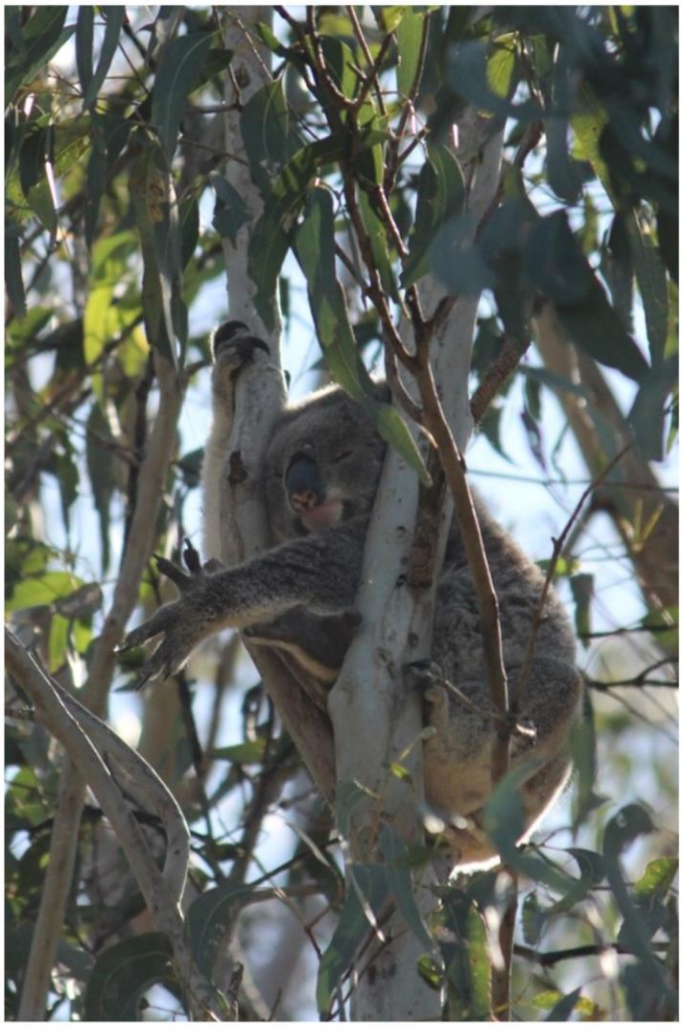
Lismore Koala Plan of Management: Monitoring



Final report to Lismore City Council

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Table of contents

Abbreviations

Abbreviation	Description
AoO	Area of Occupancy
ARKS	Area of Regional Koala Significance
CI	Confidence Interval
CKPoM	Comprehensive Koala Plan of Management
DBH	Diameter at Breast Height
EoO	Extent of Occurrence
GP	Generational Persistence
HRA	Historical Records Analysis
IUCN	International Union for the Conservation of Nature
LCC	Lismore City Council
LGA	Local Government Area
MCP	Minimum Convex Polygon
NSW	New South Wales
PKFT	Preferred Koala Food Tree
PKH	Preferred Koala Habitat
PMP	Permanent Monitoring Points

SE	Standard Error
UTM	Universal Transverse Mercator

Biolink

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Photo credit

Koala (*Phascolarctos cinereus*) in a Forest red gum (*Eucalyptus tereticornis*) at Southern Cross University, January 2024, taken by Kirsty Wallis.

Executive Summary

Lismore City Council (LCC) Local Government Area (LGA) supports one of the most significant koala (*Phascolarctos cinereus*) populations in New South Wales (NSW). To acknowledge the importance of this population and effectively manage it in the face of a range of threatening processes, LCC adopted a Comprehensive Koala Plan of Mangement (CKPoM) in 2013 which covers the south-eastern portion of the LGA, reflective of the high known koala occupancy of the Richmond River floodplain. The current report represents the third round of monitoring associated with the provisions of the CKPoM and comprises an LGA-wide analysis of historic koala records and threatening processes with a focus on disease, vehicle-strike and dog attack, and a field survey focussed on the CKPoM planning area, which is extended south the Richmond River for consistency with previous reporting and to better reflect natural barriers to koala dispersal and recruitment.

Examination of 3,437 koala sightings records for the most recent koala generation (2017-2022) confirmed that koalas remain widely distributed across the Lismore LGA, the estimated *Extent of Occurrence* (EoO) of 144,300 ha for this time period falling within the the range of variation informing that of the two preceding koala generations. Across the LGA, the *Area of Occupancy* (AoO) estimate for the 2017-2022 koala generation was 73.25% ± 0.10% (SE) of available habitat, a value that represents a small yet significant increase from that of the immediately preceding three koala generations (68.75% ± 1.27% (SE)). Within the extended CKPoM planning area[1], occupancy was slightly higher at 75.60% ± 0.97% (SE) for the 2017-2022 koala generation, which did not differ significantly from that of the immediately preceding three koala generations at 78.60% ± 1.44% (SE). Occupancy of both the extended CKPoM planning area and the Lismore LGA more broadly, has been consistently high across the last four generations. Areas supporting long-standing koala populations, as indicated by *Generational Persistence* (GP) assessment are extensive but most concentrated in the south and north-east of the LGA. The largest (southern) cluster is located within the extended CKPoM planning area and stretches to the boundary with Richmond Shire. In the context of previous reporting, GP is continuing its westward expansion. The cluster of GP in the north-east of the LGA covers the area from Repentance Creek, Dorroughby and Rosebank, illustrating the growing importance of this region as GP covers a larger area here than was detected in 2017.

Data provided by the Friends of the Koala (FoK) for the period 2017-2023 revealed that, consistent with previous reporting, the primary contributers to recorded koala mortality across the Lismore LGA are disease (57.54%), vehicle-strike (22.94%) and dog attack (6.24%). Chlamydiosis is the most

[1] The Lismore CKPoM planning area, extended south to the Richmond River.

commonly attributed disease across the LGA, with females being substantially more impacted than males (2.27 female mortalities: 1 male mortality). Detailed analysis of vehicle-strike data which utilised a refined data set from 2011-2022 to reflect generational timeframes, identified four Major Blackspots and nine Minor Blackspots which occur both inside and outside the extended CKPoM planning area. The implementation of effective mitigation measures in these blackspot areas would substantively reduce the incidence of anthropogenically driven koala mortality across the LGA. Domestic dog attack is at highest density in the urbanised parts of Lismore which interface bushland and in the argricultural landcape of McKees Hill. This remains an issue for on-going community engagement.

Field survey of koala occupancy and activity levels utilised the Spot Assessment Technique (SAT) at regularly distributed sites across the extended CKPoM planning area using the same 350m x 350m grid used for the previous two monitoring events (in 2017 and 2020). Surveyed sites fell on a range of land tenures, including private (n=40), Council (n=13), roadside/crown lands (n=11), National Parks (n=8), Department of Lands (n=2) and Transport for NSW (n=1). Sixty-six (66) of the 75 field sites surveyed contained evidence of utilisation by koalas in the form of diagnostic faecal pellets, these data enabling a field-based occupancy estimate of 88.00% ± 3.75% (SE) of mapped habitat. Koala occupancy and activity levels were compared at 41 repeated sites which were also surveyed in 2017 and / or 2020, revealing no overall differences in these measures, though there were some site based changes, likely due to active metapopulation dynamics. Survey events in 2017 and 2020 implied that the habitat was either close to, or at, peak carrying capacity. Field-based measures of koala occupancy and activity from this round of survey do not differ significantly from either of the two previous monitoring events, indicating that the population is likely to be plateauing. The implication of this is that without the expansion of habitat the local koala population is unlikely to have the capacity for growth. The density estimate for the extended CKPoM planning area of 0.34 ± 0.15 (SE) koalas ha^{-1} was derived by dividing the number of koalas sighted during 25m fixed-radius radial searches (n=5) by the total area searched (14.504 ha). This is comparable to the density estimate derived in 2017 (0.36 ± 0.06 (SE), though lower than that derived in 2020 (0.64 ± 0.23), however all three estimates fall within the bounds of error.

The extended CKPoM planning area and the Lismore LGA more broadly, continue to support a robust koala population with high occupancy and activity levels despite high disease-mediated mortality and substantial impacts from vehicle strike. The positive results of field survey and historical records analysis are not a cause for complacency, as other areas have witnessed the decline of what were formerly vigorous koala populations as a result of anthropogenic impacts. We make specific recommendations aimed at supporting the long-term management of this significant population.

1. Introduction

Koalas (*Phascolarctos cinereus*), known as burribi in the local Widjabul language, are an iconic presence through-out the Lismore Local Government Area (LGA) and the region has been recognised as an Area of Regional Koala Significance (ARKS) by the New South Wales (NSW) government (Rennison & Fisher 2017). This significant koala population is widespread, however it is most substantial in the central and southern portions of the LGA where the fertile soils of the Richmond River floodplain sustain high carrying capacity habitats (LCC 2013, Biolink 2017).

Since the 1990's the Lismore koala population has been in a process of recovery and expansion, after having previously undergone a range contraction of about 30%, along with an associated decrease of ~45% in the amount of otherwise suitable habitat that was actually being utilised by koalas (Biolink 2011). This expansion has been verified by both the analysis of historical koala sightings records and by field-based assessments (Biolink 2017, LCC 2020). The driver of population recovery cannot be determined with absolute certainty but is thought to be a lack of fire across the floodplain habitats which support the majority of the koala population in southern parts of the LGA, in addition to the planting of eucalypts in what was once the "Big Scrub Rainforest" in the north of the LGA (LCC 2013).

To acknowledge the importance of this population and effectively manage it in the face of a range of threatening processes, the Lismore Comprehensive Koala Plan of Management (CKPoM) was developed by Lismore City Council (LCC) for the south-eastern section of the LGA and this was endorsed by both LCC and NSW government in 2013 (LCC 2013). The Lismore CKPoM aims to provide a blueprint for the continued co-existence of people and koalas in and around Lismore by detailing a range of management activities to address current threats and by providing a framework for on-going monitoring of the local population. Subsequent to the development of this plan, LCC adopted a Biodiversity Management Strategy (LCC 2015) and this strategy continues to implement the management actions outlined in the Lismore CKPoM.

Long-term monitoring of Lismore's koala population is necessary to inform on any ongoing changes in koala distribution and abundance and, at the landscape-scale, such changes are arguably best measured over generational time frames[2]. The first survey event after the adoption of the Lismore CKPoM took place in 2017 (Biolink 2017) and was intended to serve as a baseline for the long-term monitoring program. A second round of (intragenerational) survey was performed in 2020 (LCC 2020), and while not directly comparable due to refinements in survey methodology, there was no evidence

[2] A koala generation is recognised as a period of six years (Phillips 2000).

for population decline, with koala occupancy remaining widespread. Collectively, these surveys (Biolink 2017, LCC 2020) along with others (Biolink 2022) indicate the continuing high occupancy of the Lismore CKPoM planning area, as well as extensions out of this area; high koala activity being documented around Ruthven to the west and in the vicinity of Dorroughby-Dunoon to the north (the latter known to be a genetically different population; Norman and Christidis 2021).

The conservation status of koalas across their broader distribution has been subject to recent change. Koala populations in Queensland, NSW and the Australian Capital Territory were formerly listed as Vulnerable under the Federal *Environmental Protection and Biodiversity Conservation Act 1999* but were upgraded to Endangered in 2022 due to widespread population declines across this range, inclusive of the impacts of the 2019/20 fire season among other threatening processes. Koalas are further listed as Endangered at the State level in NSW under the *Biodiversity Conservation Act 2016*.

1.1. Objectives

The primary objective of this report is to carry out the third round of koala monitoring according to provisions in the Lismore CKPoM, contextualised by a Historical Records Analysis (HRA) to provide an understanding of any changes in koala populations over time and a threats analysis to examine the spatial and chronological distribution of threats such as disease, vehicle-strike and dog attack. Specifically, this entails the following:

- Historical Records Analysis (HRA) for the Lismore LGA using koala sightings data up to and including 2022 to inform on any changes in the population parameters *Extent of Occurrence* (EoO), *Area of Occupancy* (AoO) and *Generational Persistence*.
- Threats analysis for the Lismore LGA utilising data from Friends of the Koala (FoK) as it pertains to the illness, injury and death of koalas.
- Field survey of koalas using the Spot Assessment Technique (SAT) at previously surveyed sites and new sites (60 – 80 sites dependant on access) to provide data on occupancy and activity levels.
- 25m fixed-radius searches at all SAT sites to inform a koala density estimate.
- Comparison with previous survey events to inform on population trends.

2. Methodology

2.1. Study Area

Lismore City Council (LCC) LGA on the far north coast of NSW encompasses an area of approximately 126,700 ha, comprising a diversity of vegetation communities and fauna habitats. Land uses are varied and include crop and livestock farming, urban and industrial development, as well as National Parks, Council and private reserves. The region is home to the people of the Bundjalung Nation, a living First Nations culture with continuous connection to place. In the south-east of Lismore LGA, bounded by Wilson River in the north and west, the administrative boundary with Ballina Shire in the east and the drainage canal south of the Tuckean Nature Reserve in the south, the Lismore CKPoM planning area encompasses 20,870 ha. For survey and assessment purposes in this report and concordant with previous reporting, the CKPoM planning area is extended south to the Richmond River, to better reflect natural barriers to koala dispersal and recruitment (revised area: 30,178 ha) and this is hereafter referred to as the extended CKPoM planning area (**Figure 1**). This area incorporates the most heavily urbanised parts of Lismore (Goonellabah, East Lismore, Lismore and Lismore Heights) as well as extensive agricultural areas that support scattered trees and windrows, interspersed with areas of native vegetation including Forested Wetlands, Wet Sclerophyll and Rainforest (according to current vegetation mapping: *NSW State Vegetation Type Map* version c1.1.M1.1). Please note that this report considers the entire Lismore LGA as the study area for HRA and threats analysis components, whereas field survey for koalas applies to the extended CKPoM planning area.

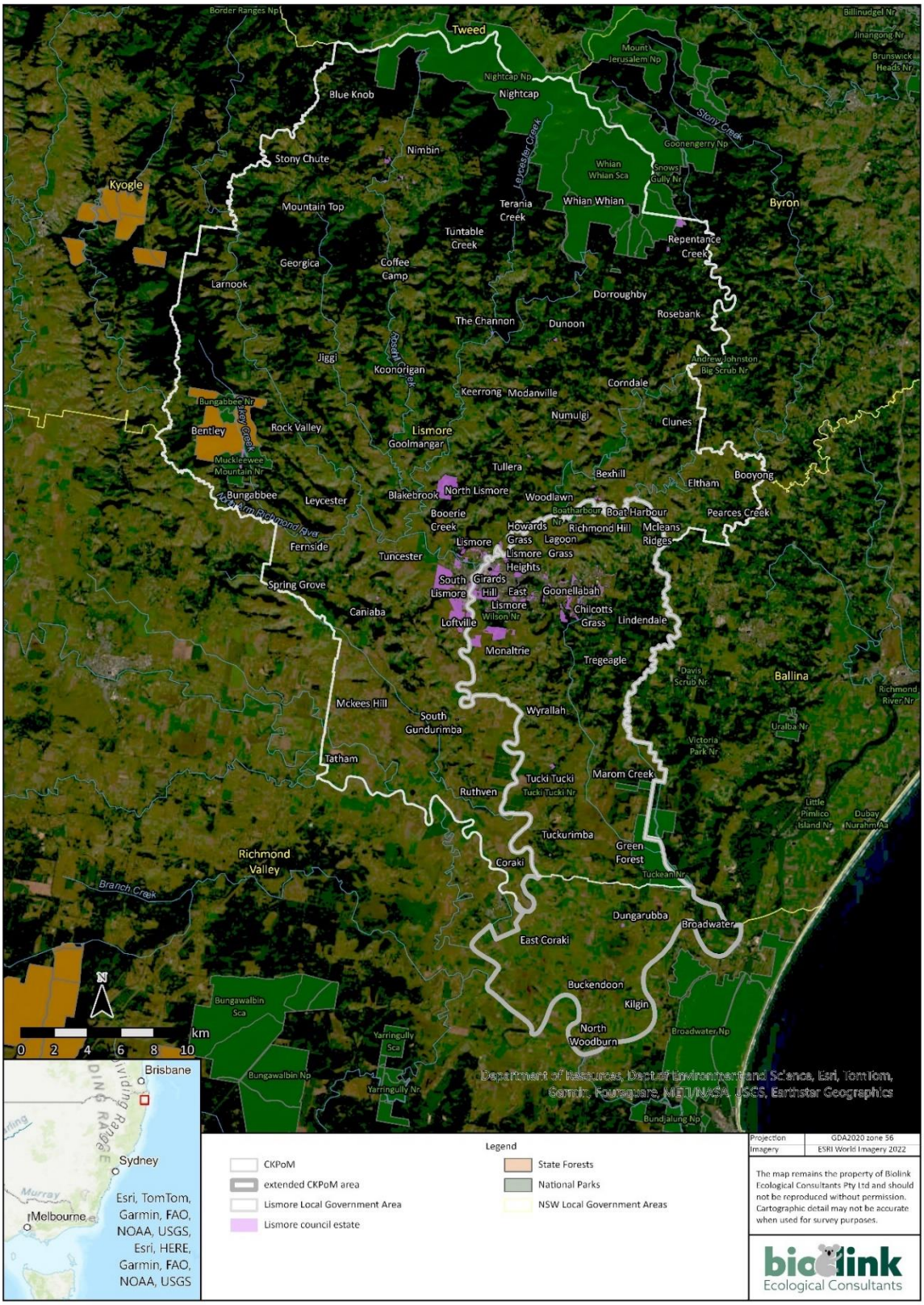

Figure 1. The boundary of Lismore City Council (LCC) Local Government Area (LGA) shown with a white line and the boundary of the extended CKPOM planning area with a thick grey line. The southern boundary of the CKPoM planning area (not extended to the Richmond River) is shown with a thin grey line. Council estate is shown in purple, State Forests are shown in orange and National Parks are shown in green.

