Cool Country Koala Project 2020 - 2021: Northern Tablelands Koala Habitat and Pilot Disease Project

Prepared for Northern Tablelands Local Land Services

By the University of the Sunshine Coast, Detection Dogs for Conservation

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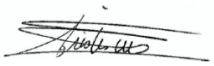
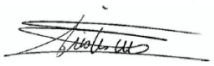
June 2021

Acknowledgements

We wish to thank Elsie Baker, Bridget Newman and Martin Dillon (NT LLS) for their support and enthusiasm during this project. We furthermore thank rangers Matt Makeham, Patrick Lupica, Adam Baillie and Sam Doak for their support in the field. We also want to thank Sam Des Forges and all the rangers from Wattleridge IPA for showing us their land and helping us to collect data.

Document version control

Version	Date	Author	Signature	Rational
V 1a	06/06/2021	Katrin Hohwieler		Presence/Absence surveys
V 1b	06/06/2021	Katrin Hohwieler		Disease results
V 2.1	11/06/2021	Romane Cristescu		Review and recommendations
V 2.2	15/06/2021	Katrin Hohwieler		Revision of V 2.1
V 2.2	15/06/2021	Romane Cristescu		Review
V 3	30/06/2021	Katrin Hohwieler		Revision V 2.2 and recommendations
V 4	14/07/2021	Katrin Hohwieler		Finalisation of report

Detection Dogs for Conservation

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Glossary and list of acronyms

This list has been compiled from many sources and is given here to facilitate the flow of the report. Each term defined below will be followed by a * when first used in the text, to alert the reader this term is explained here.

Acronym	Meaning
ALA	Atlas of Living Australia
DDC	Detection Dogs for Conservation
IPA	Indigenous Protected Area
NPWS	National Parks and Wildlife Service
NT KRS	Northern Tablelands Koala Recovery Strategy
NT LLS	Northern Tablelands Local Land Services
Pathogen	An organism that can cause disease and infection
Pathogenicity	The ability of an organism/pathogen to cause disease and infection
qPCR	Quantitative polymerase chain reaction, a technique in molecular genetics that permits the analysis of any short sequence of DNA even in samples containing only minute quantities of DNA, such as scats.
Sex ratio	The relationship between the number of males to the number of females. Typically, the sex ratio in natural populations is expected to be 1:1. Risks of extinction are increased if population sex ratios deviate from 1:1. However, a small bias of sex ratio towards females can sometimes be desirable, especially in very small or rapidly declining populations.
SD	Standard deviation
SNP	Single Nucleotide Polymorphism
USC	in this report: University of the Sunshine Coast's Detection Dogs for Conservation team
TSR	Travelling Stock Route
QLD	Queensland
NSW	New South Wales

Executive Summary

Purpose

The first aim of this study was to expand the knowledge of koala (*Phascolarctos cinereus*) distribution and habitat utilisation in areas not previously surveyed during the *Northern Tablelands Cool Country Koala Project*'s 2016-2020 fieldwork. In particular, the distribution surveys of this study were conducted in and around the following localities: Severn River, Kings Plains National Park, Washpool National Park, Guy Fawkes River National Park, Gibraltar Ranges National Park, Warra National Park, Wattleridge Indigenous Protected Area (IPA*), Travel Stock Reserves (TSRs*) and Nature Reserves around Armidale, and Oxley Wild Rivers National Park.

The second aim was to deliver a pilot disease study to understand patterns of Chlamydia disease of koalas in Armidale/Uralla and Inverell/Delungra. Chlamydia is a serious and widespread disease that can lead to severe population declines. The Armidale/Uralla and Inverell/Delungra areas have been identified as koala strongholds in previous Northern Tablelands *Cool Country Koala Project* field surveys. Information on the health of these two koala populations will enable Northern Tablelands Local Land Services (NT LLS*) to better target and prioritise conservation management initiatives to ensure these populations persist into the future.

Methods

Presence/Absence Surveys

Field-based surveys of koala scats for presence/absence mapping were conducted in or near priority areas that were 1) identified in the *Northern Tablelands Koala Recovery Strategy 2015-2025*, and 2) not surveyed during previous *Cool Country Koala Project* fieldwork surveys. Survey sites were randomly generated using GIS software and were constrained to Travelling Stock Routes (TSRs) within, or in proximity to, identified priority areas (at the exclusion of any zone with risk from 1080 baiting) and to public land (i.e. National Parks, Reserves, IPA). Koala scat surveys were conducted using detection dogs trained to locate koala scats (faecal pellets). Survey sites were generated by NT LLS and targeted for casual detection dog surveys,

where an area around the survey point was searched for the presence of koala scats. Trees were also checked for the presence of koalas when scats were found. Field surveys for koala scats presence/absence were conducted between the 9th of March and the 28th of April 2021.

Chlamydial pathogen* Assessment

During previous detection dog surveys around Armidale/Uralla and Inverell/Delungra, fresh koala scats were collected for genetic analyses between the 16th - 24th of September 2019. From these samples/extractions, it was possible to derive information on the presence of a pathogen which is a known threat to koalas: the bacteria chlamydia. Samples that were genotyped and identified as unique individuals in 2019 (N = 77) were included for the analysis and supplemented by samples collected during the 2021 surveys (N = 7).

The presence of the chlamydial pathogen was determined with two different molecular methods:

1. by looking for chlamydial DNA using a SNP panel designed for DNA extracted from koala scats, and which includes 30 probes targeting chlamydial DNA, through Diversity Array Technology (samples collected in 2019 genetic pilot study);

2. by amplifying chlamydial DNA through qPCR, using a specific method developed by the Koala Health Hub (Sydney University) for koala scats, and which is currently considered the gold standard (all genetic samples collected from 2019-2021).

Limitations

Presence/Absence Surveys

The sites were surveyed on only one occasion; therefore, the results presented here provide a snapshot of the population during this period and it can be noted that evidence of koalas found within the study areas are likely to change with repeat surveys as well as seasonally.

A negative site might reflect that koalas are not using the area (true negative) or that koalas are using the area but the survey failed to detect any scat (false negative), which could occur, for

example, if scats have decayed before the survey occurred. Rain and generally wet conditions are known to accelerate scat decay. Unfortunately, due to a higher than average rainfall during the survey period, there is a chance that scats have decayed or have been washed away before our survey.

