated population size (P%) is also provided.

---

[22] Based on estimated maximum age of a breeding female koala in TWC 5 from this population (Table 2 in Gordon 1991 refers).

Table 6.1 Estimated baseline mortality rates (M) and associated standard deviations due to environmental variation for the IPFA koala population. The column "P" details the estimated percentage representation of each cohort as currently represented in the population and should be used to calculate numbers for purposes of detailing specific age distribution for PVA purposes based on current (2015) population estimate of 196 koalas.

Age (years)	TWC	TWS	P(%)	M(%)	SD_{EV}
Females					
1	1	P4A	-	19.7	11.63
2	2	P4B	6.00	19.7	11.63
3	3	P4C	12.00	26.21	15.48
4	4	P4D	9.00	7.34	4.33
5		P4D	9.00	7.34	4.33
6	5	P4E	9.00	5.37	3.17
7		P4E	9.00	5.37	3.17
8	6	P4F	3.33	2.76	1.63
9		P4F	3.33	2.76	1.63
10		P4F	3.33	2.76	1.63
Males					
1	1	P4A	-	19.45	11.49
2	2	P4B	4.00	19.45	11.49
3	3	P4C	2.00	30.56	18.05
4	4	P4D	10.00	4.3	2.54
5		P4D	10.00	4.3	2.54
6	5	P4E	3.00	6.29	3.71
7		P4E	3.00	6.29	3.71
8	6	P4F	1.33	2.92	1.73
9		P4F	1.33	2.92	1.73
10		P4F	1.33	2.92	1.73
			(~100)		

(viii) Catastrophes

The primary catastrophes to be incorporated as baseline input parameters are **drought** and **fire**. We assess the risk of these catastrophes for PVA purposes as follows:

Drought

Based on climate data provided in Part 1 (Introduction) we assess the probability of a period of "serious" to "severe"[23] rainfall deficiencies leading to a drought event within the IPFA to be three in every 14 years (i.e. frequency of ~ **0.21**), the potential extent of any event to be global but otherwise restricted to ridgeline habitat areas we have estimated to approximate 700 ha of the 2152 ha (i.e. **32%**) within which the impacts on reproduction and survival for PVE

[23] As defined by Australian Bureau of Meteorology

purposes are estimated to be **0.85** and **1.0** respectively.

Fire

Based on the fire history provided in Part 1 (Introduction), we assess the probability of a catastrophic fire event within the IPFA to be one in every 35 years (i.e. a frequency of ~ **0.03**) and we estimate the likely geographic extent of such an event to encompass ~ **10%** of the study area, with impacts on reproduction and survival likely to be severe to moderate, the proportional estimates for PVA purposes of **0.85** and **0.60** respectively.

(ix) Mate monopolization

As detailed in Part 2 (Population demographics) we propose that this measure equates to the estimated number of male koalas in TWCs 4 – 5, and therefore should be **76.47% ± 10.6% (SD)**.

(x) Initial population size

On the basis of data detailed in Part 4 (Koala density/population size) we advise a population size estimate for the number of koalas in TWCs 2 - 7 within the IPFA of **196 ± 65 (SD) koalas**. Based on the skewed sex ratios detailed in Part 2 of this report this number translates to a population currently comprised of **125** female and **71** male koalas.

(xi) Carrying capacity

Carrying capacity

On the basis of information provided in this report, we have calculated an upper limit estimate of 556 koalas for the IPFA, which could only apply if all available habitat were to be fully occupied. However, findings from other coastal populations support an expected population occupancy rate of slightly greater than 50% of available habitat. Hence, we propose that the koala carrying capacity **(K)** for baseline PVA modeling purposes be set at **291 ± 15 (SD) koalas.**

Future change in K

For reasons outlined in the Additional Notes below we propose that this parameter be left unchecked **(i.e. a zero change in K)** for the purposes of baseline PVA modelling purposes.

(xii) Harvest

No harvest is envisaged for the purposes of baseline input parameters.

(xiii) Supplementation

No population supplementation program currently exists for baseline input parameters.

(xiv) Genetic management

No genetic management program currently exists for the purposes of baseline input parameters.

6.5 Additional notes

Given that the conditionally-approved Section 10 upgrade traverses the south-eastern corner of the IPFA, we envisage that a range of management scenarios may need to be considered and possibly informed by a two- or even three-way metapopulation PVA model. To assist this process should it be necessary, some elements of the baseline input parameters may be further partitioned as follows:

6.5.1 Modelling two populations

If required for subsequent PVA scenario testing purposes, the population can be partitioned in terms of the numbers of koalas occupying habitat to the west and east of the proposed alignment as follows: **76.19% (149 koalas) in the west** and **23.81% (47 koalas)** in the east (Source of primary partitioning parameters: numbers of occupied field sites reported by the BKHS).