2.2. Historical Records Analysis

Koala sightings records for the time period 1946-2016 comprised the records used in previous reports to LCC (Biolink 2011, Biolink 2017), the original sources of which are Bionet, FoK and LCC databases. These records were augmented with records covering the period 2017-2023 sourced from Bionet and Atlas of Living Australia, downloaded on 7th February 2024. Data from the time period 2017-2023 were checked for duplication using eastings and northings within a single meter and year, using Microsoft Access. Once duplications were removed, the resulting data set was partitioned chronologically to facilitate comparisons *pre* and *post* 2005 (the timeframes 2005-2010, 2011-2016 and 2017-2022 approximating the three most recent three koala generations[3], the measure of which is estimated to be approximately six years (Phillips 2000). This approach was taken to place results in the context of International Union for Conservation of Nature (IUCN) criteria which place weight on the concept of population change over a time period of three (taxon-specific) generations (WCUSSC 1994).

2.2.1 Extent of Occurrence

The range parameter *Extent of Occurrence* (EoO) is that area contained within the shortest continuous boundary that can be drawn to encompass all species records for a defined period and/or locality. The EoO is typically represented as the area enclosed by a Minimum Convex Polygon (MCP) constructed by connecting the outer-most records where no internal angle is greater than 180 degrees for each of the time periods and/or localities being considered. For consistency with previous reporting, the following EoOs were determined:

- All koala records (Historical EoO).
- Koala records for the current koala generation (2017-2022).

Koala records for all preceding generations are taken from previous reporting (Biolink 2011, Biolink 2017)

2.2.2 Area of Occupancy

The *Area of Occupancy* (AoO) is a key range parameter used to estimate the proportional area within the EoO that is occupied by the taxon of interest, reflecting the fact that a species will not typically be occupying the entire EoO. Historical koala records must be carefully considered when estimating the AoO because of their tendency to typically reflect observer density more so than koala density, the

[3] The most recent koala generation was taken as 2017-2022 to ensure consistency with previous reporting on generational changes, for which the previous most recent generation was 2011-2016 (Biolink 2017).

latter being best assessed via more systematic, unbiased survey effort. In most areas, there is also a tendency for the reporting rate to increase over time. Consequently, and unless corrected prior to analyses such as we describe in the following sections, range parameters such as AoO can potentially miscalculate the scale of any change that has occurred over time.

To estimate the AoO, a 2.5 km x 2.5 km (625 ha) fixed grid overlay, consistent with the grid used in Biolink (2011) and Biolink (2017), intersected[4] by the boundaries of the historical EoO and Lismore LGA was used to create a series of cells for sampling purposes, the primary assessment tool being whether a koala record for the period being investigated was either present or absent within a cell. In order to correct for changes in reporting frequency over time, the numbers of koala records utilised for analysis in each instance was determined with regard to the smaller representative data set being analysed (*i.e.* if there were only 100 records in one of the two data sets being compared and the other was represented by 250 records, then 100 records were randomly selected from the latter data set). Fifty percent (50%) of the grid-cells in the fixed-grid overlay were then randomly selected through each of 10 iterations for each period of interest. Following each iteration, the number of cells within which koala records were present were recorded to estimate the proportion of the EoO that was occupied. A mean AoO with discrete central tendency measures could then be calculated. For consistency with previous reporting, the following AoOs were determined:

- LGA-wide for the current koala generation (2017-2022).
- LGA-wide for the three immediately preceding koala generations (1999-2016).
- Extended CKPoM area for the current koala generation (2017-2022).
- Extended CKPoM area for the three immediately preceding koala generations (1999-2016).

2.2.3 Generational Persistence

Koala records were examined for re-occurrence in the same localised area over time frames that extended beyond the lifespans of individual koalas to show the location of long-standing resident populations. For the purposes of *Generational Persistence* (GP) assessment, 'localised' occurrence was that area captured within individual 2.5 km x 2.5 km grid cells previously used for estimating the AoO. GP was determined for each grid-cell based on a requirement for the presence of one or more koala records for each of the three most recent koala generations; those being generation 1 (2017-2022), generation 2 (2011-2016) and generation 3 (2005-2010).

[4] This approach will typically capture a larger area than the EoO but otherwise ensures that the entire EoO has been sampled.

2.3. Threats Analysis

Friends of the Koala (FoK) supplied details of koala call-outs for the Lismore LGA for the period 2017-2023. These were examined in terms of mortality trends to identify the primary causes of recorded koala fatality across the LGA.

Records of vehicle-strikes on koalas were the subject of particular attention, our intent being to provide an update to vehicle-strike blackspot analysis presented at the last round of threats analysis (Biolink 2017). This involved;

- Calculating the average Euclidian distance between each koala vehicle-strike and the five closest vehicle-strikes. Central tendency measures were determined for these data and the resulting 95% confidence interval utilised to define the distance parameter by which vehicle-strike data could be clustered. Vehicle-strikes that did not fall within clusters identified by this process were subsequently excluded from more detailed analysis given that they represented geographically isolated events.
- The under-reporting of koala vehicle-strike on 'rural' roads (<50% tend to be reported; Phillips & Fitzgerald 2014) was addressed by doubling the period over which vehicle-strike records on rural roads were considered such that data from two, rather than one, koala generation (*i.e.* both 2017-2022 and 2011-2016) was utilised. Urban roads were defined as those traversing areas where adjacent property lots were typically small (<600 m^2) in area.
- Partitioning urban and rural road vehicle-strike clusters whereby sections contributing disproportionately greater numbers of vehicle-strikes within identified clusters could then be isolated by partitioning each km in terms numbers of road strikes km^{-1} $generation^{-1}$.

For the purposes of black spot identification, vehicle-strike data included all koalas reported to FoK because of a vehicle collision, whether this was fatal or not. In instances where rural vehicle-strike data was only present in only the most recent generation, any indicative black-spots were omitted because they did not show persistence over time and may therefore be due to more transient and/or localised events.

2.4 Field Survey

2.4.1 Site selection

Field sites were identified using the same 350m x 350m grid used in previous monitoring events, with a focus on returning to Permanent Monitoring Points (PMPs) surveyed in 2017 (Biolink 2017) and / or 2020 (LCC 2020). Methodology for site selection was refined in 2020 such that survey only occurs at sites that contain at least one Preferred Koala Food Tree (PKFT). Consistent with accepted definitions of PKFTs in the Lismore CKPoM, the following suite of eucalypts were considered:

- Swamp mahogany (*Eucalyptus robusta*)
- Tallowwood (*E. microcorys*)
- Forest red/blue gum (*E. tereticornis*)
- Grey gums (*E. propinqua*)

Additional candidate sites were selected by overlaying the same 350m x 350m grid over the CKPoM planning area, with potential sampling points occurring at grid-cell intersections within areas of Preferred Koala Habitat (PKH) >0.5 ha in area. PKH mapping used for this purpose was a combination of vegetation mapping by Stewart *et al.* (2011), updated by McKinley & Murray (2019); habitat mapping derived by Hosking (2020); and Koala Habitat Information Base (KHIB) Sharing and Enabling Environmental Data (SEED) Potential Koala Habitat layer ('UQ_Khab_P_2ABC_fixed). To account for recent changes in PKH which may not be reflected in the mapping, Council records for clearing associated with development were compared with potential survey points, with no cases identified. Koala habitat enhancement works supported though LCC programs including its Rural Landholder Initiative were also compared with potential survey points. Potential survey points intersected three habitat enhancement sites with one of these deemed likely to provide habitat. Consent was sought from the landholders at this site but not provided. In selecting additional sites, preference was given to new sites which filled data gaps with regard to the spatial distribution of already surveyed PMPs.

Land tenure was determined using the "Council" layer provided by LCC, National Parks was determined by the boundaries identified in Six Maps Clip and Ship (*https://maps.six.nsw.gov.au/clipnship.html*) and private land tenure was determined by pre-existing information from LCC. Landholders on whose property potential sampling points occurred were consequently contacted by LCC and permission was sought to conduct a survey (opt-in system). The planned field sites identified by this process are illustrated in **Figure 2**.

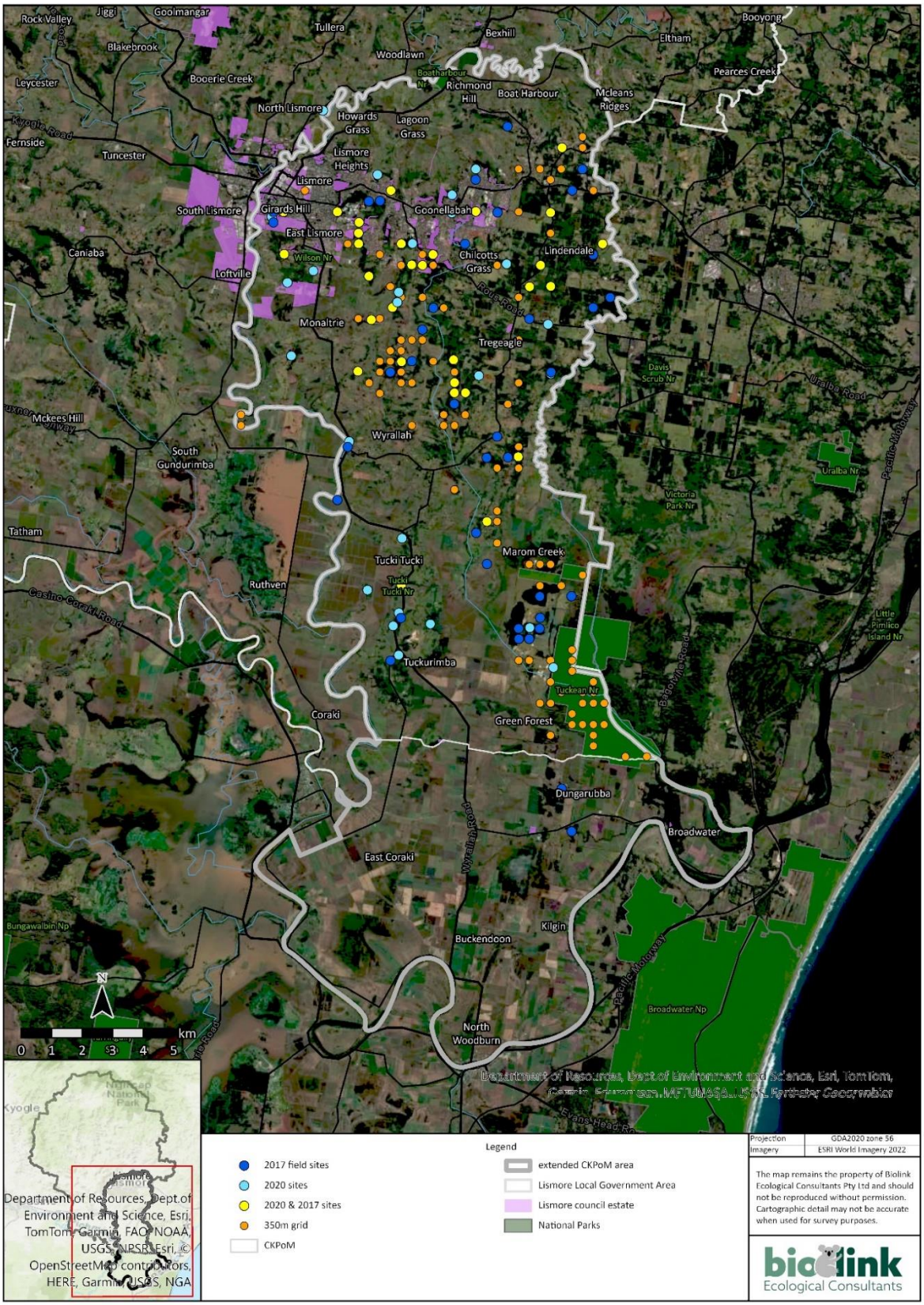

Figure 2. Planned field sites across the extended CKPoM planning area, showing re-survey of 2017 sites (dark blue circles) and 2020 sites (light blue circles), with sites which were surveyed at both events shown in yellow circles. Additional potential sites, where they occur over mapped Preferred Koala Habitat (PKH) are shown as orange circles.

2.4.2 Spot Assessment Technique (SAT) survey

Universal Transverse Mercator (UTM) coordinates for each of the field sites to be surveyed were uploaded into Garmin GPS 64s and 65s hand-held receivers, navigating on a GDA94 or GDA2020 datum respectively to assist site location in the field. Once located, field sites were assessed for koala activity using the Spot Assessment Technique (SAT) of Phillips & Callaghan (2011), whereby a 30-tree nearest-neighbour sample of all live trees with a Diameter at Breast Height (DBH) of ≥100 mm proximal to the centre tree / site coordinates were systematically assessed for the presence of koala faecal pellets within a 1m radius from the base of the trunk for a maximum period of 2 person-minutes if a koala scat was not detected earlier. In the case that a new field site was moved for logistical reasons (primarily access) UTM co-ordinates for the new centre tree were recorded.

To enable a koala density / population estimate, a direct count of koalas was conducted within a 25m (0.196 ha) fixed-radius area, focused on the centre tree at each field site. Fixed-radius searches were undertaken using two observers who walked the boundary of the 25m radial and lines internal to the radial, intensively searching the canopy from a range of angles. Trees that formed part of the 30-tree sample were also individually searched during the course of SAT survey. Where possible these observations included details of koala's age class, sex, health and the presence of pouch and/or back young as well as the tree species and DBH. Sightings of koalas made during the course of field survey, but outside the 25m fixed-radius area, were recorded as 'incidentals' which did not contribute to the density estimate.

2.4.3 Data analysis and spatial modelling

Occupancy / habitat utilisation

Occupancy / habitat utilisation was calculated according to the number of active sites divided by the total number of sites surveyed. These data are typically distributed binomially. Hence and unless otherwise specified, the Standard Error (SE) was estimated.

Habitat utilisation equation:

$$p = f/n$$

$$SE = \sqrt{pq/n}$$

where:

f = the number of sites that have one or more scats recorded
SE = standard error of the sample
p = the sample proportion
$q = 1 - p$
n = total sample size

Activity levels

Activity levels are the proportion of the 30-tree SAT sample which were scored positive for koala faecal pellets and these koala activity levels were interpreted in the context of the East Coast (high) activity level (**Table 1**).

Table 1. Categorisations of koala activity based on use of mean activity level ± 99% CI. Activity levels in the medium (normal) and high use range for East Coast (high) activity categories indicates occupancy by resident koala populations (Source: modified from Table 2 in Phillips & Callaghan 2011).

Activity category	Low use	Medium (normal) use	High use
East Coast (low)	< 9.97%	≥ 9.97% but ≤ 12.59%	> 12.59%
East Coast (high)	< 22.52%	≥ 22.52% but ≤ 32.84%	> 32.84%

Activity data from all SAT field sites was interpolated using regularised, thin-plate splining techniques using the spatial analyst extension in ArcGIS Pro. Output from the splining process was utilised to produce an activity contour model to delineate areas occupied by resident koala populations by identifying contours greater than 22.52% for East Coast (high) indicating significant activity thresholds of Phillips & Callaghan (2011) as detailed in **Table 1**. Lower activity contours were included in the activity model to assist with interpretation of connectivity. This process produces a meta-population model (or contour map) that delineates important "source" areas supporting established resident koala populations. These modelled areas of significant koala activity that encapsulate most contemporary koala records including observed breeding females (Bioink 2007).

To address the potential for temporal change in mean activity levels, data from 2020, and 2023 were tested for equal variances using the Chi squared Goodness of Fit test with Williams correction in BIOMstat version 4 (Exeter Software).

Density estimate

A density estimate was obtained by dividing the total number of koalas observed within fixed-radius searches by the total area searched. The associated SE was calculated as described in the equation on page 17 of this report.

3. Results

3.1. Historical Records Analysis

Seven thousand, seven hundred and sixty-seven (7,767) koala records were obtained for the time period 1949-2023. The chronological distribution and associated number of these records is presented in **Figure 3**. It is acknowledged that the small number of records for 2023 is likely due to a known lag in entering records into the Bionet database. As the HRA in this report utilises data only up to the end of 2022, this lag is unlikely to be impacting analytical outcomes.

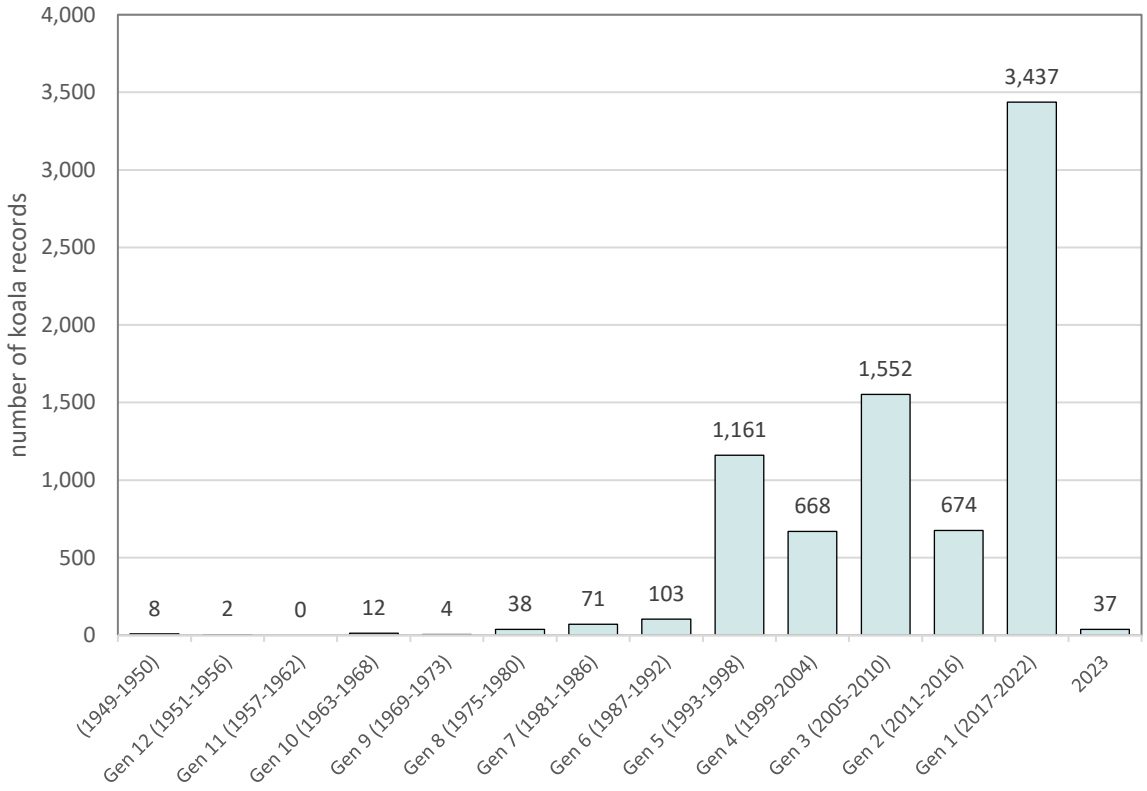

Figure 3. Frequency histogram detailing chronological distribution of 7,767 koala records from across the Lismore LGA for the time period 1949-2023.