Chlamydial pathogen Assessment

The DDC selected 84 fresh scat samples to be used for DNA extraction that represented a good spread across the two regions of Armidale and Inverell/Delungra. These were checked for the presence of chlamydial DNA. Compared to high quality samples such as swabs, the DNA extracted from scats is lower in terms of both quantity and quality. Scat DNA also presents multiple difficulties during extraction and sequencing due to inhibitors present from the koala dietary components of the scat. If the quality of an extraction is too low, this can affect accuracy and reliability of the results.

Very fresh scats yield the best quality DNA. In the field, each scat was therefore assessed for its age and categorised from age 1 (very fresh with mucus) to age 5 (very old and degraded) (see Table 1) and usually only scats of age 1 and age 2 are collected for genetic analyses. In 2019, when the majority of the scats for the disease study were collected, aging of the scats in the field was at times difficult due to the pronounced effects of the drought. Very fresh koala scats were much drier than usual and would appear older than they actually were. The DDC therefore also sampled scats that appeared to be of age 3 to balance this potential bias.

It has to be noted that both samples collected during the 2019 surveys as well as the 2021 surveys were included for the chlamydia assessment. However, only 2019 samples have been previously genotyped and allowed unique individual identification and therefore exclusion of duplicated samples. This was not possible for the seven samples collected in 2021, as the time frame did not allow samples to be sent for genotyping. For these samples, Chlamydia testing was done using qPCR but it remains unknown whether there are duplicates included.

Summary of Findings

Presence/Absence surveys

Koala presence was detected at six of the 100 survey sites, with scats detected in two separate locations within two of these sites (total of 8 scat locations). Scats of multiple ages were found at 50% of the locations, indicating that these sites were likely used over a longer period of time. At seven of the eight scat locations (87.5%), fresh scats were found and collected to be included in the analysis of disease prevalence (N samples = 7). Live koalas were not visually detected during the surveys.

These results were added to data from previous iterations of the NT LLS *Cool Country Koala Project* (2016, 2018 and 2019 surveys) to create a map of the whole region. Recommendations in this report were selected for their potential for rapid and achievable implementation.

Chlamydial pathogen assessment

A total of 84 samples were used for the analysis of chlamydia prevalence in koala populations of the Northern Tablelands. This included 77 known unique individuals as well as seven samples that have not been genotyped and thus not assessed for duplicates. Overall, through qPCR, 59 samples tested negative for the presence of chlamydial pathogen and the remaining 25 samples (30%) tested positive (six clear positive samples, 17 likely, and two weak positive). In comparison, genetic testing of chlamydia presence through SNPs resulted in 53 individuals testing negative for the pathogen and 24 individuals (31%) testing positive. The results of the two methods were highly concordant (96%), which strengthens their validity. With the results of genetic testing for chlamydia, all but two individuals that tested positive were located in and around Armidale. The other two were located in Inverell. The qPCR revealed that two of the seven samples that were collected in 2021 tested positive for chlamydia, both of which were found in Imbota Nature Reserve near Armidale. Note again that these two scat samples could potentially stem from the same individual (the scats were only a few hundred metres apart).

1. Introduction

1.1 *Cool Country Koala Project 2020-2021*: *Northern Tablelands Koala Habitat and Pilot Disease Project*

In 2020, University of the Sunshine Coast's Detection Dogs for Conservation team (DDC) was contracted by the Northern Tablelands Local Land Services (NT LLS) to undertake the *Cool Country Koala Project 2020-2021*: *Northern Tablelands Koala Habitat and Pilot disease Project*, with two key aims.

- Aim 1: to conduct field-based surveys of koala presence/absence in additional priority areas of the Northern Tablelands not covered by previous projects; and
- Aim 2: to assess the presence and distribution of *Chlamydia spp.* in koalas at two areas of high koala activity (Armidale/Uralla and Inverell/Delungra), as identified through previous projects.

To establish koala presence/absence, DDC used detection dogs trained to locate koala faecal pellets (scats) at sites in the priority areas, a method proven to be both accurate and efficient (Cristescu et al. 2015). DDC surveyed sites for koala scats in and around the following localities: Severn River, Kings Plains National Park, Washpool National Park, Guy Fawkes River National Park, Gibraltar Ranges National Park, Warra National Park, Wattleridge IPA, TSRs and Nature Reserves around Armidale, and Oxley Wild Rivers National Park. Due to rain and flooding events, the survey was interrupted and completed during two separate periods: 9th-21st of March and 25th-29th of April.

Genetic samples for chlamydia detection were collected between 16th - 25th September 2019 around Armidale/Uralla area and Inverell/Delungra. DDC used a detection dog trained to identify fresh (< 14 days old) koala scats to use for DNA extraction and chlamydia analysis (Cristescu et al. 2019a). These samples were supplemented with samples collected during the 2021 presence-absence surveys.

1.2 Background

The koala (*Phascolarctos cinereus*) is an iconic Australian marsupial that is broadly distributed across south-eastern Australia, particularly in regions that have experienced high levels of habitat fragmentation due to human residential, commercial and industrial activities (Martin and Handasyde 1999). Despite their iconic status and global appeal, koala conservation has become a growing national concern (McAlpine et al. 2015). The combined koala populations of Queensland (QLD), New South Wales (NSW) and the Australian Capital Territory are listed as Vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Shumway et al. 2015). In NSW, the koala is listed as Vulnerable under the *Threatened Species Conservation Act 1995*. Koala conservation is emphasised heavily in policy and planning at both Federal and State government levels, as is demonstrated by the development of the *National Koala Conservation Management Strategy 2009-2014* and the *New South Wales Recovery Plan for the Koala 2008*. In addition, NSW has developed a scheme that focuses on threats to koalas: 1) *NSW Koala Research Plan 2019–28, A 10-year plan under the NSW Koala Strategy NSW*, 2) *Securing the Koala in the wild in NSW for 100 years, Saving Our Species Iconic Koala Project 2017–21* and 3) *Koala Research Plan: Expert Elicitation* (Office of Environment and Heritage 2017, Hemming et al. 2018, Office of Environment and Heritage 2019). In 2019-2020, bushfires have been unprecedented in both their extent and intensity (Figure 1). Some of the areas surveyed for this report were impacted by these fires, after already having been impacted by a severe drought period. It is clear that the fires have affected the number of koalas, especially in NSW, and this will further heighten the conservation significance of the remaining koala populations, including Northern Tablelands. There are calls to up-list the koala status to endangered in NSW, with some reporting a loss of a fifth of the state population (Lane et al. 2020).