6.5.2 Modelling three populations

If required for subsequent PVA scenario testing purposes, the population can be partitioned in terms of the numbers of koalas occupying habitat to the north, west and east of the proposed alignment as follows: **19.05% (37 koalas) in the north**, **57.14% (112 koalas) in the west**, **and 23.81% (47 koalas) in the east** (Source of primary partitioning parameters: numbers of occupied primary field sites reported by the BKHS).

6.5.3 Future changes in K

It is acknowledged that approximately 130 ha of additional habitat is proposed to be re-created should the project proceed, this value will need to be reduced by the total area of habitat that would be lost to the road construction process and will need to factor in the time required for trees to advance to a stage where they could support koalas. Scenario modelling will also need to accommodate both the loss of preferred koala food trees as a consequence of Private Native Forestry practices (three licenses currently in force, one application currently being processed), and the ongoing removal (without replacement) of tallowwood windrows elsewhere within the IPFA.

6.5.4 Harvesting and associated mortality considerations arising from road construction

Construction of the conditionally approved Section 10 highway upgrade would result in a loss of vegetation cover, some of which currently supports resident koala populations. As detailed in Part 5 of this report (Wardell meta-population survey), three key localities have been confirmed where animals will be directly impacted by habitat modification/removal. These localities and the approximate number of koalas to be impacted in each instance are as follows:

1. Chainage 146000 – 146800 (Law's Point): displacement/disruption of resident koalas (*n* = 4 – 6).
2. Chainage 149600 – 151400 (Jali Lands (west): displacement/disruption of resident koalas (*n* = 2).
3. Chainage 152200 – 153600 (Thurgate's Lane to Buckombil Mountain Road): displacement/disruption of resident koalas (*n* = 4 – 6).

An appropriate strategy for management of these displaced koalas will be required for subsequent PVA modelling purposes, in the absence of which we would estimate that a minimum of 10 – 14 koalas must be assessed as potentially lost from the population as a consequence. The removal of these koalas from the population would need to be factored into the PVA model as a progressive harvest initiated at the date construction work commences and ending on the date construction works are completed.

Appendix 1 Koala capture data

Codes as follows: DoC = Date of Capture; FRS = Female Reproductive Score (Part 2 refers); TWS = Tooth-wear Score (Gordon 1991); COH = Cohort (A = Adult, S/A=Sub-adult); MCHIP = Microchip number; Other ID = identification assigned on admission to the FoK Care Centre or Currumbin Sanctuary Wildlife Hospital (CSWH), or the existing ear tag number

DoC	Easting	Northing	Sex	FRS	Weight (kg)	TWS	COH	Tag	MCHIP	Other ID	Detail
2/12/2014	543060	6806472	F	1	4.00	P4D	A	na	na	021214_01	Domestic dog attack
15/12/2014	541534	6793953	M	na	7.00	P4D	A	0381Red	76906CE	na	capture
16/12/2014	540292	6793889	F	2	5.4	P4E	A	0382Red	7690493	na	capture
18/12/2014	546412	6800737	F	1	4.9	P4C	A	na	na	181214_01	road-kill
18/12/2014	539495	6794281	M	na	6.1	P4D	A	0368Red	7710682	na	capture
2/01/2015	539639	6794338	M	na	6.9	P4D	A	0383Red	768FD69	na	capture
5/01/2015	545432	6805736	F	1	5.4	P4FM1G	A	0370Red	7693984	na	capture
7/01/2015	539678	6794086	F	4	5.7	P4E	A	0384Red	768F7DF	na	capture
8/01/2015	544274	6796413	M	na	7	P4D	A	0386Red	769143C	na	capture
8/01/2015	544290	6796262	F	1	5.95	P4D	A	0367Red	769005B	na	capture
9/01/2015	539646	6794219	M	na	8.2	P4D	A	0388Red	7710876	na	capture
9/01/2015	539581	6794223	M	na	5.8	P4E	A	0387Red	771066C	na	capture
11/01/2015	544394	6796993	F	2	6.3	P4E	A	0369Red	77104BC	na	capture
27/01/2015	538387	6796522	F	2	7.3	P4E	A	na	768FECE	TVWC 026	capture
6/02/2015	538439	6796479	M	na	7.25	P4D	A	0362Red	7710BEB	na	capture
17/02/2015	541183	6793594	M	na	5.95	P4D	A	0361Red	76937AE	na	capture
17/02/2015	542553	6792693	M	na	7.2	P4E	A	0364Red	768FDDF	na	capture
18/02/2015	541199	6793976	F	3	5.05	P4E	A	0363Red	7710665	na	capture
18/02/2015	542577	6792692	F	3	5.15	P4D	A	0366Red	770E9C9	na	capture