3.1.1 Extent of Occurrence

Three thousand, four hundred and thirty-seven (3,437) koala records covering the period of the most recent koala generation (2017-2022) occur in the Lismore LGA; these records collectively indicating an EoO of 144,300 ha (**Figure 4**). The EoO has changed little over time, being estimated at 128,660 ha for the immediately preceding koala generation (2011-2016) (Biolink 2017) and 146,554 ha for the koala

generation preceding that (2005-2010) (Biolink 2011) (**Table 2**). The current EoO can therefore be seen to fall within the range of variation informing the two preceding koala generations.

Considering the time since the earliest record (1949-2023), there are 7,767 historical records across the Lismore LGA, collectively indicating an historic EoO of 150,707 ha (**Figure 4**).

Table 2. Changes in the *Extent of Occurrence* (EoO) of koalas across the Lismore LGA over the time period 1975-2022. The EoO has expanded by 28,049 ha over the three generations which precede the current one (1999-2016).

Time Period	EoO (ha)	Source
1975 - 1980	65,962	(Biolink, 2011)
1981 – 1986	78,778	(Biolink, 2011)
1987 - 1992	77,053	(Biolink, 2011)
1993 - 1998	126,445	(Biolink, 2011)
1999 - 2004	108,350	(Biolink, 2011)
2005 - 2010	146,554	(Biolink, 2011)
2011 - 2016	128,660	(Biolink, 2017)
2017 - 2022	144,300	
Average change 1999 - 2016	**28,049**	

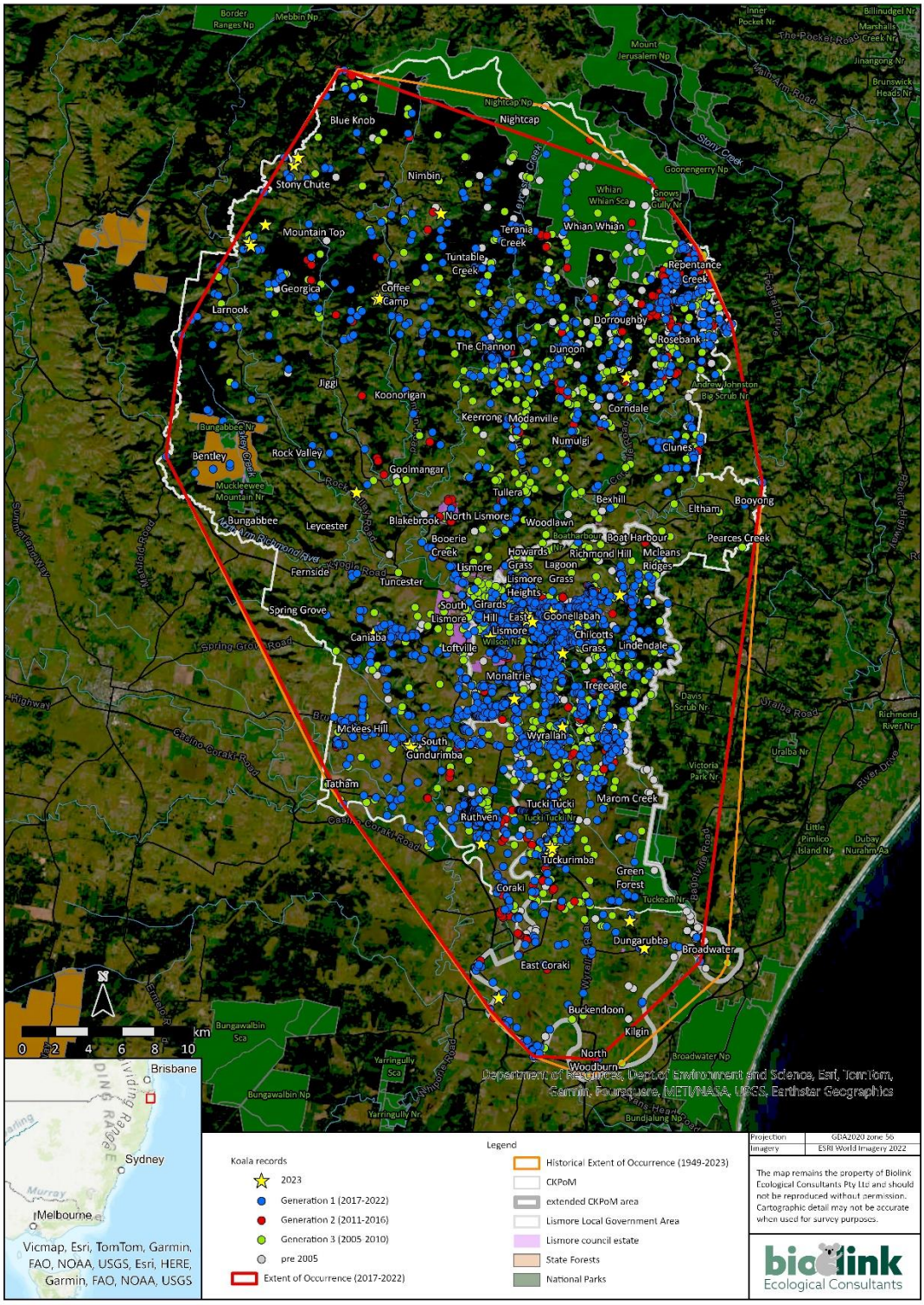

Figure 4. Distribution of 7,767 koala records across the Lismore LGA for the time period 1949-2023. Generation 1 (2017-2022) is denoted by blue circles, generation 2 (2011-2016) by red circles and generation 3 (2005-2010) by green circles. Records from 2023 are shown with yellow stars and *pre* 2005 records are shown with grey circles. The *Extent of Occurrence* (EoO) for the most recent koala generation (2017-2022) is 144,300 ha (red polygon) and covers almost the entirety of the LGA (thin grey polygon) and is inclusive of the extended CKPoM planning area (thick grey line). The historical EoO (1949-2023) is slightly larger at 150,707 ha and is shown with an orange polygon.

3.1.2 Area of Occupancy

Two hundred and forty-nine (249) 2.5 km x 2.5 km grid-cells cover the intersection of historical EoO and the Lismore LGA. The occupancy rate was estimated from 2,894 records for the time-period 1999–2016 (the most recent three koala generations preceding the current one) compared to a subset of 2,894 randomly selected records for the time-period 2017 – 2022. Randomly sampling 50% of the 249 grid cells within the historical EoO over 10 iterations for each of these two time periods returned the following results:

Lismore LGA

1999-2016: AoO estimated at 68.75% ± 1.27% (SE) of available habitat

2017–2022: AoO estimated at 73.25% ± 0.10% (SE) of available habitat

A comparative analysis of the data-sets informing the preceding outcomes implies that Lismore LGA-wide occupancy has been consistently high within the last four generations and there has been a small but significant increase in the proportional amount of habitat being utilised by koalas when comparing the last koala generation (2017 - 2022) to the period preceding this (1999 - 2016) ($t=-2.787$, $df=17$, $P = 0.006327$).

Extended CKPoM planning area

Seventy-three (73) 2.5 km x 2.5 km grid-cells cover the intersection of historical EoO and the extended CKPoM planning area. The occupancy rate was estimated from 1,764 records for the time-period 1999–2016 (the most recent three koala generations preceding the current one) compared to a subset of 1,764 randomly selected records for the time-period 2017-2022. Randomly sampling 50% of the 73 grid cells within the historical EoO over 10 iterations for each of these two time periods returned the following results:

1999-2016: AoO estimated at 78.60% ± 1.44% (SE) of available habitat

2017–2022: AoO estimated at 75.60% ± 0.97% (SE) of available habitat

A comparative analysis of the data-sets informing the preceding outcomes implies that occupancy has been consistently high within the last four generations and there has been no significant difference in the proportional amount of habitat being utilised by koalas when comparing the last koala generation (2017 - 2022) to the period preceding this (1999 - 2016) ($t=1.718$, $df=16$, $P = 0.052535$).

3.1.3 Generational Persistence

Seventy-four (74) of the 249 2.5 km x 2.5 km grid cells located within the historical EoO and Lismore LGA returned evidence of GP. Cells evidencing GP were primarily clustered in the south and north-east of the LGA, the largest of these clusters located within the extended CKPoM planning area and stretching to the western boundary of the LGA, *i.e.* from Coraki in the south to Boat Harbour in the north and across to McKees Hill and Tatham in the west. The clustering of interconnected cells of GP in the north-east covers the area from Repentance Creek, Dorroughby and Rosebank. There are other, more sparsely distributed cells of GP across the LGA as illustrated in **Figure 5**. Considering the 73 grid cells that intersect the extended CKPoM planning area, 32 (43.84%) show GP.

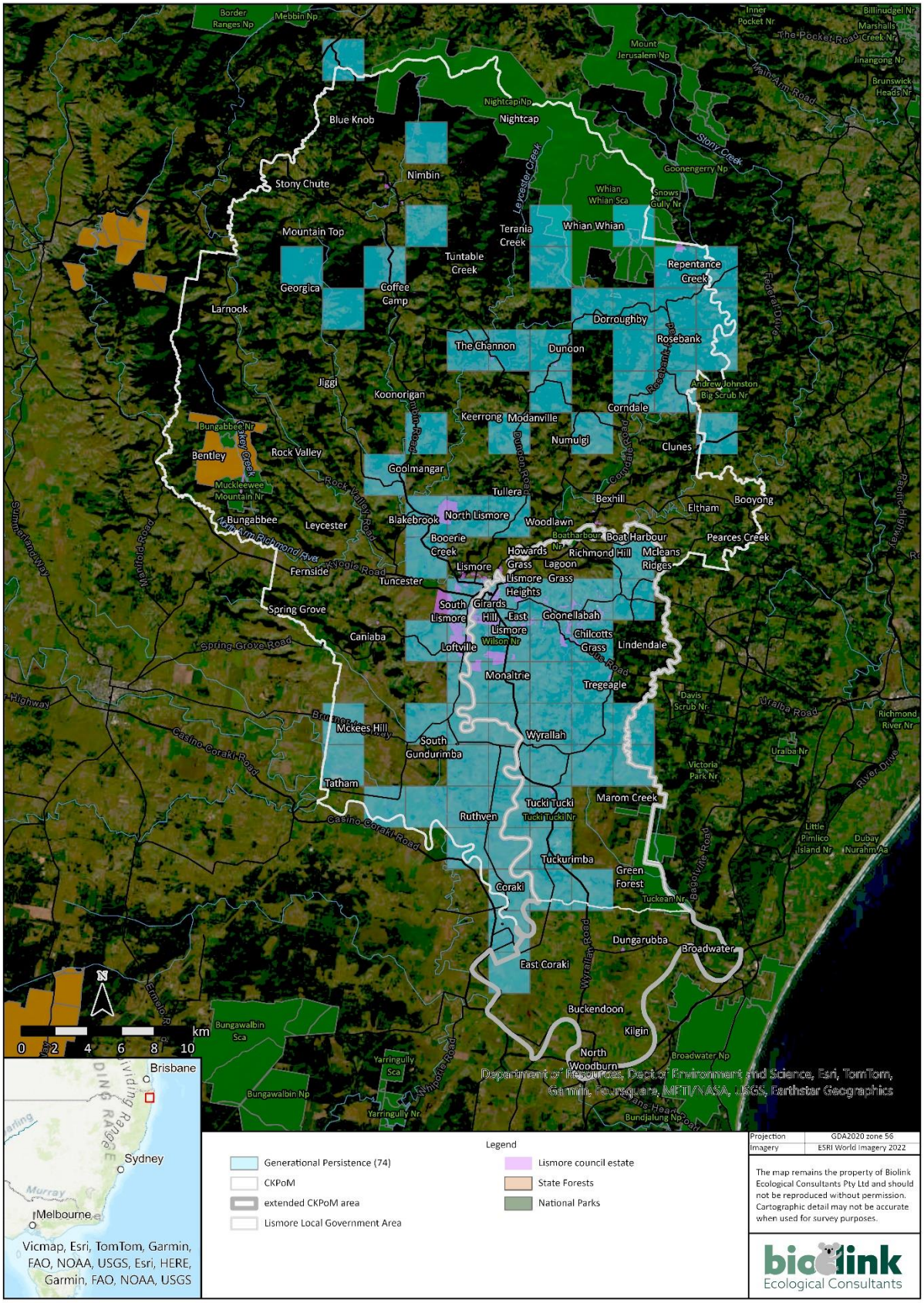

Figure 5. Areas of *Generational Persistence* (GP) across the Lismore LGA for the time period 2005-2022 are shown in blue 2.5km x 2.5 grids.

3.2. Threats Analysis

The FoK database contained information associated with 4,735 'koala-calls' across the Lismore LGA for the period 2017-2023[5], of which 994 relate to a koala mortality. The predominant factors contributing to known koala mortalities across the LGA were disease (572/994 = 57.54%), vehicle-strike (228/994 = 22.94%) and dog attack (62/994 = 6.24%). A further 6.54% of mortalities were due to a range of disparate factors including falls, injuries resulting from indeterminate cause and becoming orphaned, while the causes behind the remaining 6.94% of mortalities were unknown. The three primary contributing factors associated with known mortalities are discussed in more detail in the following sections.

3.2.1 Disease

Chlamydiosis is the most commonly attributed disease across the Lismore LGA, resulting in the mortality of 423 koalas out of a total 745 koalas presenting with the condition over the period 2017–2023. Females account for a disproportionately greater number of koalas who present with the disease (1.42 females: 1 male) and ultimately die from it (2.27 females: 1 male). Partitioning the data according to years, chlamydia (as measured by confirmed mortalities[6]) did not fluctuate significantly over this time period (Grubbs' test: $Z = 2.02$, $P > 0.05$) though it can be seen to peak in 2019 and be elevated for several years thereafter (**Figure 6**). The geographic spread of chlamydial disease is broadly reflective of sightings records through-out the LGA, though the lack of recorded chlamydia around McKees Hill, Tatham and the western parts of South Gundurimba is noteworthy given the otherwise high concentration of koala sightings in this area (**Figure 7**).

[5] Historical Records Analysis (HRA) from Section 3.1 used data partitioned by koala generations (a period of six years), the most recent generation being 2017 – 2022 to align with previous reporting. Threats analysis additionally uses records from 2023 unless, as is the case for some vehicle strike analysis, there is a need to use generational timeframes.

[6] To avoid counting the same animal more than once.

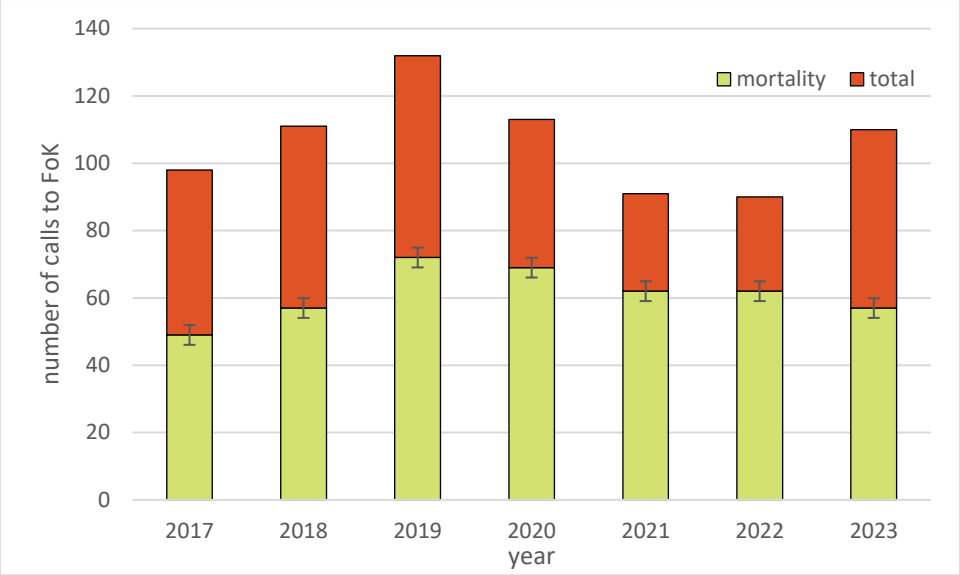

Figure 6: Trends in the numbers of koalas with chlamydiosis reported to the Friends of the Koala (FoK) and associated mortalities over the period 2017 - 2023. The light green section of the column shows the number of calls to FoK that related to a koala mortality event, the red section of the column shows calls that did not relate to a koala death. Error bars display the Standard Error (SE) for mortality rates.