Diseases are recognised as major drivers of global diversity loss. In Australia, a notorious case is the *Chlamydia spp.* Disease that threatens the iconic koala (*Phascolarctos cinereus*) (McAlpine et al. 2015). Koalas are distributed along the east- and south-east coast of Australia and are classified as vulnerable. They are particularly threatened in the northern part of their distribution, in NSW and QLD, and although they face multiple threats including habitat loss and climate change (e.g. fires, heat waves), chlamydial disease has been singled out as the

number one cause of hospital admissions (Gonzalez-Astudillo et al. 2017) and is a major contributor to the dramatic population declines (Fabijan et al. 2019). Chlamydia is such a critical threat that, when adequately addressed, population declines can be reversed (Rhodes et al. 2011b, Beyer et al. 2018).

Chlamydia are ubiquitous bacteria that cause significant diseases in many species including livestock (Storz and Page 1971, Polkinghorne et al. 2013). Whether (and which of) the chlamydia species and strains present in koala are endemic or originated from livestock is unknown (Polkinghorne et al. 2013). Chlamydia is widespread across Australia's koala distribution, and in some populations affects up to 100% of individuals (Polkinghorne et al. 2013). Of the two species infecting koalas, *Chlamydia pneumoniae* and *C. pecorum*, the latter is consistently more prevalent (i.e. percent individuals infected) (Polkinghorne et al. 2013) and more pathogenic (Jackson et al. 1999).

Chlamydia bacteria only replicate inside the host cells, which is a key factor in their ability to remain hidden from immune responses and to cause persistent infections (Storz and Page 1971). Chlamydial disease primarily affects the ocular and urogenital tracts in koalas and decreases both survival and reproduction rates (Brown et al. 1987). The severity of the disease varies greatly between individual koalas as well as populations (Ellis et al. 1993, Waugh et al. 2016). The hypotheses for this variation centers around three pillars: the koala host (i.e. its ability to fight the pathogen), the chlamydial pathogen, and the environment (especially through external stressors). Hosts/pathogen tend to co-evolve into a balanced state so that infection does not necessarily lead to clinical disease, however, at the start of this co-evolution, hosts will be spread along the continuum between resilience and susceptibility (Munson et al. 2010). Many factors can also upset this balance; such as environmental (including some stressors known to have been present in Northern Tablelands in recent years, e.g. heat waves, drought, fires, dieback) or physiological stressors, nutrition or concomitant infections or new and virulent mutations in the pathogen (Merianos 2007). In the koala/chlamydia case, the cause(s) for variability in pathogenicity* between individual koalas and between populations remain(s) speculative (McCallum et al. 2017, Quigley et al. 2018). In particular, not all koalas that are infected (i.e. in whom the pathogen is present) progress to diseased status (i.e. showing clinical signs of disease). In one rare longitudinal study of koalas with chlamydial infection (N

= 38), 29% resolved infection without progressing to disease, 5% showed chronic but asymptomatic infection, and 66% progressed to disease (Robbins et al. 2019).

Our ability to understand the relationship between host, pathogen and environmental factors has been hindered by insufficient fundamental knowledge on host susceptibility, pathogen distribution, prevalence, diversity, drivers of pathogen emergence and virulence and interactions with other threats (e.g. urban pressure, heat, drought) (Grogan et al. 2017, Quigley et al. 2018). This is largely due to the difficulty of collecting unbiased samples at a large scale in the wild (Ryser-Degiorgis 2013) and, generally, wildlife disease impacts on biodiversity remain poorly understood (Smith et al. 2006). Collection of high-quality samples is either expensive (koala catching and veterinary examination) or biased (e.g. there are inherent biases in the "convenience-sampling" approach, which relies on samples from wildlife hospitals or carcasses (2006)). Increased accuracy and efficiency of pathogen diagnostics are critical steps to improve our understanding of relationships between ecological factors and disease prevalence and severity in the wild (Marsh et al. 2011, Miller et al. 2012). Non-invasive scat surveys have been proposed as a monitoring methodology that can be 1) deployed at a large scales, 2) cost effective, 3) unbiased (if appropriately designed), and 4) more ethical than direct sampling of wildlife (Cooper 1998, Ryser-Degiorgis 2013).

In this present study, the chlamydia aim (Aim 2) was to analyse scats collected during 2019 and 2021 fieldwork, to determine the chlamydia prevalence of two koala hotspots in the Northern Tablelands, and map chlamydial distribution and potential existence of chlamydial hotspots.