DoC	Easting	Northing	Sex	FRS	Weight (kg)	TWS	COH	Tag	MCHIP	Other ID	Detail
27/02/2015	538421	6796349	F	1	4.9	P4D	A	na	na	FoK8039	capture
26/02/2015	541933	6793709	M	na	7.85	P4FM1H	A	0379Red	770C8C2	na	capture
26/02/2015	541092	6793851	F	1	na	P4B	SA	na	na	260215_01	body in tree
27/02/2015	541212	6794012	M	na	6.1	P4D	A	0365Red	76905FE	na	capture
4/03/2015	538391	6796435	F	1	5.12	P4D	A	0372Red	76919B5	na	capture
5/03/2015	538422	6796261	M	na	8.17	P4E	A	0380Red	770FD1A	na	capture
5/03/2015	539682	6793884	F	3	6.1	P4E	A	0371Red	770CB5E	na	capture
13/03/2015	542802	6798218	F	1	5.71	P4FM1G	A	0345Red	770C794	na	capture
25/03/2015	544768	6797159	F	3	5.25	P4C	A	0346Red	770C766	na	capture
28/03/2015	540625	6793834	M	na	1.8	P4B	SA	0347Red	770C727	na	capture
8/04/2015	542330	6799857	F	1	5.25	P4FM1H	A	0348Red	na	na	capture
13/04/2015	539626	6794227	M	na	na	P4D	A	na	na	130415_01	road- kill
15/04/2015	546278	6799664	F	1	4.6	P4D	A	na	na	140415_01	road-kill
16/04/2015	543774	6806077	M	na	7	P4D	A	0349Red	na	na	capture
17/04/2015	541421	6798534	F	1	5.45	P4FM1G	A	0350Red	na	na	capture
17/04/2015	543577	6803659	F	1	5.92	P4FM1IM2H	A	0351Red	770CA87	na	capture
23/04/2015	542778	6798561	F	2	4.85	P4C	A	0352Red	7691358	na	capture
30/04/2015	547016	6806988	F	1	na	-	A	na	na	na	road-kill
5/05/2015	542496	6799656	F	3	6.25	P4E	A	0353Red	na	na	capture
8/05/2015	542983	6792452	F	3	6.05	P4D	A	0389Red	na	na	capture
9/05/2015	541959	6804916	F	3	6.06	P4C	A	0390Red	na	150508	road-kill
14/05/2015	539567	6794192	F	1	5.1	P4D	A	0391Red	na	na	capture
14/05/2015	542668	6801601	F	1	2.77	P4B	SA	0392Red	7690717	na	capture
21/05/2015	540608	6806450	F	1	4.8	P4D	A	0393Red	na	CSWH 40192	capture
22/05/2015	540641	6806535	M	na	3.32	P4B	SA	0394Red	770E7E2	na	capture

DoC	Easting	Northing	Sex	FRS	Weight (kg)	TWS	COH	Tag	MCHIP	Other ID	Detail
23/05/2015	540724	6806511	F	3	7.32	P4E	A	0395Red	na	na	capture
23/05/2015	540657	6806518	F	1	3.1	P4B	SA	0396Red	768FAF3	na	capture
27/05/2015	543426	6805606	F	1	6.45	P4C	A	0397Red	770D286	na	capture
11/06/2015	541771	6799825	M	na	7.69	P4FM1H	A	0398Red	na	na	capture
29/06/2015	539580	6794311	M	na	6.65	P4D	A	na	na	01_28062015	killed by dog/fox
7/07/2015	545796	6798190	F	1	4.2	P4E	A	na	na	na	Domestic dog attack