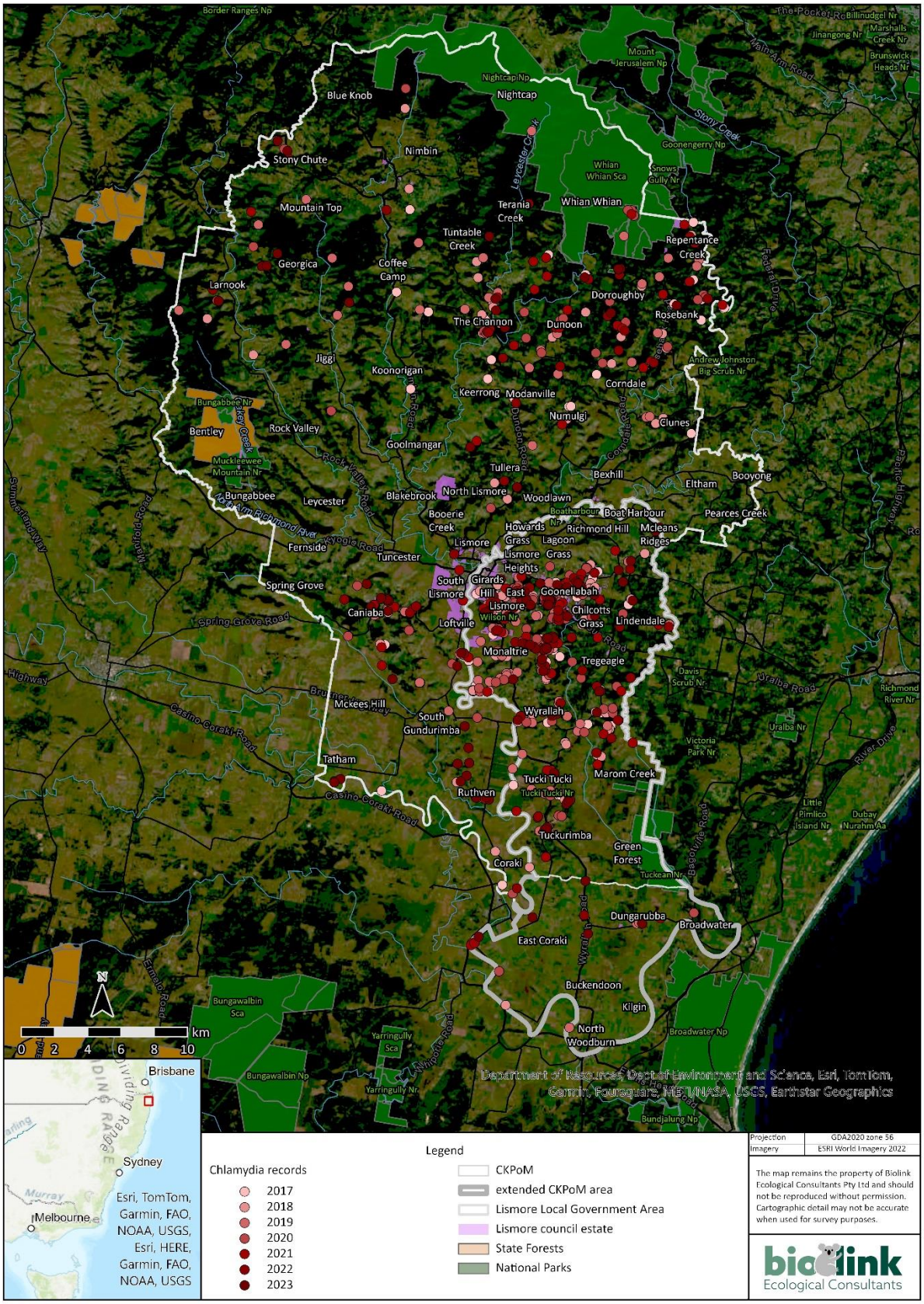

Figure 7. Instances of chlamydia, as reported to Friends of the Koala (FoK), across the Lismore LGA with records from 2017 – 2023 shown as circles in a gradation of colour starting at light red (2017) to dark red (2023).

Over the recording period of interest there were 183 koalas who presented with disease, but for whom the nature of this disease was not explicit (classified as "disease – other"). Of these koalas, the vast majority represent mortalities (n = 149). In contrast to chlamydiosis, a greater proportion of males present with "disease – other" (1.18 males: 1 female) and die as a result (1.22 males: 1 female), though the degree of this sex bias is not as pronounced as seen with chlamydiosis. Partitioning the data according to years, "disease – other" (as measured by confirmed mortalities) did not fluctuate significantly over this time period (Grubbs' test: $Z = 2.02$, $P > 0.05$) (**Figure 8**).

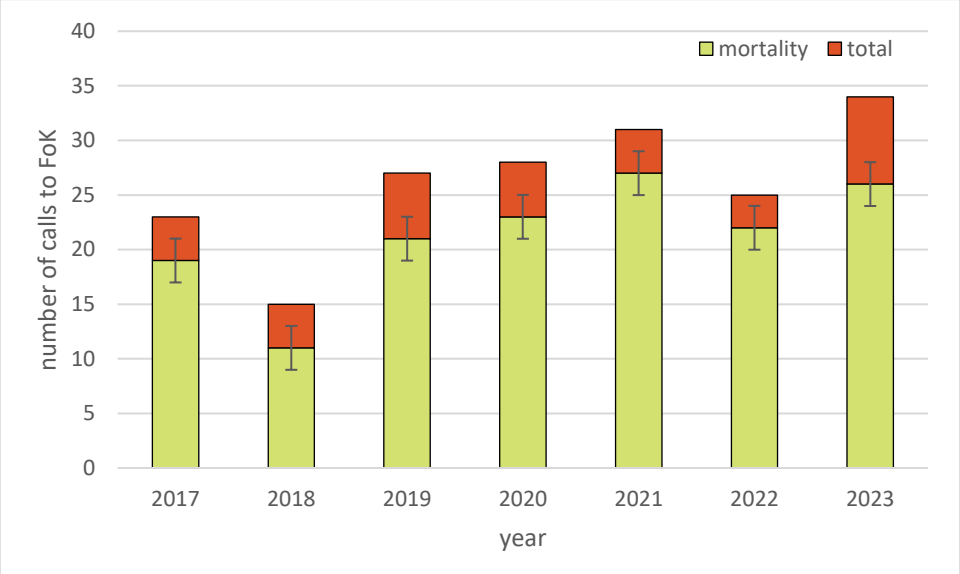

Figure 8: Trends in both the numbers of koalas with "disease – other" reported to the Friends of the Koala (FoK) and associated mortalities over the period 2017 - 2023. The light green section of the column shows the number of calls to FoK that related to a koala mortality event, the red section of the column shows calls that did not relate to a koala death. Error bars display the Standard Error (SE) in mortality rates.

3.2.2 Vehicle strike

During the period 2017-2023 there were 302 koala vehicle-strikes reported to FoK across the Lismore LGA, 75.50% (*n* = 228) of which resulted in the death of the koala. The greater proportion of vehicle-strikes were recorded as males (2.08 males: 1 female) and the outcome, in terms of mortality, was the same across sexes with females being as likely to die when struck by a vehicle (81.11% mortality of females) as a male (77.01% mortality of males), in instances where the sex of the animal was known. Partitioning this data chronologically reveals a slight downward trend (R^2= 0.1176) in vehicle-strike, but there was no significant fluctuation over this time period (Grubbs' test: $Z = 2.02$, $P > 0.05$) (**Figure 9**). Wyrallah Road has been a location of specific interest for koala vehicle-strike in previous reporting and here we report that it continues its slight upward trend (**Figure 10**).

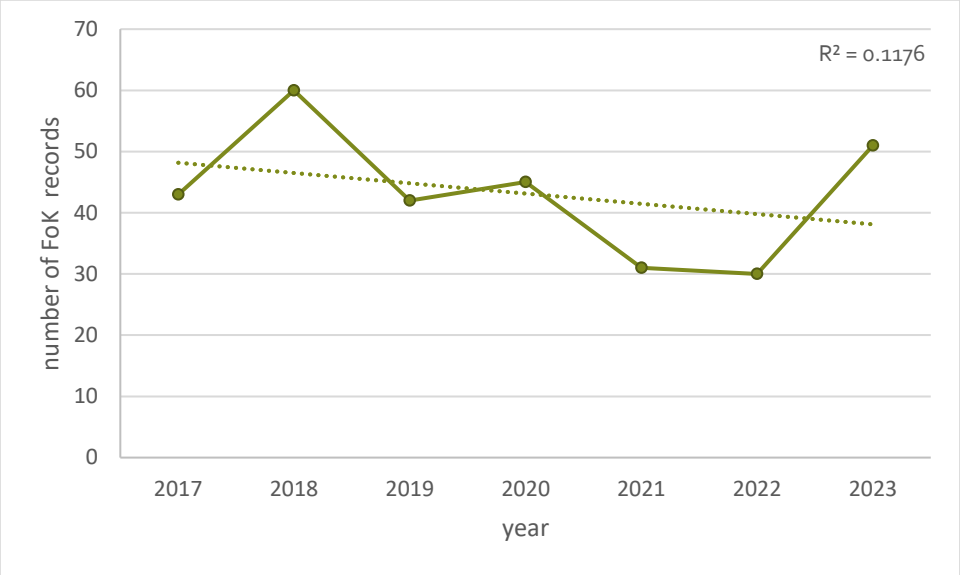

Figure 9: Trends in the numbers of koala vehicle-strikes reported to the Friends of the Koala (FoK) over the period 2017 - 2023.

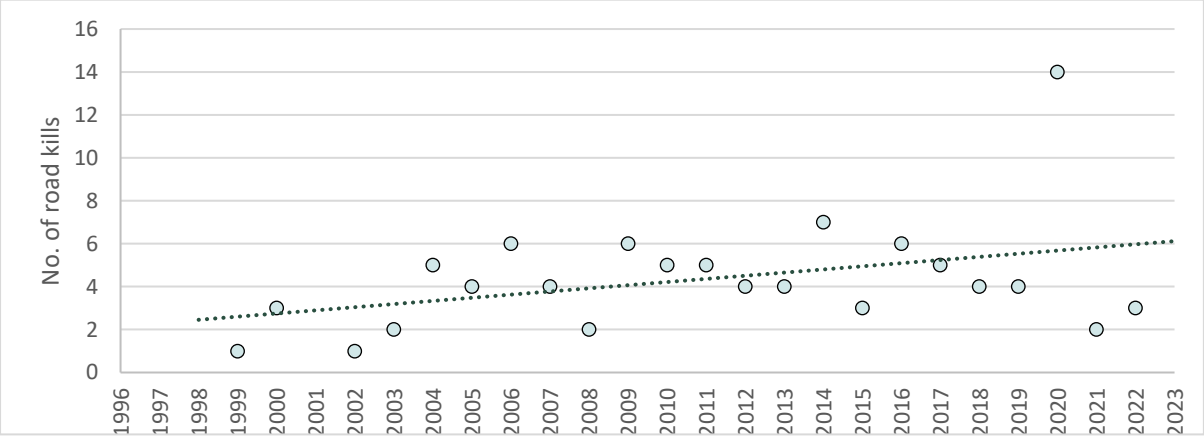

Figure 10: Trends in the numbers of koala vehicle-strike reported along Wyrallah Road, with data for the most recent koala generation (2017-2022) reported to Friends of the Koala (FoK) and data from 1996-2016 as reported by Biolink (2017).

Due to the analytical approach used for vehicle-strike blackspot analysis, which puts weight on the concept of koala vehicle-strike km^{-1} $generation^{-1}$, a refined dataset was used for this process which included a single koala generation (2017-2022) or two koala generations on rural roads (2017-2022 and 2022-2016) to correct for the under-reporting of vehicle strike on rural roads, as described in previous reporting (Biolink 2017).

Application of the clustering and generational parameters resulted in the capture of 261 vehicle-strike records and the identification of 13 blackspots for koala vehicle-strike across the Lismore LGA (**Figure 11**). **Table 3** provides a summary of the vehicle-strike data in terms of road length and the numbers of koalas being struck at each of these blackspots, both as a total figure and as vehicle-strikes km^{-1} $generation^{-1}$. Consistent with previous reporting, blackspots that had an average number of vehicle-strikes km^{-1} $generation^{-1}$ ≥3.5 and / or sections of road within the blackspot that had a strike rate of ≥9 road strikes km^{-1} $generation^{-1}$ were designated as 'Major Blackspots' and are discussed in detail. The remaining blackspots were designated as 'Minor'.

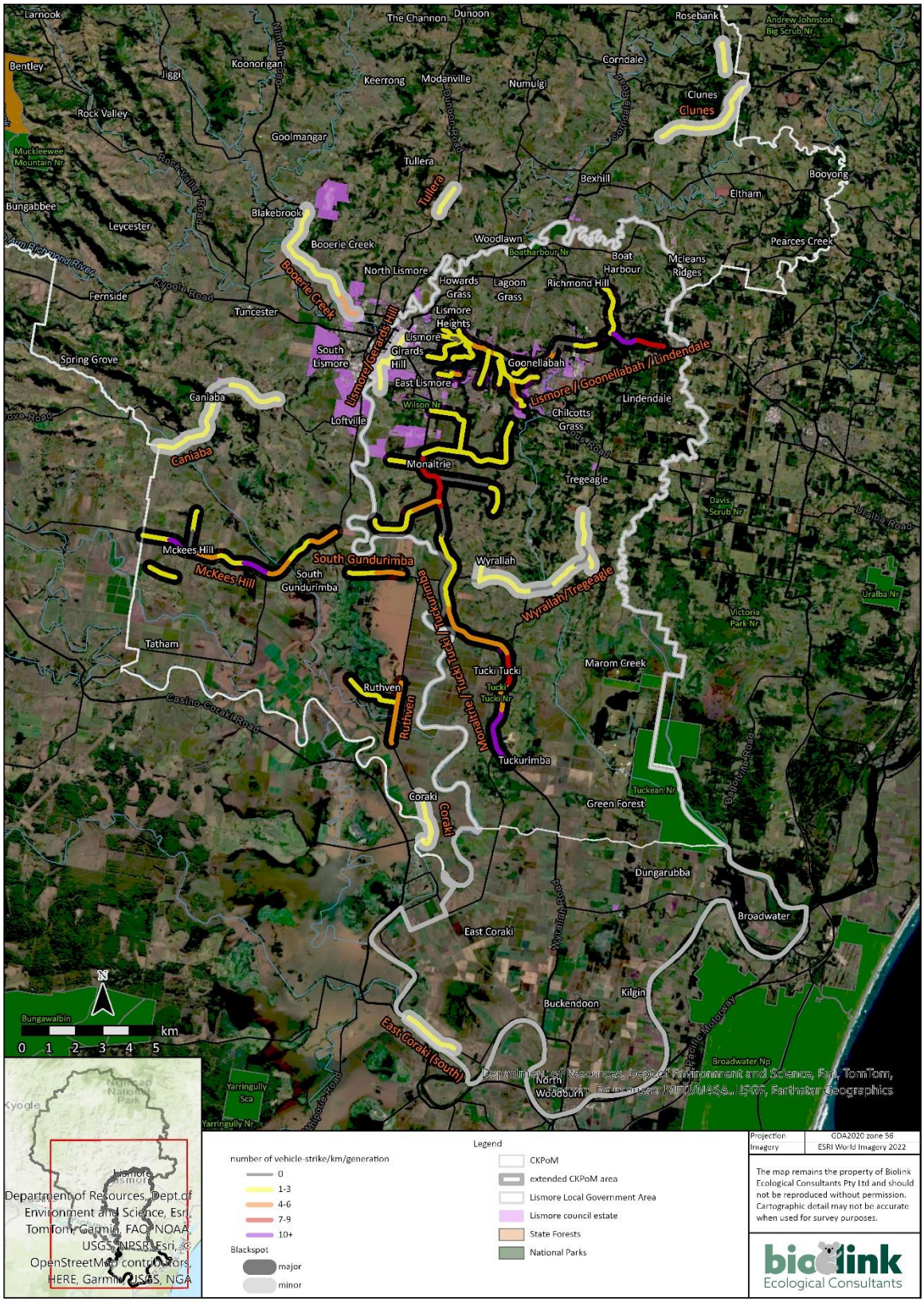

Figure 11. Vehicle-strike blackspots across the Lismore Local Government Area (LGA), with Major Blackspots shown with black shadows and Minor Blackspots shown with light grey shadows. The number of vehicle-strikes km^{-1} generation^{-1} are colour coded with 1-3 vehicle-strikes km^{-1} generation^{-1} in yellow, 4-6 in orange, 7-9 in red and ≥10 in purple.

Table 3. Details of blackspots for koala vehicle-strike. L = length of blackspot, *N*= number of vehicle-strikes. Major Blackspots are defined as those that that had an average number of vehicle-strikes km^{-1} generation^{-1} ≥3.5 and / or sections of road within the blackspot that had a strike rate of ≥9 vehicle-strikes km^{-1} generation^{-1}. Major Blackspots are marked with a *.