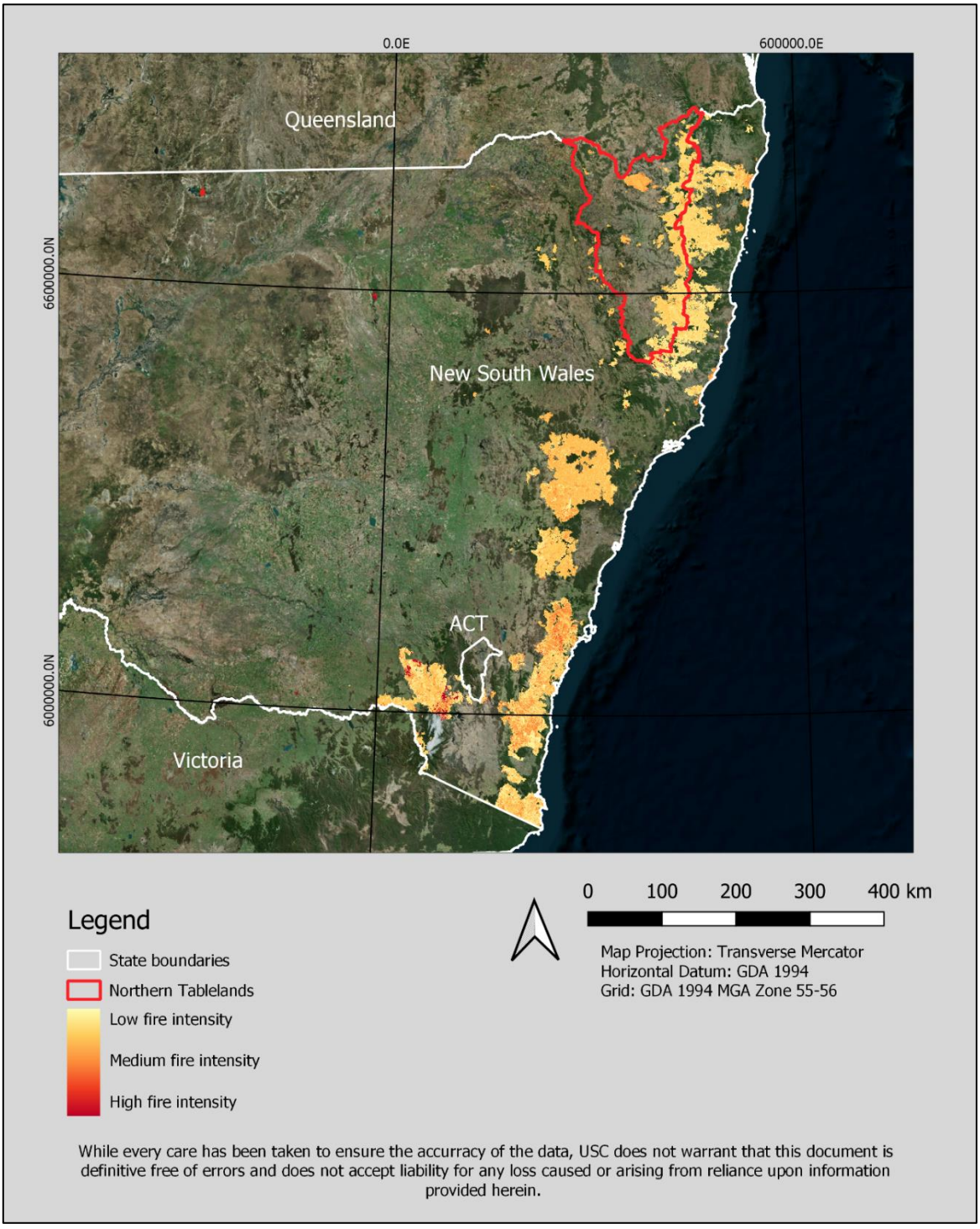

Figure 1: Fire extent during the 2019-2020 season in NSW

1.3 Previous Work

The DDC was engaged by the NT LLS to deliver the Northern Tablelands Koala Habitat Project in 2016 (in parallel with Stringybark Ecological), which was supplemented with further fieldwork in 2018, and 2019. This research delivered a comprehensive analysis of the presence of koalas in the main priority areas as defined in the *Northern Tablelands Koala Recovery Strategy* (NT KRS*). In 2016, 2018 and 2019, DDC conducted 517 surveys across identified priority areas in the Northern Tablelands as well as 47 surveys in 2019 to collect genetic samples in previously identified koala hotspots. Altogether, the NT LLS *Cool Country Koala Project* surveys found relatively high areas of koala activity in some regions (e.g. Inverell/Delungra and Armidale/Uralla), while finding very low koala activity levels in other areas. Some of these areas showed high historical levels of koala activity (e.g. Ashford), suggesting large declines in these regions.

In 2021, 100 surveys were conducted in areas where historical records of koalas, but no recent evidence of their presence, existed. Survey sites were targeted to fall in, or near, previously identified priority areas (as per the *Northern Tablelands Koala Recovery Strategy* 2015-2025) and were chosen to target areas not previously surveyed by the *Cool Country Koala Project*, to further fill knowledge gaps of koala distribution.

As a whole, the *Cool Country Koala Project* contributed to the objectives of the NT KRS to gain a baseline knowledge of koala distribution and abundance as well as genetic population structures and chlamydia prevalence with the aim to promote recovery, avert any ongoing decline, and minimise the risk of extinction of koalas within the Northern Tablelands region in NSW, while building community engagement.

2. Objectives of the *Cool Country Koala Project 2020 - 2021: Northern Tablelands Koala Habitat and Pilot Disease Project*

The Northern Tablelands *Cool Country Koala Project 2020 – 2021: Koala Habitat and Pilot Disease Project* contributes to the objectives of the NT KRS, which are to:

- Consolidate and improve baseline knowledge of koala distribution and abundance, threatening processes and impacts upon koala populations on the Northern Tablelands; and
- Develop a recovery strategy in collaboration with stakeholders that prioritises actions for koala protection and areas for effective investment on the Northern Tablelands.

This study contributes to these objectives through the following aims:

- To address data deficiencies through field-based surveys – in this study the DDC focussed on areas not covered in previous projects and identified as areas with knowledge gaps;
- To inform future investment in koala habitat restoration and revegetation; and
- To undertake a pilot chlamydia monitoring project of two koala populations identified through previous surveys to assess the level of threat presented by chlamydial disease.

This report;

1. describes the outcomes of the 2021 field-based surveys in Travelling Stock Routes (TSRs), Nature Reserves, and National Parks across the Northern Tablelands,
2. provides the results from the pilot chlamydia study undertaken using samples that were collected in Armidale/Uralla and Inverell/Delungra in 2019 and supplemented by samples collected in 2021.

3. Methodology

3.1 Priority Survey Areas/Survey Site Locations

In 2016, priority areas for surveys were determined by a panel of experts gathered by NT LLS. The determination of these areas is defined in the NT KRS (layer provided by NT LLS, Figure 2). Many of the priority areas have been previously surveyed as part of the *Cool Country Koala Project* surveys between 2016 and 2019. Survey sites for the 2021 surveys were generated by

NT LLS in and around these priority areas using ArcGIS (Figure 3). Survey sites were constrained to fall in TSR lands, National Parks, and conservation areas that were further constrained to be at least two kilometres away from areas that had been baited with 1080 dog baits within the past 2 months. These parameters were decided in collaboration with NT LLS. A total of 166 survey potential start points were created, with the understanding that at least double the number of survey points were provided at each site so that survey starts could be selected depending on accessibility. Note that previous reports showed historical records of koalas in the ALA database prior to 2016, because this data was used by the expert group in the NT KRS to determine priority areas. For this report, updated ALA records (last updated 01/06/2021) were used for all Figures but Figure 2. In Appendix 1, we highlight the records that have been added to ALA since 2016.