Appendix 2 Transect data

Site No.	Ha	n	K	Easting	Northing
ES Feb10_5	1	1	0	546264.213	6800030.86
ES Feb10_6	1	1	0	541764.113	6798521.401
ES Feb10_7	1	1	1	542764.11	6798521.40
ES Feb10_8	1	1	0	542764.11	6798021.40
ES Feb10_9	1	1	0	541774.82	6797522.11
ES Feb10_10	0.36	1	0	542764.11	6797521.40
ES Feb10_12	1	1	0	542764.11	6794521.40
ES Feb10_13	1	1	0	542764.11	6794021.40
ES Feb10_14	1	1	0	542764.11	6793521.40
ES Feb10_15	1	1	0	542264.11	6793021.40
ES Feb10_16	1	1	0	542764.11	6793021.40
ES Feb10_18	1	1	0	542765.27	6792520.78
ES Apr10_5	1	1	0	542751.16	6800010.67
ES Apr10_9	1	1	0	543751.16	6799510.67
ES Apr10_10	1	1	0	544751.16	6799510.67
ES Apr10_12	1	1	0	542751.16	6799010.67
ES Apr10_18	1	1	0	541251.16	6795010.67
ES Apr10_19	1	1	1	541251.16	6794010.67
0.5K 008	1	1	0	540251.16	6797010.67
0.5K 014	1	1	1	539251.16	6796010.67
0.5K 055	1	1	0	542251.16	6794010.67
0.5K 057	1	1	0	543251.16	6794010.67
0.5K 064	1	1	0	541751.16	6794510.67
0.5K 085	1	1	0	541751.16	6795010.67
0.5K 086	1	1	0	542251.16	6795010.67
0.5K 087	1	1	0	541751.16	6796010.67
0.5K 088	1	1	0	541751.16	6796510.67
0.5K 089	1	1	0	542251.16	6797010.67
1K 002	1	1	0	541251.16	6793510.67
1K 003	1	1	0	542251.16	6793510.67
1K 004	1	1	0	543251.16	6793510.67
1K 007	1	1	0	542251.16	6794510.67
1K 011	1	1	0	542251.16	6795510.67
1K 013	1	1	0	538251.16	6796510.67
1K 014	1	1	0	539251.16	6796510.67
1K 016	1	1	0	542251.16	6796510.67
1K 017	1	1	0	544251.16	6796510.67

Site No.	Ha	n	K	Easting	Northing
1K 020	1	1	0	538251.16	6797510.67
1K 023	0.98	1	0	542251.16	6797510.67
1K 024	1	1	0	543251.16	6797510.67
1K 025	1	1	0	544251.16	6797510.67
1K 027	1	1	0	540251.16	6798510.67
1K 030	1	1	0	540251.16	6799510.67
1K 031	1	1	0	546251.16	6799510.67
1K 033	1	1	0	542251.16	6800510.67
1K 036(b)	1	1	0	546313.00	6800372.00

Appendix 3 Field sites – Wardell koala meta-population survey

Site	Type	Easting	Northing	p	n	Activity %
1	Primary	542774	6792530	2	30	6.67
2	Primary	542541	6792763	10	25	40.00
3	Primary	542990	6792758	0	27	0.00
4	Primary	542749	6793027	0	25	0.00
5	Primary	542483	6793245	0	25	0.00
6	Primary	542996	6793284	1	26	3.85
7	Primary	542784	6793538	5	30	16.67
8	Primary	543244	6793524	0	26	0.00
9	Primary	542479	6793726	2	30	6.67
10	Primary	542997	6793821	1	27	3.70
11	Primary	542663	6793899	0	25	0.00
12	Primary	543217	6793968	3	30	10.00
13	Primary	542489	6794316	0	29	0.00
14	Primary	543024	6794270	2	30	6.67
15	Primary	543501	6794274	0	26	0.00
16	Primary	542205	6794527	1	30	3.33
19	Primary	542550	6794778	0	25	0.00
20	Primary	543494	6794777	0	26	0.00
21	Primary	542249	67955083	4	30	13.33
22	Primary	543723	6795017	0	26	0.00
23	Primary	542487	6795273	0	25	0.00
24	Primary	542230	6795514	2	30	6.67
25	Primary	543762	6795512	11	22	50.00
26	Primary	542017	6795811	0	25	0.00
28	Primary	543785	6795995	0	26	0.00
29	Primary	541988	6796286	6	30	20.00
32	Primary	541967	6796767	7	30	23.33
36	Primary	541917	6797287	10	27	37.04
39	Primary	544074	6797280	0	26	0.00
40	Primary	542259	6797542	1	30	3.33
44	Primary	544237	6797602	3	30	10.00
45	Primary	544760	6797511	3	30	10.00
46	Primary	542471	6797792	0	25	0.00
48	Primary	543455	6797739	4	30	13.33
49	Primary	542724	6798051	7	30	23.33
50	Primary	543742	6798050	4	30	13.33
51	Primary	544148	6797982	0	26	0.00
52	Primary	544702	6797956	1	30	3.33
53	Primary	545247	6798069	2	30	6.67
54	Primary	542516	6798234	2	30	6.67