	2017 analysis				2023 analysis			
Blackspot name	2017 Black Spot No.	*L* (km)	*N*	Average numbers and range (in brackets) of vehicle-strikes km^{-1} generation^{-1}	Description	*L* (km)	*N*	Average numbers and range (in brackets) of vehicle-strikes km^{-1} generation^{-1}
McKees Hill *	1	6	17	2.8 (1 – 5)	The Bruxner Highway where it enters the LGA from the west and extending 8km to the east near the intersection with Johnson Road, McKees Hill. Also includes 2km of McInnes Road and 1km of Rogerson Road.	11	53	4.8 (1 - 16)
South Gundurimba *					Coraki Road, commencing 150m west of the intersection with McMahon Road, extending east for 2km.	2	9	4.5 (3 - 6)
Monaltrie/ Tucki Tucki/ Tuckurimba*	2	9	35	3.9 (1 – 12)	Commencing at its most southern point 1km south of the intersection of Wyrallah Road and Hazlemount Lane, Tuckurimba and extending north along Wyrallah Road to Durheim Road, Monaltrie and including parts of Skyline Road, Durheim Road, Monaltrie Road, Monaltrie Lane and Riverbank Road.	21	67	3.2 (0- 11)
	5	8	19	2.4 (1 – 5)				
Ruthven					Commencing at intersection of Flood Reserve Road and Coraki Road, Ruthven and extending west for 2km along Flood Reserve Road and 750m north and 1.25km south along Coraki Road.	4	12	3 (1-5)
Lismore / Goonellabah/ Lindendale *	4 (East)	4	19	4.8 (1 – 7)	Commencing on the Bruxner Highway, 150m from the Byron LGA boundary, Lindendale and extending west through urbanised Lismore, including parts of High Street, Ballina Road, New Ballina Road, Rotary Drive and University Road. It branches off the Bruxner Highway at Goonellabah and includes Invercauld Road, Jarmin Drive, Cambridge Drive and McDermott Avenue. It also includes a 2km branch to the north of Richmond Hill Road, Richmond Hill.	29	73	2.5 (0-14)
	4 (Central)	10	14	1.4 (1 -3)				
	4 (West)*	10	26	2.6 (1 -9)				

	2017 analysis				2023 analysis			
Blackspot name	2017 Black Spot No.	*L* (km)	*N*	Average numbers and range (in brackets) of vehicle-strikes km^{-1} generation^{-1}	Description	*L* (km)	*N*	Average numbers and range (in brackets) of vehicle-strikes km^{-1} generation^{-1}
Booerie Creek					Commencing in the south at the intersection of Wilson Street, Terania Street and Nimbin Road, Booerie Creek and extending along Nimbin Road for 3km to the north.	3	7	2.3 (1 - 4)
Coraki					Commencing 100m to the north of the intersection of Coraki Road and Goswell Road and extending 2km south, 150m past the intersection with Casey Road, Coraki.	2	4	2 (1 - 3)
Clunes					A 4km stretch of Bangalow Road, Clunes extending east to the intersection of James Gibson Road. An additional 1km non-adjoining section beginning in the south at the intersection of James Gibson Road and Macquire Road, extending north on Macquire Road.	5	10	2 (1 - 3)
Tullera					1km stretch of Dunoon Road that begins in the east, 280 m from intersection with Bentley Road and extending north-east.	1	2	2 (2)
Lismore /Girards Hill					Commencing in the north at Dawson Street and Larkin Lane, Lismore extending along Dawson Street and ending 780m south of the intersection of Keen Street and Bernstein Street, East Lismore.	2	3	1.5 (1 - 2)
Wyrallah/Tregeagle	3	3	5	1.7 (1 – 3)	Commencing 1km north of the intersection of Skyline Road and Tregeagle Road, Wyrallah, extending south and then east along Tregeagle Road for 8km, including a 1km branch along Grennan Road from Tregeagle Road, Tregeagle.	9	13	1.4 (0 - 3)
Caniaba					Commencing at the LGA boundary on Canabia Road and extending east for 6km to the intersection with Nimoola Road, Canabia.	6	7	1.2 (0 - 3)
East Coraki (south)					Commencing 1km to the north-west of Swan Bay Ferry Road and Oatland Road, East Coraki, extending for 1km along Oakland Road to the north-west.	1	1	1 (1)

McKees Hill blackspot (formerly blackspot 1)

There is an 8km stretch of road on the Bruxner Highway, west of the extended CKPoM planning area that contains two very high density areas of vehicle-strike, the first is 1.4 km west of Pelican Creek with 16 vehicle-strikes km^{-1} generation^{-1}. This is the highest density of vehicle-strike across the Lismore LGA. The second area starts 2km west of the highest density section and has 11 vehicle-strikes km^{-1} generation^{-1}. It further incorporates McInnes Road for a 2km section extending north from the Bruxner Highway and an additional 1km section that is not joined to Bruxner highway but is on Rogerson Road, approximately 1.2km south. This 1km area is included in the blackspot grouping by the analytical process due to its close proximity within an interconnected road system. This blackspot totals 11km in length (**Figure 12**).

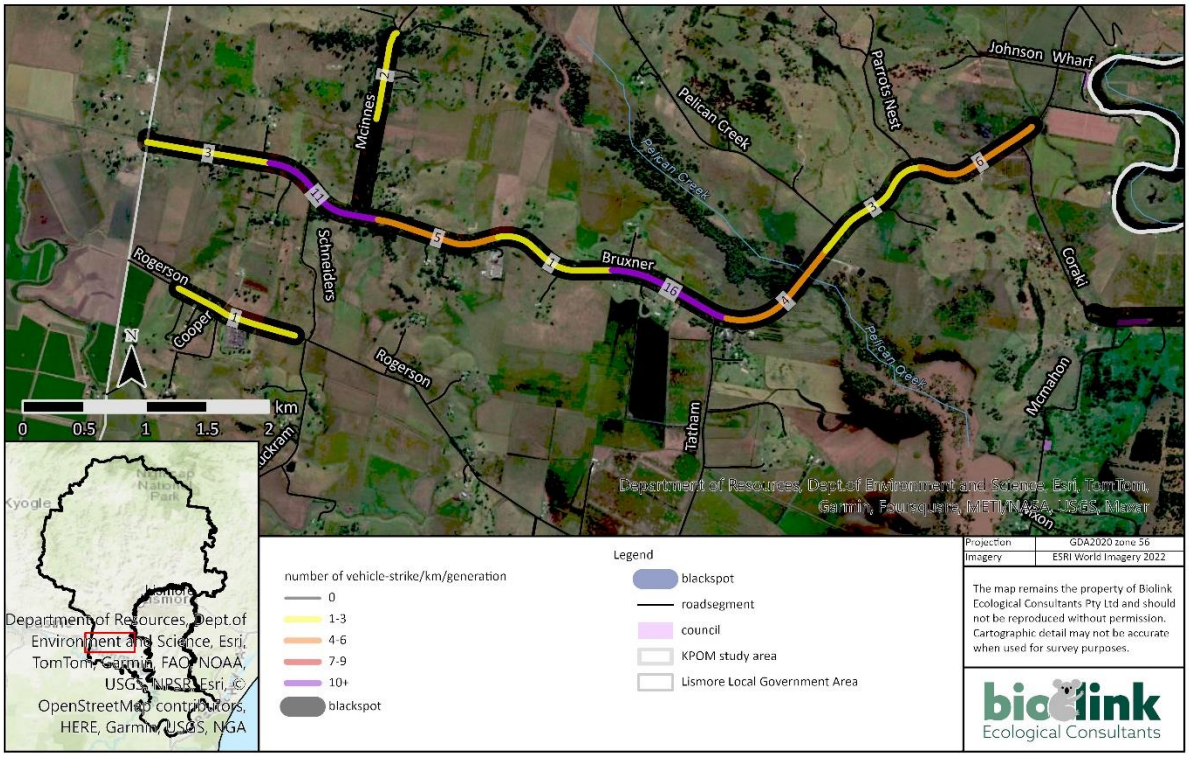

Figure 12. McKees Hill blackspot (formerly blackspot 1), showing 1-3 vehicle-strikes km^{-1} generation^{-1} with a yellow line, 4-6 vehicle-strikes km^{-1} generation^{-1} with an orange line, 7-9 vehicle-strikes km^{-1} generation^{-1} with a red line ≥10 vehicle-strikes km^{-1} generation^{-1} with a purple line.

South Gundurimba blackspot

This is a new blackspot that consists of a 2km stretch of Coraki Road, west of the extended CKPoM planning area. It contains a 1km stretch of 6 vehicle-strikes km^{-1} generation^{-1} between Malone Lane and Walsh Lane and an adjoining section of blackspot that continues on Coraki Road, 100m past the intersection of McMahon Road, with 3 vehicle-strikes km^{-1} generation^{-1} (**Figure 13**).

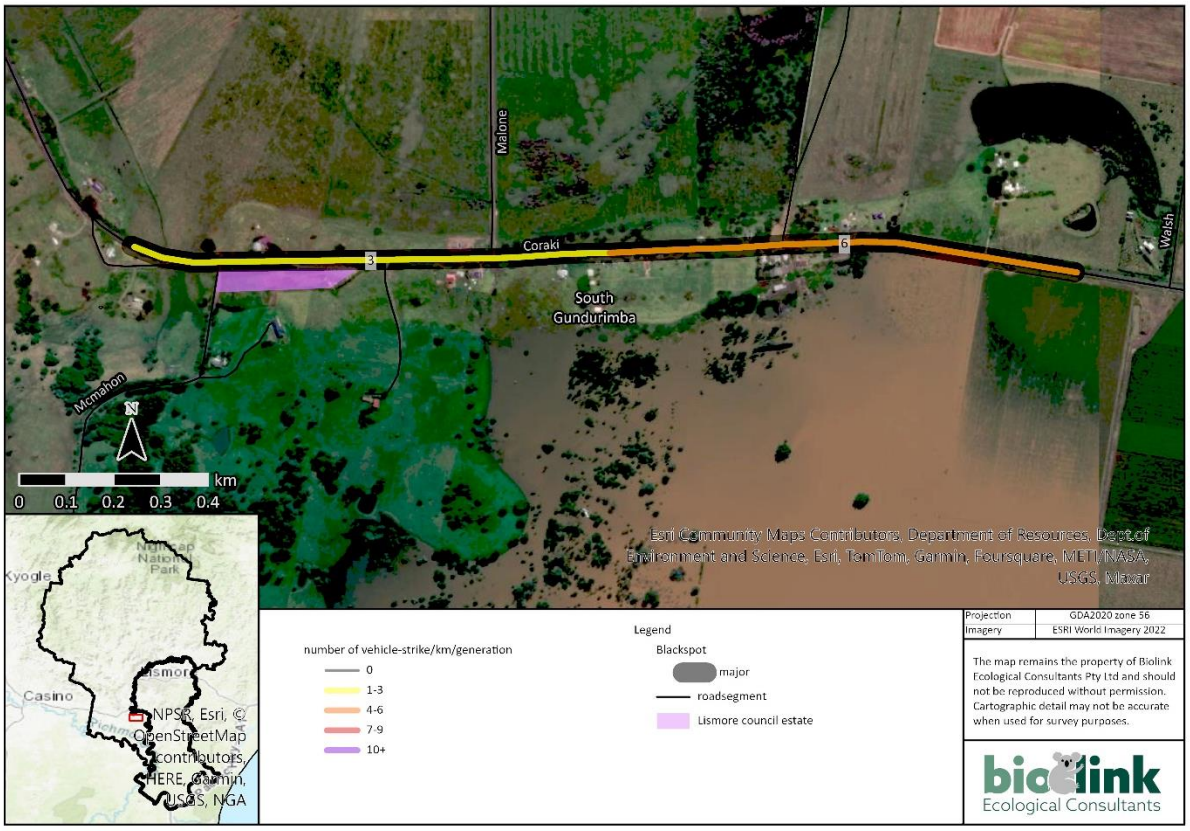

Figure 13. South Gundarimba blackspot, showing 1-3 vehicle-strikes km^{-1} generation^{-1} with a yellow line and 4-6 vehicle-strikes km^{-1} generation^{-1} with an orange line.

Monaltrie/ Tucki Tucki/ Tuckurimba blackspot (formerly blackspots 2 and 5)

Almost the entirety of Wyrallah Road on the western side of the extended CKPoM planning area has experienced koala vehicle-strike, with the highest density being a 2km stretch at the intersection of Tuckurimba Road with 11 and 10 vehicle-strikes km^{-1} generation^{-1}. One (1)km north of this is a 1km stretch with 9 vehicle-strikes km^{-1} generation^{-1}. There is another 1km stretch, just south of Monaltrie, with 7 vehicle-strikes km^{-1} generation^{-1} (**Figure 14**).

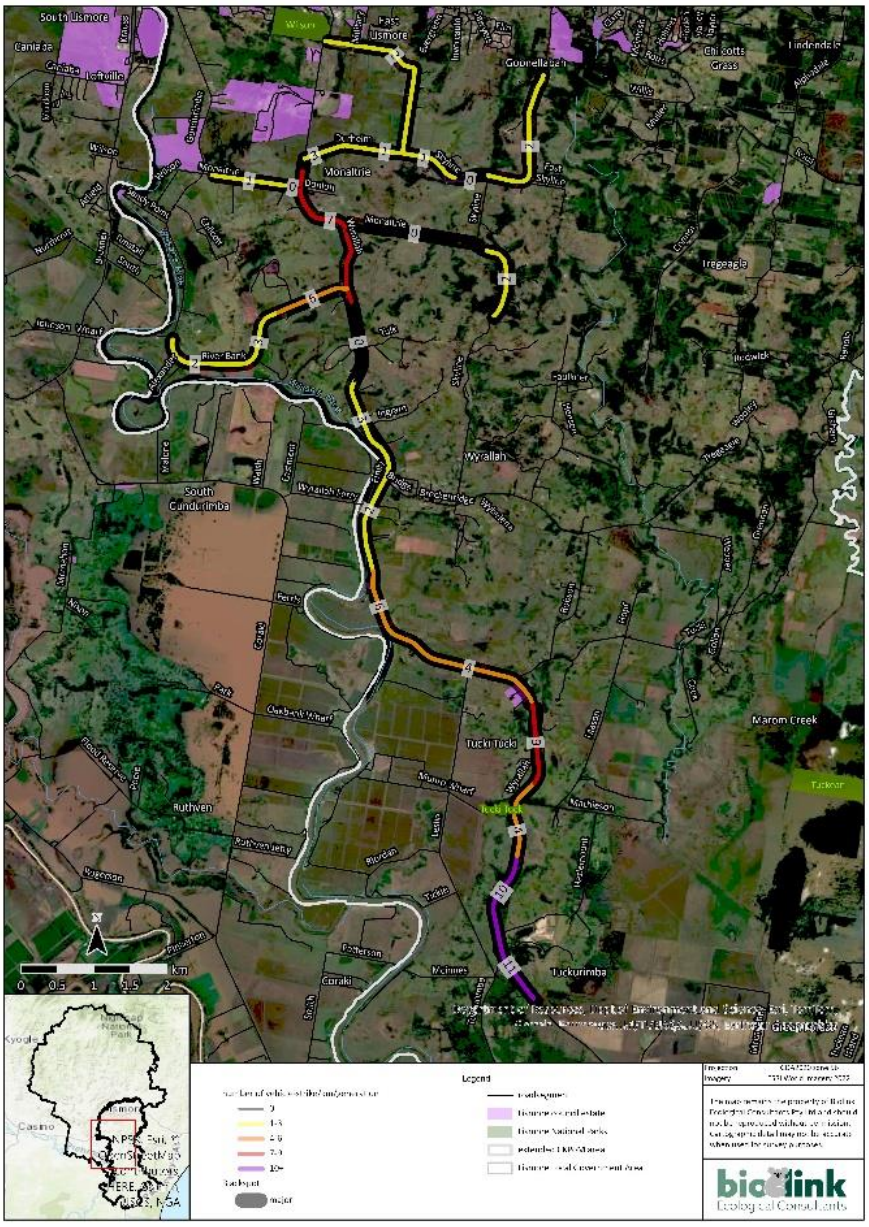

Figure 14. Monaltrie / Tucki Tucki / Tuckurimba blackspot (formerly blackspots 2 and 5), showing 1-3 vehicle-strikes km^{-1} generation^{-1} with a yellow line, 4-6 vehicle-strikes km^{-1} generation^{-1} with an orange line, 7-9 vehicle-strikes km^{-1} generation^{-1} with a red line ≥10 vehicle-strikes km^{-1} generation^{-1} with a purple line.

Ruthven blackspot

This is a new blackspot that consists of a 2km stretch of Coraki Road, west of the extended CKPoM planning area that also extends 2km along Flood Reserve Road where the two roads intersect. The highest density of vehicle-strikes in this blackspot is 5 vehicle-strikes km^{-1} generation^{-1} which adjoins an area of 4 vehicle-strikes km^{-1} generation^{-1}, both of which are on Coraki Road (**Figure 15**).

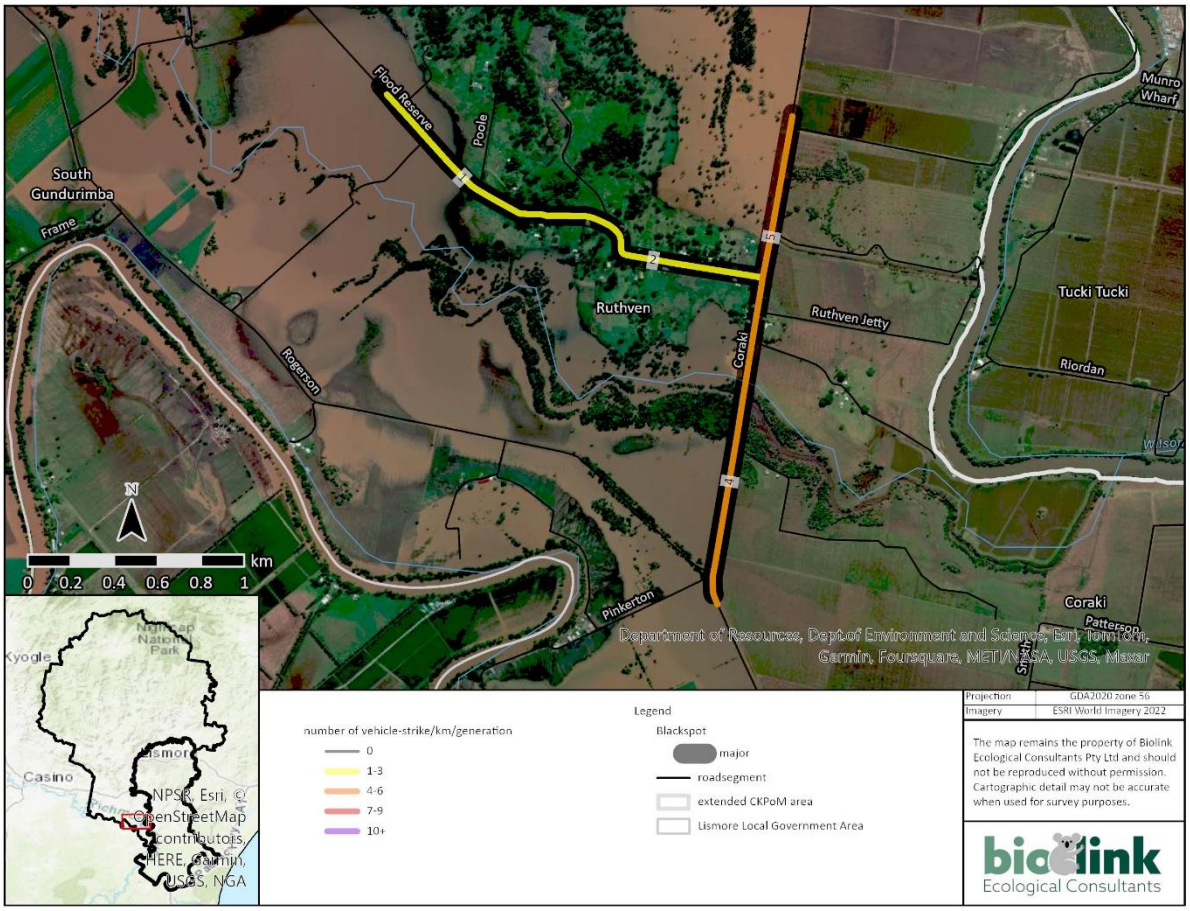

Figure 15. Ruthven blackspot, showing 1-3 vehicle-strikes km^{-1} generation^{-1} with a yellow line and 4-6 vehicle-strikes km^{-1} generation^{-1} with an orange line.