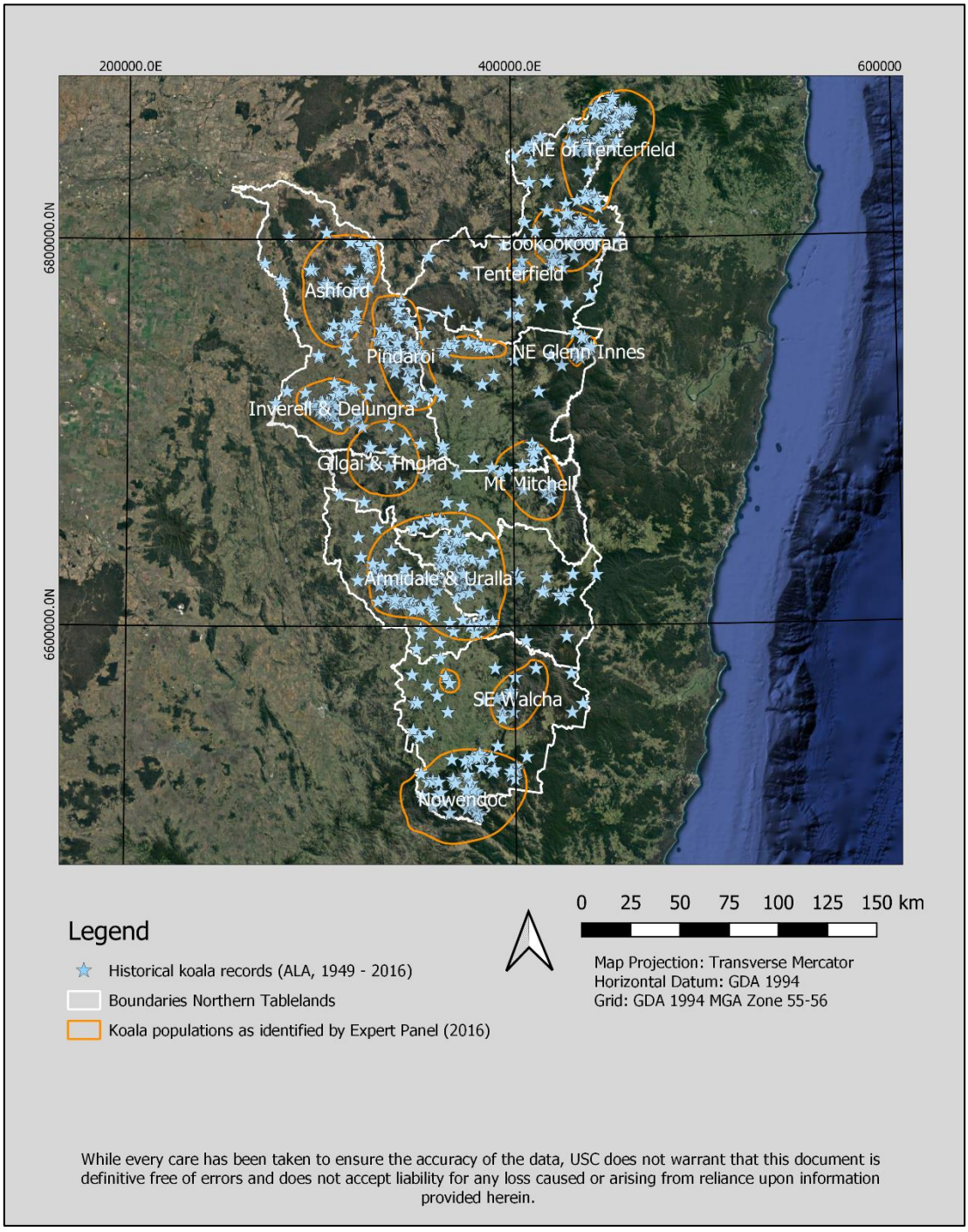

Figure 2: Priority areas of the Northern Tablelands, taken from the Northern Tablelands Koala Recovery Strategy and showing historic koala records from ALA (1949 – 2016)

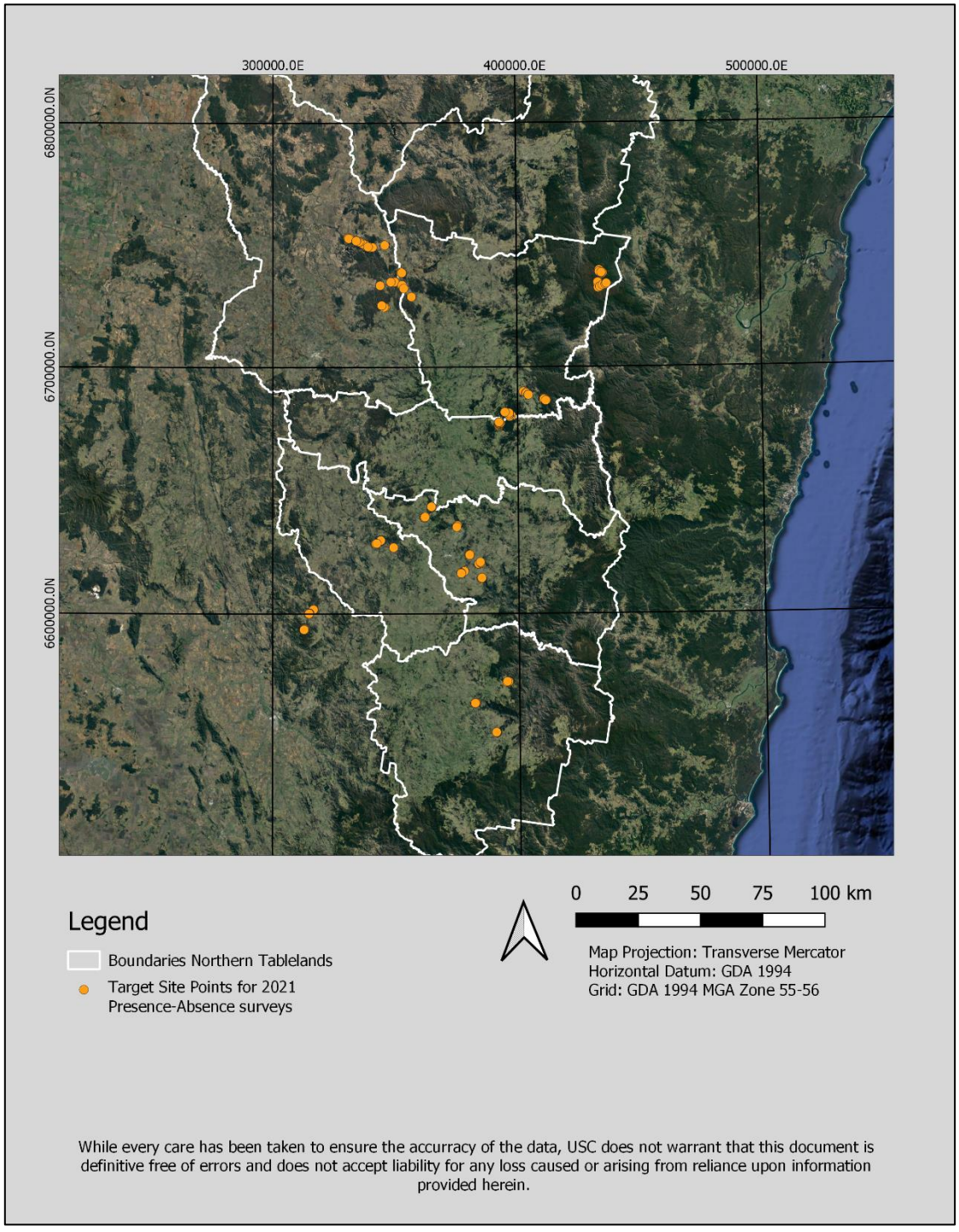

Figure 3: Survey sites generated by Northern Tablelands Local Land Services for the Detection Dogs for Conservation koala surveys in 2021