Site	Type	Easting	Northing	p	n	Activity %
55	Primary	542927	6798226	1	28	3.57
57	Primary	542755	6798542	12	18	66.67
58	Primary	542539	6798782	13	13	100.00
62	Primary	543520	6799356	0	26	0.00
63	Primary	544462	6799231	0	26	0.00
64	Primary	544899	6799313	0	26	0.00
65	Primary	545596	6799244	0	26	0.00
66	Primary	543733	6799513	0	26	0.00
68	Primary	546019	6799766	0	26	0.00
69	Primary	546208	6800005	2	30	6.67
83	Primary	542957	6792354	13	27	48.15
87	Primary	543997	6796766	0	24	0.00
102	Primary	544511	6797240	0	29	0.00
18	Supplementary	543491	6794529	0	26	0.00
31	Supplementary	544270	6796520	1	26	3.85
33	Supplementary	544389	6796647	2	30	6.67
70	Supplementary	546303	6799815	10	23	43.48
71	Supplementary	542498	6795551	11	19	57.89
72	Supplementary	542344	6795454	3	30	10.00
73	Supplementary	542654	6792885	7	30	23.33
74	Supplementary	542615	6792652	7	30	23.33
75	Supplementary	543898	6795636	12	30	40.00
76	Supplementary	543625	6795644	0	27	0.00
77	Supplementary	543569	6795435	11	30	36.67
84	Supplementary	542863	6792392	2	30	6.67
85	Supplementary	544487	6797030	13	25	52.00
86	Supplementary	544336	6794727	2	29	6.90
88	Supplementary	544279	6796283	17	27	62.96
89	Supplementary	542759	6792762	3	29	10.34
90	Supplementary	542986	6792500	12	29	41.38
92	Supplementary	543638	6795116	0	27	0.00
94	Supplementary	543497	6795502	4	30	13.33
97	Supplementary	543906	6795865	0	26	0.00
99	Supplementary	542854	6792626	1	27	3.70
100	Supplementary	542250	6796457	9	30	30.0
101	Supplementary	542202	6796045	9	30	30.0

Revision History

Revision No.	Revision date	Details	Prepared by	Approved by
00	10/07/2015	Koala Genetics and Population Demographic Surveys, Woolgoolga to Ballina Pacific Highway Upgrade: Section 10 (Wardell to Coolgardie) - Draft	Steve Phillips, Managing Director/Principal Ecologist (Biolink); Grant Brearley, Senior Ecologist (Ecosure); and John Callaghan, Director/Conservation Biologist (Biolink)	Steve Phillips (Biolink)
01	24/08/2015	Incorporates comments on the Draft from Roads and Maritime Services, Associate Professor Jonathon Rhodes (University of Queensland) and Dr Rod Kavanagh (Niche Consulting)	Steve Phillips, Managing Director/Principal Ecologist (Biolink); Grant Brearley, Senior Ecologist (Ecosure); and John Callaghan, Director/Conservation Biologist (Biolink)	Steve Phillips (Biolink)
02	02/10/2015	Incorporates further comments on the Revised Draft from Roads and Maritime Services, Associate Professor Jonathon Rhodes (University of Queensland) and Dr Rod Kavanagh (Niche Consulting)	Steve Phillips, Managing Director/Principal Ecologist (Biolink); Grant Brearley, Senior Ecologist (Ecosure); and John Callaghan, Director/Conservation Biologist (Biolink)	Steve Phillips (Biolink)
Final	03/12/2015	Incorporates final comments on the Revised Draft from Roads and Maritime Services and Associate Professor Jonathon Rhodes (University of Queensland)	Steve Phillips, Managing Director/Principal Ecologist (Biolink); Grant Brearley, Senior Ecologist (Ecosure); and John Callaghan, Director/Conservation Biologist (Biolink)	Steve Phillips (Biolink)

Distribution List

Copy #	Date	Type	Issued to	Name
1	03/12/2015	Electronic	Roads and Maritime Services	Simon Wilson
2	03/12/2015	Electronic	Ecosure	Administration
3	03/12/2015	Electronic	Biolink	Steve Phillips

Citation: Phillips, S., Brearley, G., and Callaghan, J. 2015. *Koala Population Survey - Woolgoolga to Ballina Pacific Highway Upgrade: Section 10 (Wardell to Coolgardie)*, Final report to Roads and Maritime, Biolink Ecological Consultants and Ecosure Pty Ltd.

Report compiled by Biolink Ecological Consultants and Ecosure Pty Ltd

GW116_V4-RE.Koala Preconstruction Surveys.Final.docx