Lismore /Goonellabah/ Lindendale blackspot (formerly blackspot 4)

This is a 12km stretch of road in the north of the extended CKPoM planning area, centred on the Bruxner Highway (Ballina Road) where it travels through the most heavily urbanised part of Lismore. The highest density of vehicle-strike is a 2km stretch to the south of Richmond Hill where vehicle strike is 14 and 7 vehicle-strike km^{-1} generation^{-1} (**Figure 16**).

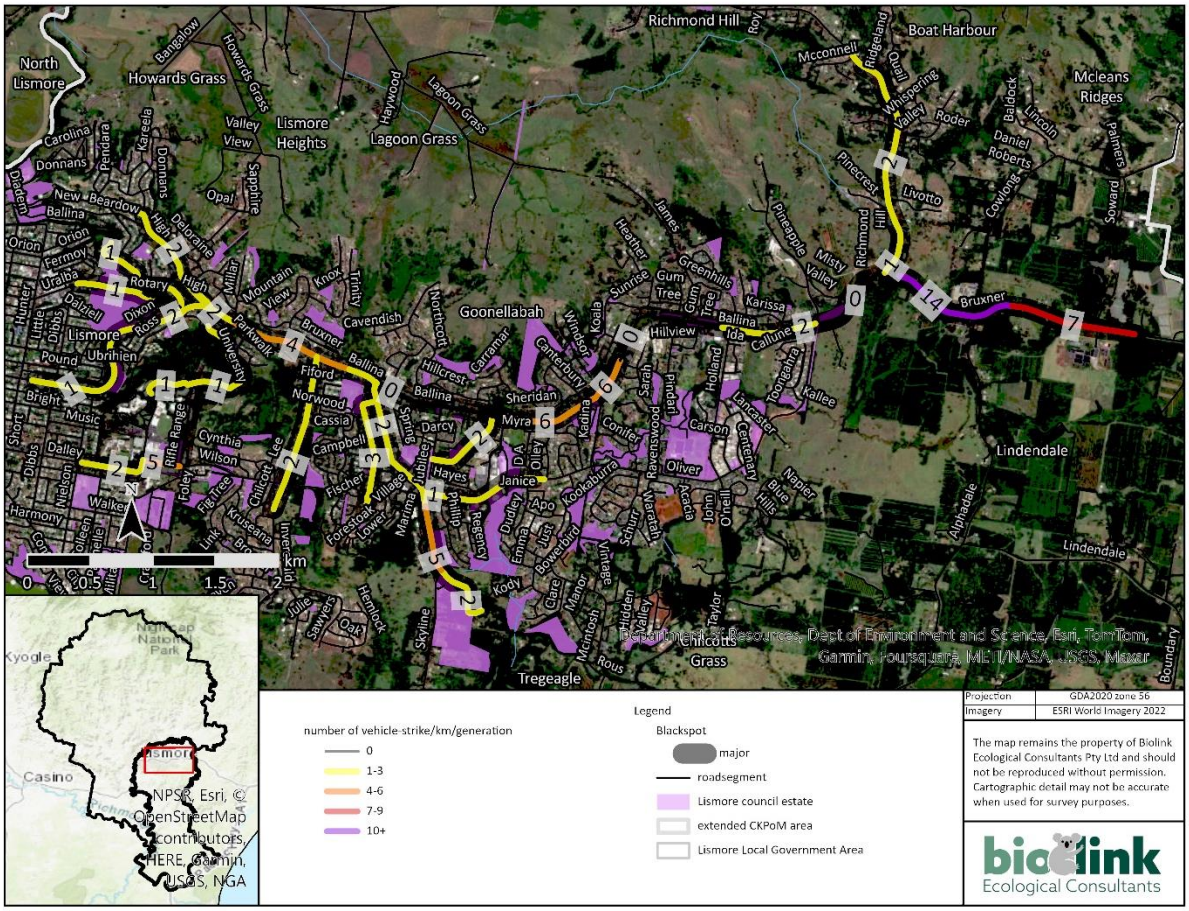

Figure 16. Lismore / Goonellabah / Lindendale blackspot (formerly blackspot 4), showing 1-3 vehicle-strikes km^{-1} generation^{-1} with a yellow line, 4-6 vehicle-strikes km^{-1} generation^{-1} with an orange line, 7-9 vehicle-strikes km^{-1} generation^{-1} with a red line ≥10 vehicle-strikes km^{-1} generation^{-1} with a purple line.

3.2.3 Dog attack

There were 89 domestic dog attacks on koalas reported to FoK in the 2017-2023 period, 77.53% of which (n=62) were fatal (**Table 4**). While reports of domestic dog attacks were widely distributed across the Lismore LGA, the highest densities occurred in urban areas of Goonellabah (n=19) and adjoining East Lismore (n=6) that interface bushland and in the agricultural landscape of McKees Hill (n=8) (**Figure 17**). Six of the koala mortalities reported in McKees Hill are associated with three addresses. In cases where the sex of the koala was determined, approximately the same number of males (n=42) and females (n=38) were impacted, though females were somewhat more likely to survive, with 79.07% of males and 65.80% of females dying as a consequence of their injuries. The number of dog attacks was relatively stable across time and partitioning the data according to years revealed no significant fluctuations over this time period (Grubbs' test: $Z = 2.02$, $P > 0.05$).

Table 4. Number of koalas reported to FoK as a result of domestic dog attack with the number of mortalities shown in brackets.

	2017	2018	2019	2020	2021	2022	2023
No. dog attacks reported to FoK (mortalities)	13 (9)	16 (11)	12 (7)	14 (11)	14 (9)	7 (6)	13 (9)

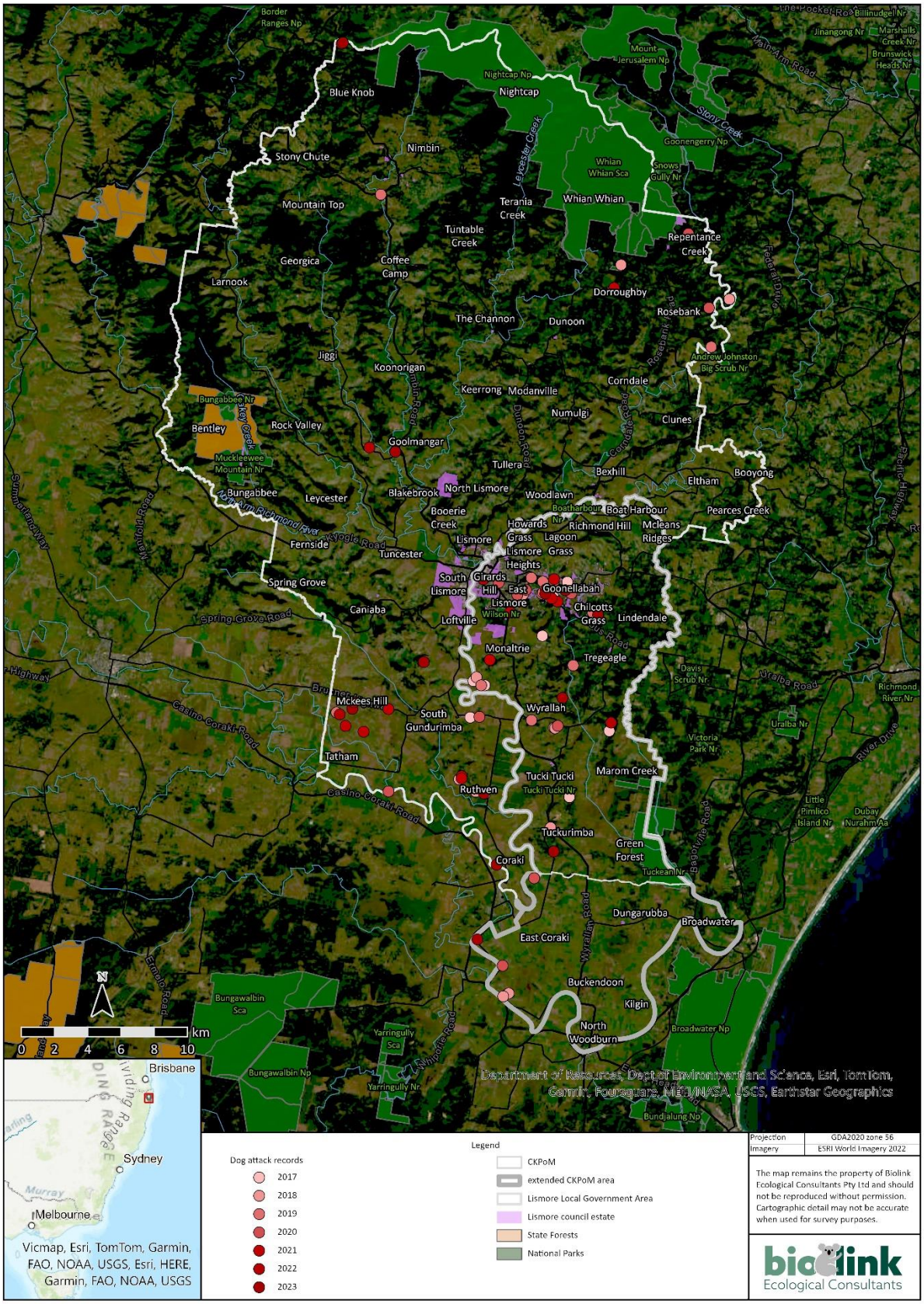

Figure 17. Instances of domestic dog attack, as reported to Friends of the Koala (FoK), across the Lismore LGA with records from 2017 – 2023 shown in a gradation of colour starting at light red (2017) to dark red (2023).

3.3. Field Survey

Field survey assessments were undertaken 20th September 2023 - 13th February 2024, during which time 75 field sites were assessed, 74 of which fell within the extended CKPoM planning area, with one site to the west. Of these 75 sites, 41 are repeat sites from 2017 and / or 2020 while the remaining 34 sites represent new survey points. The tenure of these sites comprised private (n=40), Council (n=13), roadside/crown lands (n=11), National Parks (n=8), Department of Lands (n=2) and Transport for NSW (n=1). The spatial distribution and outcomes of SAT survey are illustrated in **Figure 18** and **Figure 19,** a summary of the associated data is provided in **Appendix 1** and a summary of the number of sites *per* land tenure, with regard to whether it is a new or repeated site is shown in **Table 5**. The details of potential new PMPS which were subject to a site inspection but were found not to support any PKFTs are provided in **Appendix 2**.

Table 5. The number of field sites surveyed across land tenures, showing whether they are new or repeated sites.

Tenure	New	Repeat	**Total**
Council	4	9	**13**
Dept of Lands	-	2	**2**
NPWS	6	2	**8**
Private	14	26	**40**
Roadside	9	2	**11**
Transport for NSW	1	-	**1**
Total	**34**	**41**	**75**

3.3.1 Occupancy

Koala presence at each field site, as evidenced by diagnostic faecal pellets, was recorded at 66 of the 75 sites that were sampled, giving a habitat occupancy estimate of 88.00% ± 3.75% (SE). If occupancy is calculated for the extended CKPoM planning area, excluding the one occupied site surveyed outside this area, it is slightly altered at 87.84% ± 3.80% (SE) **Figure 18** illustrates the spatial distribution of active (occupied) and inactive (unoccupied sites).

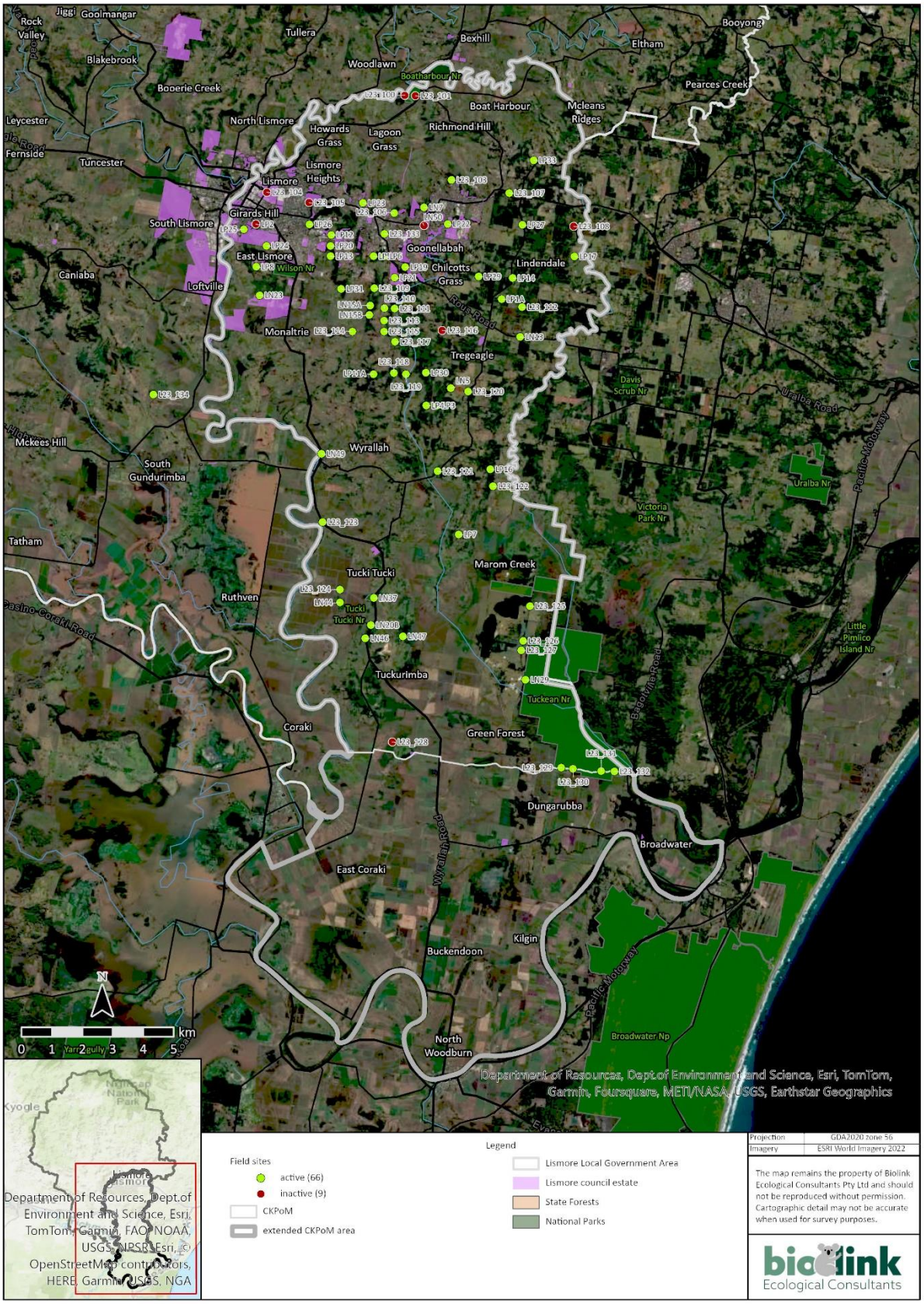

Figure 18. Locations of 74 sampled field sites across the extended CKPoM planning area, with an additional site to the west, in South Gundurimba.

3.3.2 Activity levels

Of the 66 sites with koala activity, activity levels ranged from 3.33% to 83.33% (mean = 41.72% ± 2.87% (SE)) (**Figure 19**, **Appendix 1**). Considering all active sites, 18 of these sites recorded low use[7], seven sites recorded medium use and 41 sites recorded high use, these latter two categories being considered collectively to indicative significant / resident koala activity., *i.e.* collectively 48 of the 75 surveyed sites indicated the presence of resident koala/s. Note that 'no' and 'low' use are statistically indistinguishable and both represent areas where koalas are transient / non-resident. The activity contours shown in yellow, orange and red in **Figure 19** show the location of known breeding aggregates of koalas at the time of survey, with blue contours showing low activity indicative of transient koala use. The broadscale area supporting significant (medium and high) koala activity stretches from Green Forest in the south to Goonellabah and Lismore Heights in the north. Please note that this field survey provides a snapshot of koala activity at the surveyed site locations only and does not indicate a lack of activity in areas which were not surveyed.

[7] Considering the thresholds for East coast (high) areas, as outlined in **Table 1** of this report.