3.2 Field Methods

3.2.1 Koala Presence/Absence Surveys

3.2.1.1 Dog Handling and Data Recording

Direct observation of animals is time-consuming, particularly for koalas, which have a cryptic nature, occur in low densities, and have large home ranges (Tyre et al. 2001, Kéry 2002). Locating secondary evidence of animals (fur, scats, feathers, tracks, etc.) is a common technique for establishing species occurrence across large areas because secondary evidence indicates species presence and use of the habitat even when the animal is not on site (Putman 1984, Wilson and Delahay 2001). The best method to confirm koala presence and habitat utilisation is to use detection dogs specifically trained on the odour of koala scats. DDC has proven that the detection dog method surpasses human-only teams in both accuracy and efficiency (Cristescu et al. 2015, Cristescu et al. 2019a).

Detection dogs ‘Baxter’, ‘Maya’, and ‘Austin’, all Border Collie cross breeds, were used for the koala scat presence/absence surveys (Figure 4). For each survey, the detection dog was fitted with a GPS collar, motivated with a tennis ball and given the command to search. Two dog handlers conducted the surveys, Katrin Hohwieler (KH) and Russell Miller (RM), both research assistants with the University of the Sunshine Coast.

Figure 4: Detection dog Maya fully equipped for survey work

Upon arrival at the survey sites and prior to the dog deployment, site information was recorded including location name and unique survey identifying number, and site photos captured. Any ecological characteristics that might have influenced the detectability and decay of scats were recorded (e.g. wet areas will increase decay rates; therefore, scats will be detectable for a shorter amount of time (Cristescu et al. 2012a)). It was also recorded whether the site had been burnt recently.

3.2.1.2 Casual koala scat survey

The casual surveys are an excellent and fast way to determine whether koalas are present at a site of interest. This method is designed to maximise the chance of detecting koala presence in the minimum amount of time.

In the casual surveys, the dog is not constrained by the handler, and can follow its nose roaming over an area of up to two hectares within an approximate 30-minute timeframe, or until the handler deems the search to have covered the site thoroughly. The start point of the survey can be determined by the handler, on site, and rely on the handler's assessment of the potential for the area to be used by koalas (this increases the chances of finding koala scats but also increases bias); or can be a random (under certain constraints) point generated in GIS, as in this report.

Scat details (age and size of scats) were recorded for all positive surveys. Typical koala scats (Figure 5) have the following characteristics (Triggs 1996):

- symmetrical and bullet-shaped (not jelly-bean shaped);
- generally about 1.5 cm long by 0.5 cm wide (adult koala scat size);
- even-sized and especially fine particles;
- absence of insect parts (koalas do not eat insects); and
- very compact.

Figure 5: Koala scats – very fresh on the left, fresh on the right

When scats were found, the number of scats, their age category (Table 1) and their size (based on scat width, Figure 6) were recorded as well as their GPS coordinates (GDA94). When only one size of scat and age class (see Table 1 below) is present, the tree is considered less used than when scats of different age classes (indicative of repetitive visits) and sizes (indicative of different individuals) are present. Age of scats allowed DDC to classify sites as recently used or not.

Table 1: Koala scat age categories

Scat age categories	Characteristics
1	Very fresh (covered in mucus, wet) – 1 day old or less
2	Fresh (shine and smell) – few days old
3	Medium fresh (shine or smelly when broken) – weeks old
4	Old (no shine, no smell) – months old
5	Very old and discoloured – many months to years old

Figure 6: Koala scats of different sizes (widths)

3.2.1.3 Incidental koala/koala scat sighting

Researchers conducting the surveys are also visually looking for incidental, or opportunistic, koalas and koala scats. This can happen while on foot or in the car, moving between survey sites; or thanks to information passed on to DDC researchers from members of the public, property owners or passers-by. The public is always considered as a source of knowledge and individuals are questioned on koala presence, past and present, whenever possible. When koalas or koala scats were located during incidental surveys, the animal was observed with binoculars to try to ascertain: (1) koala sex, (2) external signs of chlamydial disease such as ocular or urinary tract infection, and (3) presence of a joey. In case of finding a sick or injured koala, WIRES was contacted.

3.2.2 Samples used to determine presence of the Chlamydial pathogen

Surveys for the collection of genetic samples were conducted in 2019 using a genetic detection dog, Billie-Jean, a dog specifically trained to find fresh (age category 1-3) koala scats. Areas of known koala presence were targeted to maximise sampling success. Dog handling followed the same procedures as described for "Presence/Absence surveys" (see section 3.2.1 Dog Handling and Data Recording). In 2021, the detection dogs indicated on scats of all ages, but

again, only fresh scats were targeted. Fresh scats were collected in a sterile tube without direct skin contact to avoid potential contamination and loss of DNA from the scat. Tubes were kept on ice until they were stored in a -20 degrees Celsius freezer.

3.3 DNA Isolation, SNP Genotyping and qPCR for detection of Chlamydia

3.3.1 DNA Isolation

Note that genetic terms written **in bold and carrying a *** when used for the first time are defined in the glossary.

DNA from scats was extracted using a next-generation sequencing protocol described in Schultz et al. (2018). Briefly, koala DNA was isolated from the intestinal epithelial cells present on koala scats, as chlamydia bacteria are intracellular. Epithelial cells from the surface of each scat were separated by slicing off the top-most layer of the scat using a scalpel. These surface slices were then used to extract DNA using the QIAamp PowerFecal Pro DNA Kit (Qiagen), following the manufacturer's protocol, with the following variations: after adding CD1 buffer, samples were incubated at 65° C for 10 minutes, and then vortexed for seven minutes at maximum speed using Genie 2 Vortex Mixer (Scientific Industries). Final DNA isolates were eluted in 100µl of C6 elution buffer. Each isolate was tested for quality DNA isolation on a 1.5% agarose gel. Isolates that passed this quality control were then stored at -80° C.

3.3.2 Single nucleotide polymorphism (SNP) genotyping for chlamydia detection

Please note that the genotyping method below is given for completeness but is not essential to the understanding of the genetic results. The reader might choose to skip the genotyping section altogether.