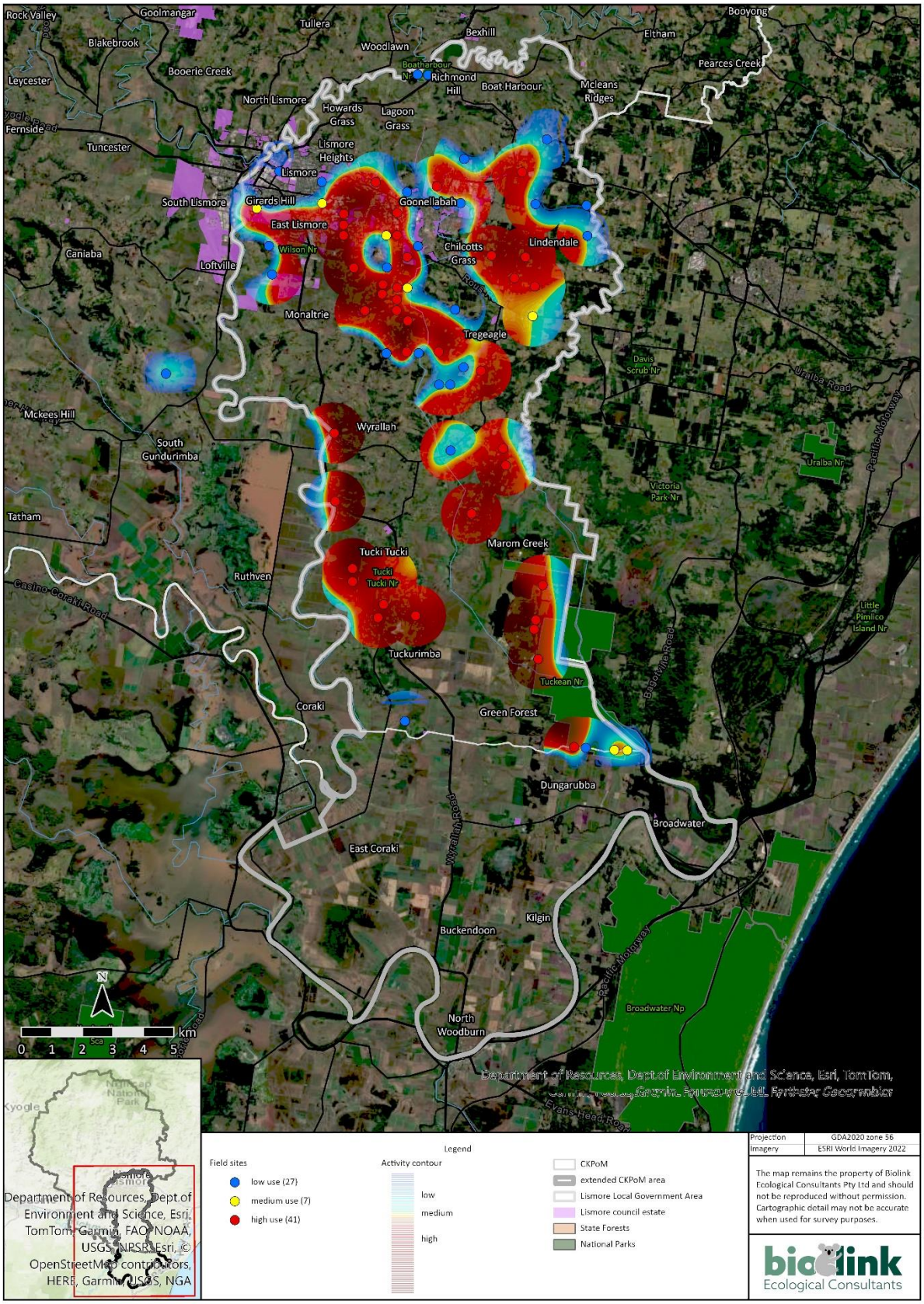

Figure 19. The distribution of 74 koala survey points across the extended CKPoM planning area and one site to the west in South Gundurimba, showing the location of koala activity with significant (medium and high) koala activity in yellow, orange and red and non-resident/transient activity in blue.

3.3.3 Density estimate

Of the 74 SAT sites which were located within the extended CKPoM planning area, five sites recorded koalas within 25m fixed-radius (0.196 ha) searches of the canopy, giving a density estimate of 0.34 ± 0.15 (SE) koalas ha^{-1}, the associated 95% confidence interval is of 0.344 ± 0.298 (95% CI) koalas ha^{-1},[8]. Five additional koalas were observed during the course of field survey, but outside of 25m fixed-radius searches (**Table 6**).

Table 6. Details of the five koalas sighted within 25m fixed-radius search of the canopy and five koalas which were observed during the course of survey, but outside of fixed-radius searches.

Date	Field site	Sex	Easting	Northing	Tree species	Koala condition	Comments
27-Sep-23	LP12	unknown	529590	6811740	*E. tereticornis* 204mm DBH	Clear eyes, clean rump, tick near eye	1 x koala in radial
04-Oct-23	LIS123	unknown	531684	6808235	*E. microcorys* 460mm DBH	Clear eyes, rump not visible.	1 x koala in radial
04-Oct-23	LN44	Male	529852	6799699	*Neolitsia dealbata* 235mm DBH	Very robust male, clear eyes, clean rump	1 x koala in radial
16-Oct-23	LP7	unknown	533775	6801918	*E_grandis* 494mm DBH	Eyes not visible, clean rump	1 x koala in radial
01-Nov-23	LN47	unknown	531944	6798574	*Acacia* sp.	Small koala, clear eyes and clean rump	1 x koala in radial
25-Oct-23	near LP16	unknown	535199	6804206	*E. robusta*	Clear eyes, clean rump	incidental
30-Oct-23	near LN46	unknown	530730	6798453	*C. intermedia* 365mm DBH (2 stems)	Clear eyes, clean rump. Different sized fresh scats beneath - likely mum with joey but not confirmed	incidental
25-Oct-23		unknown	534813	6805054	*E. robusta*	Clear eyes, clean rump, subadult	incidental
27-Nov-23		Female	531211	6808622	*E. tereticornis* 220mm DBH	Clear eyes, clean rump	incidental
27-Nov-23		unknown	531212	6808636	*E. tereticornis* 280mm DBH	Clear eyes, clean rump	incidental

[8] The density estimate is not used to inform a population estimate due to the large Standard Error.

3.3.4 Temporal change

The subset of 41 field sites which were surveyed at this monitoring event and also previously surveyed in 2017 and / or 2020 are shown in **Appendix 3**. Overall, there is no significant difference in activity levels when comparing the 2020 and 2023 monitoring events (Mann Whitney U test: U=763.5, z=0.53, *p*=0.60), though there were site-based differences with categorical changes in activity level at 16 of the 41 sites (**Appendix 3**).

Considering changes in koala occupancy more broadly (*i.e.* not restricted to repeated sites), there is significant variation amongst the three monitoring events in terms of occupancy, as calculated with a Chi squared Goodness of Fit test (G=9.19, *df*=2, *P*=0.01). *Post hoc* testing reveals that this difference is between 2017 and 2020 only, with 2020 recording the highest overall occupancy and 2017 the lowest (**Table 7**, **Figure 20)**. There was no significant difference between the current monitoring event and either 2017 or 2020. Similar to occupancy estimates, the density estimate for 2020 is elevated compared to either 2017 or 2023, however all three estimates fall within the bounds of error (**Table 7**).

Table 7. Occupancy and koala activity, as revealed by SAT survey, comparing results for 2017, 2020 and 2023.

	2017	2020	2023
No. sites in extended CKPoM planning area with PKFTs	44	58	74
No. sites outside extended CKPoM planning area with PKFTs	0	2 (1 active, 1 inactive)	1 (active)
No. active sites inside extended CKPoM planning area	33	56	65
Occupancy inside extended CKPoM planning area (mean % ± SE)	75.00 ± 6.53 *	96.55 ± 2.40	87.84 ± 3.80
% high activity sites inside extended CKPoM planning area	n/a	33/58 (56.90%)	41/74 (55.41%)
% medium activity sites inside extended CKPoM planning area	n/a	10/58 (17.24%)	7/74 (9.46%)
% low activity sites inside extended CKPoM planning area	n/a	15/58 (25.86%)	26/74 (35.13%)
Density (koalas ha^{-1}) (± SE) for extended CKPoM planning area	0.36 ± 0.06 (SE)	0.64 ± 0.23	0.34 ± 0.15 (SE)

* Occupancy for 2017 is calculated here only using sites with PKFT present, to allow direct comparison with 2020 and 2023 results. Occupancy is stated in the 2017 report as 77.3% ± 6.32% (SE) due to the inclusion of a single occupied site without PKFTs.

Patterns of significant (residential) koala activity can be compared between the time periods 2020 *versus* 2023, as there were methodological differences in 2017. **Figure 21** illustrates activity contours from these two monitoring events showing broadscale occupancy of the extended CKPoM planning area in both instances.

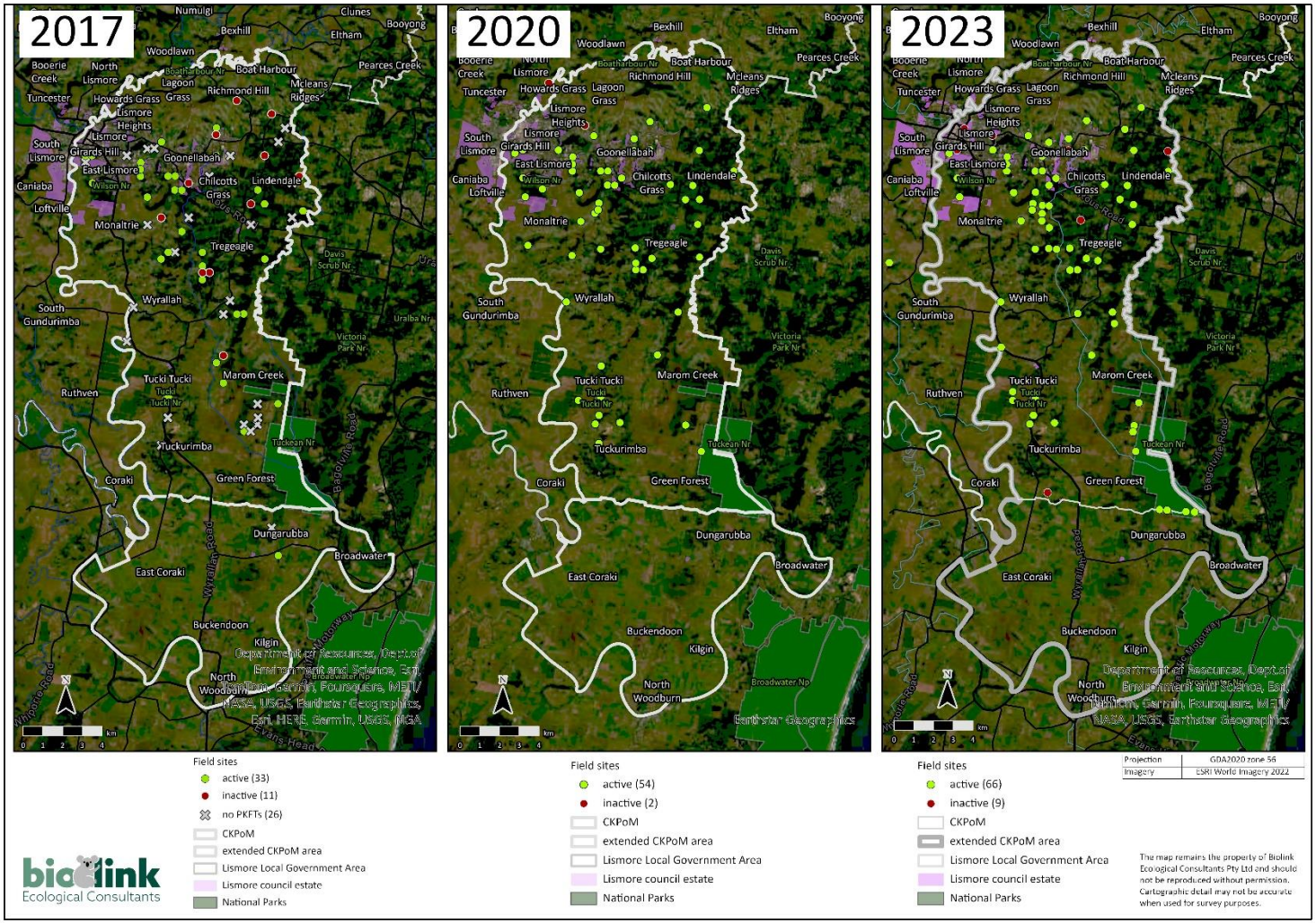

Figure 20. Comparison of survey outcomes from 2017 (left) 2020 (middle) and 2023 (right) in terms of koala occupancy. Active (occupied) sites are shown with green circles and inactive (unoccupied) sites with red circles. The map for 2017 shows sites with no Preferred Koala Food Trees (PKFTs) with a cross. Sites without PKFTs were not included for survey in subsequent (2020 and 2023) monitoring events.

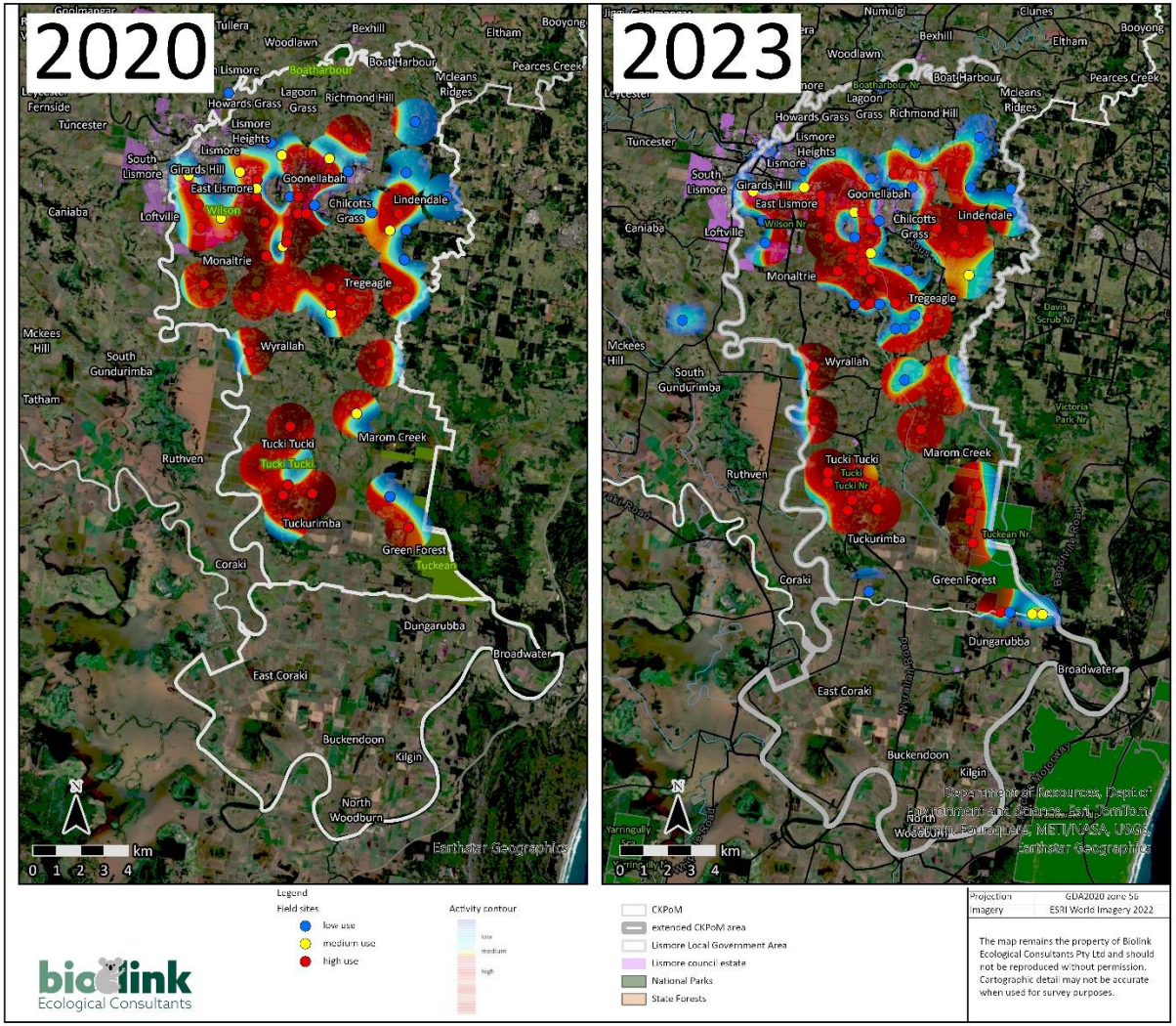

Figure 21. Comparison of survey outcomes from 2020 (left) and 2023 (right), showing the location of koala activity with significant (medium and high) koala activity in yellow, orange and red and non-resident/transient activity in blue. There are changes in the location of some survey points between 2017 *versus* 2023 and a lack of survey at a given location should not be interpreted as a lack of koala activity.

4. Discussion

Analysis of koala sightings records confirms the expansive distribution of koalas across almost the entire Lismore LGA with relative stability in the parameter EoO for the most recent koala generation (2017-2022) at 144,300 ha, which falls within the range of variation informing the three preceding koala generations. There is a small yet significant increase in the proportional area within this geographic extent which is actually occupied by koalas, the AoO for the most recent koala generation (2017-2022) being 73.25% ± 0.10% (SE) of the available habitat, compared to the AoO for the three preceding koala generations (1999-2016) being 68.75% ± 1.27% (SE) of the available habitat. This temporal change in AoO applies only to LGA-wide analysis and when the data is restricted to the extended CKPoM planning area, there is no significant change over time (2017-2022: 75.60% ± 0.97% (SE) *versus* 1999-2016: 78.60% ± 1.44% (SE)). Occupancy of both the Lismore LGA and the extended CKPoM planning area has been consistently high across the last four generations. Areas of GP are extensive, with 74 of the 249 grid cells across the LGA returning evidence of GP. These grid cells are clustered in the south and north-east of the LGA, the largest (southern) cluster located within the extended CKPoM planning area and reaching the western boundary of the LGA, from Coraki in the south to Boat Harbour in the north and across to McKees Hill and Tatham in the west. In the context of previous reporting (Biolink 2017), GP is extending further westward out of the extended CKPoM planning area to the boundary with Richmond Shire. The cluster of grid cells of GP in the north-east of the LGA covers the area from Repentance Creek, Dorroughby and Rosebank and this increase in cells of GP since 2017 illustrates the growing importance of this region in supporting a long-standing koala population.