Genotyping of **single nucleotide polymorphism (SNP)*** genetic markers was conducted by Diversity Arrays Technology, Canberra, using proprietary DArTseq™ technology. DArTseq™ represents a combination of DArT complexity reduction methods and next-generation sequencing platforms (Kilian et al. 2012, Courtois et al. 2013, Von Mark et al. 2013, Raman et al. 2014). Specifically, for this study, SNP genotyping was conducted using a DArTcap

approach, which is a targeted application of DArTseq™ technology allowing for the sequencing of targeted markers. DArTcap is used in similar applications as DArTseq, but it applies a selective step after complexity reduction to genotype specific markers from DArTseq representations. This selection is achieved with the use of the nucleic acid "capture probes" that bind to restriction fragments in the representations carrying the specific DArTseq markers.

Capture probes included 30 specific sex markers and 30 specific Chlamydia markers. The presence of the chlamydial pathogen was assessed based on the detection of these specific SNPs, and a koala was classified as chlamydial positive above a specific threshold (>9 out of the 30 SNPs detected). Note that the presence and load of chlamydia do not necessarily mean koalas are sick, as they can be passive carriers of the bacteria, or have recovered (Robbins et al. 2019). Samples were classified as 'No Chlamydia detected', 'Chlamydia Possible' (presence of chlamydia above threshold) or 'Chlamydia Likely' (chlamydia detected but below threshold).

3.3.3 Chlamydia detection through qPCR*

For a second method of determining chlamydia presence from scats, DNA extractions were sent to the Koala Health Hub (KHH) to quantify the *C. pecorum* bacterial load in a sample through quantitative PCR (qPCR) assays. Sample aliquots were first tested for presence of koala DNA (B actin) which indicates adequate DNA quality and absence of significant inhibition. Out of 84 samples, 12 contained PCR inhibitors and were therefore diluted which helped to successfully overcome inhibitions. Primers and probes used in this assay have been previously published (Hulse et al. 2018). Samples were classified as 'Negative', 'Positive', 'Suspect' (no amplification for the specific *C.pecorum* strain but for the general *Chlamydia* genus, likely due to background noise) and 'Weak positive' (chlamydia only detected through dilution of sample).

3.4 Data Analysis

All data collected in the field was entered into the DDC database. Historical sightings from the Atlas of Living Australia database were plotted on maps of the Northern Tablelands and compared with the locations of positive scat searches during the study. This enabled us to examine changes in koala distribution on the Northern Tablelands: i.e. we compared our study with historical koala sightings to identify sites where koalas previously occurred and are no longer present, as well as sites where koalas have not been recorded in the past but where scats were found in the study. All results were mapped in ArcGIS v10.2 and QGIS 3.12.0.

Presence of chlamydia in scat samples from koalas was determined using two different methods as described above. Results of the two methods were compared and assessed for differences. Prevalence of chlamydial pathogen in the koala populations was inferred based on these results and maps were established showing disease hotspots.

3.6 Limitations

3.6.1 Survey site selection

Survey sites were selected with multiple limitations. To avoid having to access private properties, focus was put on Travelling Stock Reserves (TSRs), National Parks and Nature Reserves. Sites were chosen to be accessible by car. Furthermore, sites where 1080 baiting occurred less than 12 months prior to the time of the survey had to be excluded from the design. Sites were chosen and delivered by NT LLS.

Two sites (Booroolong TSR and Yarrowick TSR) were not accessible due to high and thick understory that prevented the team from walking outside of existing car track and made it difficult for the dog to sniff the ground. Mt Yarrowick Nature Reserve was assessed but trees were scarce, with predominantly epicormic growth, and the understory was thick with thorny shrubs. Therefore, the team decided to prioritise other sites, as Mt Yarrowick was already surveyed by the detection dogs for the genetic pilot study in 2019. Booroolong Nature Reserve was inaccessible due to flooding as communicated to the DDC by the Ranger in Charge. In Wattleridge IPA, survey start points were chosen at site with the guidance of the indigenous

rangers. Therefore, survey sites in this area differ to the proposed starting points. Finally, some survey areas burnt during the 2019/2020 bushfires, which may have affected koala presence in the habitat (Appendix 2).

3.6.2 Presence/Absence data

The sites were surveyed on only one occasion; therefore, the presence/absence results presented here provide a snapshot of the population during this period and it should be noted that evidence of koalas found within the study areas is likely to change seasonally [as koala movements vary with time (Ellis et al. 2009)].

The rate at which scats decay may also vary significantly between sites due to varying ground layer structure, composition, moisture, sunlight, local weather events and invertebrate activity (Rhodes et al. 2011a, Cristescu et al. 2012b). Decomposed scats may lose their unique scent mark and the dog may no longer detect it – however this has not yet been proven to occur (Cristescu et al. 2015). Higher than average rainfall during the 2021 survey period may have had an influence on scat detection. In addition, scats deposited prior to the 2019/2020 fire would probably have been consumed and no longer detectable.

Failure to detect koala scats in an area is not necessarily conclusive of koala absence. Failure to detect koala scats may suggest either of the following:

- Koalas are not present in the area (i.e. true absence) at the time of the survey. Note that true current absence does not infer that the site has not been used in the past, or could not be used in the future, i.e. it could still be potential koala habitat.
- Koalas occur in the area, however scats were not detected (false negative) because:
    - Scats were present at some stage but decayed and disappeared from the environment before the survey was conducted;
    - The dog did not detect the scat; and/or,
    - The dog indicated the presence of a scat, but it was too decayed to be confirmed.

"The presence of absence does not equal the absence of presence" – to infer true absence, multiple surveys through time are generally necessary (MacKenzie and Royle 2005).

Therefore, through one-time detection dog surveys, only presence can be confidently ascertained.

3.6.3 Chlamydia assessment

Genotyping was conducted non-invasively from material contained in the surface of koala scats (both koala and bacterial DNA). This allows for large scale, relatively cheap, unbiased sampling of DNA compared to more widely used methods (catching, anaesthetising and collecting biopsy/swab, or relying on Hospital samples). However, compared to high quality samples (biopsies/swabs), scat DNA is lower in quantity and quality, and presents multiple extraction difficulties (due to inhibitors present from the koala dietary component of the scat). However, we were able to alleviate some of these limitations by designing a new genotyping method in 2018 (DArTcap, see methods), which targeted specific loci.