Within the extended CKPoM planning area, field-based measures of occupancy are generally comparable to the AoO with evidence of koalas recorded at 65 of the 74 sites[9], giving a habitat occupancy estimate of 87.84% ± 3.80% (SE). This again confirms that the Richmond River floodplain has the highest koala occupancy that we have recorded between the Tweed and Clarence Rivers (Biolink 2011, Biolink 2012, Biolink 2013, Biolink 2015, Biolink 2017, Biolink 2022). Survey events in 2017 and 2020 implied that the landscape was likely either close to, or at, peak carrying capacity. Field-based measures of occupancy from this round of survey do not significantly differ from either of the

[9] One site was surveyed to the west of the extended CKPoM planning area in South Gundurimbah and evidenced low koala activity.

two previous monitoring events, with the population likely plateauing at peak carrying capacity of the existing habitat.

It has been postulated that the drivers of high koala occupancy across the extended CKPoM planning area are the fertile soils of the Richmond River floodplain, which support high carrying capacity habitats, in combination with a lack of fire across this landscape. In this context, the bush fire season of 2019/2020 should be considered as it is known to have substantially impacted koala populations across NSW more broadly (Lane *et al.* 2020). Inspection of fire mapping (see **Appendix 4**) shows that these fires did not intersect the extended CKPoM planning area and both HRA and field survey confirm that the widespread decline in koalas across NSW is not reflected in Lismore. Further, there is no evidence from the data presented in this report, either sightings records or field survey results, that the large flood event of February-March 2022 had a population-level impact on koalas across Lismore.

Koala activity / metapopulation modelling within the study area identified that significant (medium and high) koala activity extends from Richmond Hill in the north to the Tuckean Nature Reserve in south. The only difference between the current and previous round of survey, in terms of activity contour modelling, is a contraction of koala activity around Richmond Hill and an expansion of koala activity south into the Tuckean Nature Reserve. These differences are due to the greater number of sites surveyed during the current monitoring event and do not reflect actual change. Caution should always be applied when interpreting the results of activity contour modelling as areas of no activity may be due to a lack of access for survey, rather than a lack of koala activity.

Five koalas were sighted within 25m fixed-radius searches during the course of field survey, informing a density estimate of 0.34 ± 0.15 koalas ha^{-1}. This is comparable to the density estimate derived in 2017 (0.36 ± 0.06 (SE), though lower than that derived in 2020 (0.64 ± 0.23), however all three estimates fall within the bounds of error.

Koala are persisting in the highly fragmented urban and agricultural landscapes of the Lismore LGA. The importance of windrows and scattered paddock trees, both as habitat and movement pathways, have frequently been highlighted in relation to the Lismore koala population. A reliance on windbreak plantings of Tallowwood (*E. microcorys*) and Forest red gum (*E. tereticornis*) is problematic when many such plantings occur on rural lands with little protection under current clearing codes. Roadside windrows in landscapes which are otherwise devoid of habitat also increase the vulnerability of koalas to vehicle-strike, potentially exacerbating persistent blackspots. There is a need to bolster the landscape to lessen the current reliance on windrows and increase landscape permeability via tree plantings and habitat restoration, particularly away from roadsides.

Disease-mediated koala mortality remains high across the Lismore LGA, accounting for 57% of known deaths recorded by FoK. In the context of the relative population stability indicated by both HRA and field survey, the population continues to present a conundrum in terms of disease management. The consequences of elevated koala density can include an increased incidence of the clinical signs of disease, stemming from added social and nutritional pressures and antagonistic interactions between individual koalas when habitat is limited (Phillips unpub data, Gordon *et al*. 1990, Melzer *et al.* 2000, McAlpine *et al.* 2017, McCallum *et al.* 2018, Narayan 2019). It is possible that disease represents a symptomatic rather than causal issue affecting koala population viability and its association with low genetic diversity, a feature of the Lismore and Tyagarah koala populations (Lee *et al*. 2013, Phillips 2017), further necessitates a nuanced consideration of the implications of disease generally. Though there is conflicting data as to the efficacy of current vaccines for chlamydia (*e.g.* Simpson et al. 2023), FoK are embarking on a vaccination program, the impacts of which will be followed with interest.

The positive results of field survey and records analysis represented in this report are not a cause for complacency as other areas (*e.g.* the Koala Coast in South East Queensland) have witnessed the decline of what were formerly robust koala populations as a result of anthropogenic impacts. Mortality drivers, including vehicle-strike and dog attack can still drive population declines and must be addressed.

5. Recommendations

- According to the provisions of the Lismore CKPoM (LCC 2013) the next round of (intragenerational) monitoring is due in 2026. The next round of (intergenerational) monitoring, which is inclusive of HRA and threats analysis, is due in 2029 and should include koala sightings records up until the end of 2028.
- If future monitoring events evidence a reduction in koala occupancy to less than 40% of the available habitat for two consecutive monitoring events, this should trigger a review of the CKPoM and a re-assessment of threatening processes.
- The Lismore CKPoM was endorsed in January 2013 and is to remain in effect for a period of 15 years unless amended and/or superseded, meaning that it will expire in January 2028. To reflect the extension of areas supporting long-standing koala populations (GP) out of the current CKPoM planning boundary, we recommend that at the next round of review LCC considers an extension of the CKPoM planning area, west to the Richmond Shire boundary.
- Preparation for CKPoM review can and should be incorporated into the next monitoring event (in 2026) to inform on changes in koala distribution and abundance. Extending the field survey

program to the west and (if funds allow) the north will allow LCC to better align any future CKPoM boundaries when the current CKPoM expires.

- Rural landholders should be encouraged to plant and maintain PKFTs on their properties to keep the landscape amenable to koala movement and ensure the linkage of populations. This will assist LCC in pursuing the long-term goal of strengthening koala habitat availability and connectivity across the landscape.
- The importance of Tallowwood (*E. microcorys*) and Forest red gum (*E. tereticornis*) windrows on private land and in road reserves should be recognized as a resource for koalas. While there is some security for PKFTs in relation to new developments, current rural clearing codes offer little protection. The development of a Significant Tree Register for the LGA, to recognise windbreaks and scattered paddock trees in the agricultural landscape, may be an option.
- LCC to support direct community engagement to reduce the incidence of domestic dog attack on koalas across the LGA. This should include an educational program for owners of rural (working) dogs and domestic pets in urban areas, and information should be provided specifically in areas with high incidence of dog attack.
- Urgently address the four Major Blackspots for koala vehicle-strike identified by this report with mitigation plans tailored to the unique threats and topographical features of each, these being: McKees Hill; South Gundurimba; Monaltrie / Tucki Tucki / Tuckurimba and; Lismore / Goonellabah / Lindendale. As evidenced by the absence of vehicle-strike data arising from the 2007 Skyline Road upgrade, the effectiveness of black-spot mitigation approaches can be determined during monitoring events that include records analysis.

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Appendix 1: Field survey data

no.	Site name	Easting	Northing	Activity	Tenure	new/repeat	Public place name
1	LP2	527121	6812087	0	private	repeat	
2	LP3	533076	6806144	16.67	private	repeat	
3	LP4	532711	6806143	16.67	private	repeat	
4	LN5	533518	6806714	10.00	private	repeat	
5	LP5	530983	6811036	26.67	private	repeat	
6	LP6	531334	6811039	36.67	private	repeat	
7	LP7	533779	6801918	66.67	private	repeat	
8	LP8	527134	6810690	3.33	private	repeat	
9	LN13	535787	6808390	23.33	private	repeat	
10	LN15A	530870	6809425	60.00	private	repeat	
11	LN15B	530847	6809113	66.67	private	repeat	
12	LN20B	530894	6798945	63.33	Dept of Lands	repeat	
13	LN23	527241	6809758	20.00	council	repeat	Waste Facility, Sewage treatment plant
14	LN29	535966	6797151	70.00	NPWS	repeat	Tuckean Nature Reserve
15	LN37	530991	6799834	43.33	NPWS	repeat	Tucki Tucki Nature Reserve
16	LN44	529875	6799689	63.33	private	repeat	
17	LN46	530709	6798511	66.67	Dept of Lands	repeat	
18	LN47	531944	6798574	66.67	roadside	repeat	Hazlemount Lane
19	LN49	529276	6804557	70.00	private	repeat	
20	LN50	532633	6812046	0	council	repeat	Kinda St Reserve
21	LN7	532637	6812640	33.33	council	repeat	Public Reserve, Windsor Court
22	LP11A	530984	6807171	10.00	private	repeat	
23	LP12	529590	6811740	70.00	private	repeat	Southern Cross University
24	LP13	529576	6811037	70.00	private	repeat	Southern Cross University
25	LP14	535546	6810322	63.33	private	repeat	
26	LP16	534813	6804054	36.67	private	repeat	
27	LP17	537574	6811025	20.00	private	repeat	
28	LP19	532021	6810681	10.00	private	repeat	
29	LP1A	535182	6809632	43.33	private	repeat	
30	LP20	529576	6811380	63.33	council	repeat	Public Reserve, Fig Tree Drive
31	LP21	531668	6810332	70.00	council	repeat	Crematorium & Lawn Cemetry, Skyline Road
32	LP22	533418	6812094	16.67	council	repeat	Hepburn Park-Platypus Park
33	LP23	530637	6812779	43.33	council	repeat	Neighbourhood Urban Park, Bruxner Crescent
34	LP24	527469	6811381	56.67	council	repeat	Albert Park
35	LP25	526732	6811919	30.00	council	repeat	Robinsons Lookout, Albert Park
36	LP26	528881	6812084	26.67	private	repeat	Southern Cross University
37	LP27	535870	6812062	10.00	roadside	repeat	Alphadale Road
38	LP29	534434	6810372	66.67	private	repeat	
39	LP30	532699	6807218	43.33	private	repeat	
40	LP31	529918	6809970	66.67	private	repeat	
41	LP33	536241	6814184	10.00	private	repeat	
42	LIS_100	532010	6816312	0	NPWS	new	Boatharbour Nature Reserve
43	LIS_101	532355	6816297	0	NPWS	new	Boatharbour Nature Reserve
44	LIS_103	533538	6813538	10.00	private	new	
45	LIS_104	527477	6813137	0	council	new	Oaks Oval, Uralba Street

no.	Site name	Easting	Northing	Activity	Tenure	new/repeat	Public place name
46	LIS_105	528865	6812794	0	council	new	Rotary Park Extension, McKenzie Lane
47	LIS_106	531663	6812456	6.67	council	new	Neighbourhood Urban Park, Redwood Grove
48	LIS_107	535432	6813108	43.33	Transport for NSW	new	
49	LIS_108	537549	6812018	0	private	new	
50	LIS_109	531000	6809986	16.67	private	new	
51	LIS_110	531338	6809332	43.33	private	new	
52	LIS_111	531676	6809317	23.33	private	new	
53	LIS_112	535856	6809368	33.33	private	new	
54	LIS_113	531325	6808930	40.00	private	new	
55	LIS_114	530284	6808570	70.00	private	new	
56	LIS_115	531321	6808573	53.33	private	new	
57	LIS_116	533236	6808605	0	private	new	
58	LIS_117	531684	6808235	76.67	roadside	new	Skyline Road East
59	LIS_118	531652	6807212	53.33	private	new	
60	LIS_119	532042	6807176	3.33	private	new	
61	LIS_120	534083	6806603	40.00	roadside	new	Tregeagle Road
62	LIS_121	533088	6803988	16.67	roadside	new	Tregeagle Road
63	LIS_122	534903	6803496	53.33	roadside	new	Tucki Road
64	LIS_123	529309	6802321	53.33	roadside	new	Woodburn Wyrallah Road
65	LIS_124	529876	6800116	83.33	roadside	new	Munro Wharf Road
66	LIS_125	536114	6799571	40.00	roadside	new	Tuckean Island Road/Jali
67	LIS_126	535887	6798428	76.67	roadside	new	Tuckean Island Road
68	LIS_127	535831	6798125	83.33	roadside	new	Tuckean Island Road
69	LIS_128	531595	6795115	0	private	new	
70	LIS_129	537141	6794271	50.00	NPWS	new	Tuckean Island Nature Reserve
71	LIS_130	537521	6794243	10.00	NPWS	new	Tuckean Island Nature Reserve
72	LIS_131	538454	6794169	26.67	NPWS	new	Tuckean Island Nature Reserve
73	LIS_132	538881	6794155	23.33	NPWS	new	Tuckean Island Nature Reserve
74	LIS_133	531336	6811770	53.33	council	new	Western Park near Tennis club
75	LIS_134	523761	6806504	20.00	private	new	

Appendix 2: Sites without PKFTs

no.	Name	Easting	Northing	Description	Vegetation
1	1356	536916	68192080	Brockley property, Bruxner Highway	Camphor laurel (*Cinnamomum camphora*) and a single Flooded gum (*Eucalyptus. grandis*)
2	1390	537270	6812430	Brockley property	Rainforest
3	1357	537270	6812080	Brockley property	Brush box (*Lophostemon confertus*), Pines, Flooded gum (*E. grandis*)
4	1372	530970	6812430	Ballina Road	Paperbark tea-tree (*Melaleuca quinquenervia*)
5	1371	530615	6812430	Ballina Road & Invercada Road	Paperbark tea-tree (*M. quinquenervia*) with small amounts of Swamp oak (*Casuarina glauca*)
6	3	537620	6794230	Tuckean Island Nature Reserve	Paperbark tea-tree (*M. quinquenervia*) with small amounts of Camphor laurel (*C. camphora*)
7	4	537970	6794230	Tuckean Island Nature Reserve	Paperbark tea-tree (*M. quinquenervia*)
8	319	534815	6799130	between Tuckean Island Road & Mathieson Lane	Paperbark tea-tree (*M. quinquenervia*)
9	2946				Paperbark tea-tree (*M. quinquenervia*) with small amounts of Camphor laurel (*C. camphora*)
10	609	534815	6803330		Cleared with regenerating *Acacia* sp.
11	970	534470	6808230	Tregeagle Oval Reserve Sports Ground	Point falls in open weedy paddock. Closest trees are Camphor laurel (*C. camphora*) with no PKFT visible within 50m radius. There are some Forest red gum (*E. tereticornis*) near the road, ~150m distant.
12	1175	533070	6810350	Council Reserve off Hidden Valley Court	Point falls near the road. There is nearby riparian vegetation with eucalypts but no PKFT visible. Canopy dominated by Camphor laurel (*C. camphora*), Swamp Oak (*Casuarina glauca*) and Flooded gum (*E. grandis*).
13	1341	531669	6812080	D'Arcy Drive Park	Forest red gum (*E. tereticornis*) is present however there are not enough trees to form a SAT site (<10 trees in park).
14	1251	532019	6811380	Next to Council offices Alphadale Road & Lindendale road	Rainforest.
15	979	526730	6808580	Council Reserve Wilson Street & Gundurimba Road	Weedy paddock
16	980	526730	6808580	Council Reserve Wilson Street & Gundurimba Road	Weedy paddock
17	1014	526415	6808937	Council Reserve Wilson Street & Gundurimba Road	Weedy paddock
18	1049	526415	6809280	Council Reserve Wilson Street & Gundurimba Road	Weedy paddock
19	1050	526930	6809280	Council Reserve Wilson Street & Gundurimba Road	Weedy paddock

Appendix 3: Repeat sites

no.	Site name	Easting	Northing	Tenure	2017 presence / absence	2020 activity level	2023 activity level
1	LP2	527121	6812087	private	presence	10.00	0
2	LP3	533076	6806144	private	absence	40.00	16.67
3	LP4	532711	6806143	private	absence	26.67	16.67
4	LN5	533518	6806714	private		53.00	10.00
5	LP5	530983	6811036	private	presence	10.00	26.67
6	LP6	531334	6811039	private	presence	66.67	36.67
7	LP7	533779	6801918	private	absence	23.33	66.67
8	LP8	527134	6810690	private	presence	33.33	3.33
9	LN13	535787	6808390	private	n/a	6.67	23.33
10	LN15A	530870	6809425	private	n/a	60.00	60.00
11	LN15B	530847	6809113	private	n/a	70.00	66.67
12	LN20B	530894	6798945	Dept of Lands	n/a	33.33	63.33
13	LN23	527241	6809758	council	n/a	36.67	20.00
14	LN29	535966	6797151	NPWS	n/a	43.33	70.00
15	LN37	530991	6799834	NPWS	presence	20.00	43.33
16	LN44	529875	6799689	private	n/a	70.00	63.33
17	LN46	530709	6798511	Dept of Lands	n/a	76.67	66.67
18	LN47	531944	6798574	roadside	n/a	83.33	66.67
19	LN49	529276	6804557	private	n/a	46.67	70.00
20	LN50	532633	6812046	council	n/a	63.33	0
21	LN7	532637	6812640	council	n/a	23.33	33.33
22	LP11A	530984	6807171	private	presence	40.00	10.00
23	LP12	529590	6811740	private	presence	33.33	70.00
24	LP13	529576	6811037	private	presence	46.67	70.00
25	LP14	535546	6810322	private	presence	50.00	63.33
26	LP16	534813	6804054	private	presence	60.00	36.67
27	LP17	537574	6811025	private	absence	6.67	20.00
28	LP19	532021	6810681	private	absence	6.67	10.00
29	LP1A	535182	6809632	private	absence	30.00	43.33
30	LP20	529576	6811380	council	presence	30.00	63.33
31	LP21	531668	6810332	council	presence	76.67	70.00
32	LP22	533418	6812094	council	presence	3.33	16.67
33	LP23	530637	6812779	council	presence	23.33	43.33
34	LP24	527469	6811381	council	presence	6.67	56.67
35	LP25	526732	6811919	council	presence	30.00	30.00
36	LP26	528881	6812084	private	presence	30.00	26.67
37	LP27	535870	6812062	roadside	absence	13.33	10.00
38	LP29	534434	6810372	private	n/a	16.67	66.67
39	LP30	532699	6807218	private	n/a	60.00	43.33
40	LP31	529918	6809970	private	presence	86.67	66.67
41	LP33	536241	6814184	private	absence	6.67	10.00

Appendix 4: Fire mapping (2019/2020 fire season)

Since the 2020 monitoring event, fire has been largely absent from the Lismore LGA, the exception being areas burnt in the north at Whian Whian and Nightcap National Parks, totalling ~3,800 ha during the 2019/2020 bushfire season. This was determined via GEEBAM (Google Earth Engine Burnt Area Map), as represented in the Figure below.