Chlamydia assessment from scats has been difficult in the past due to low sensitivity and specificity of tests (Wedrowicz et al. 2016, Cristescu et al. 2019b), however, molecular ecology is a field of constant and rapid improvements. The DDC team has developed a DArTcap targeting chlamydia, and the KHH a qPCR (commonly referred to as the gold standard) – these methods are promising and being tested with results soon to be released. Here, employing two new methods and comparing their results was used to strengthen the confidence in an observed trend.

3.4 Health and Safety

A Job Safety Analysis was completed. Detection dogs, Baxter, Austin and Maya have been trained so as not to pose a threat to wildlife. The wellbeing of the detection dogs was assessed by Animal Ethics (USC: ANA18128 and ANS1752). Baxter, Austin and Maya were regularly treated against ticks and thoroughly checked for bites after each survey. All DDC detection dogs are insured in the event of a snake bite. Surveys were conducted only after it was confirmed that no known wild dog baiting occurred in the areas to be surveyed, additionally, the dogs wore a muzzle. Baxter, Austin and Maya were thoroughly brushed before entering

the area so that no weed propagules were introduced. The handler was always in view of the dog and controlled the movements of the dog by voice, which means the risk of the dog escaping and getting lost or injured was remote. Surveys were conducted under valid wildlife and scientific research permits (OEH scientific license number SL101741 under Part 2 of the Biodiversity Conservation Act 2016, valid until January 2022).

4. Results

4.1 Field Surveys

Field surveys to assess koala scat presence/absence occurred between the 9th of March and the 28th of April 2021. A total of 100 koala scat presence/absence surveys were performed. At 28 of the survey sites, severe signs of fire were recorded, most of which likely occurred during the 2019/2020 mega bushfires. Evidence of increased scat decay was found at 61 sites, mostly due to wet ground after rain.

Out of the 100 koala scat presence/absence surveys, six were positive for koala scats (6%, Figure 7). No koalas were sighted during or outside of presence/absence surveys. For close-up details of presence and absence outcomes of surveys and the according tracks that were covered by the dogs, see Appendix 3.

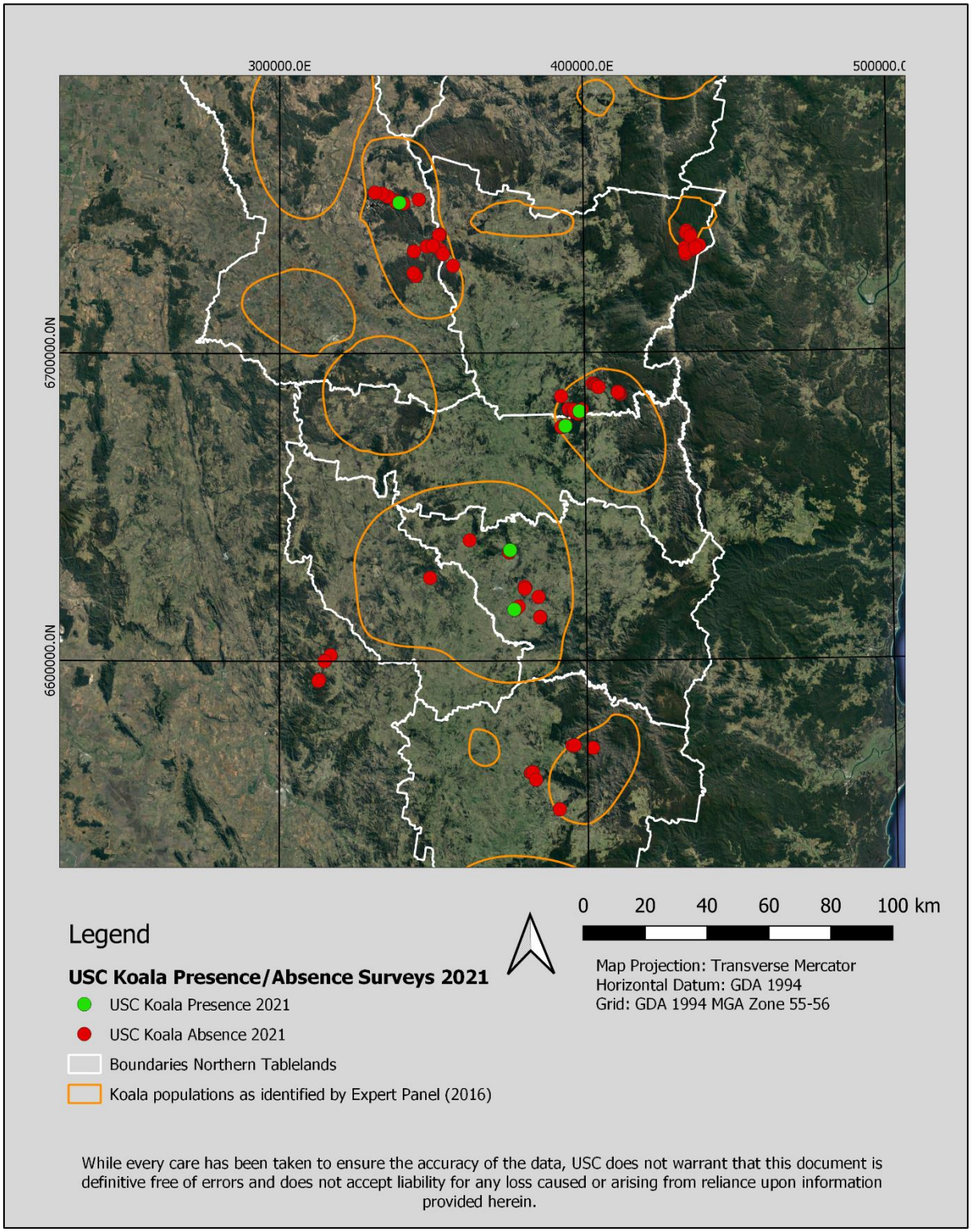

Figure 7: Koala scat presence/absence survey conducted in 2021

4.2 Presence/Absence of Koalas and Comparison to Historical Records

The survey sites where DDC found evidence of koala presence typically aligned with, or were near to, sites where koalas have historically (ALA records) been seen (see Figure 8). No historic ALA records exist for the Watson's creek area. We did not find evidence of koala presence during our surveys and it is therefore likely that koalas are not regularly using this particular area. It should be noted that some of the habitat in this particular Nature reserve was burnt in the 2019/2020 mega bushfires and is now recovering. While no evidence of koalas could be found, several other species were sighted during the surveys, such as spotted pardalotes (*Pardalotus punctatus*).

Historic records in other focus areas of the 2021 surveys were also scarce, especially in comparison to the Armidale or Inverell/Delungra area. In the area around Severn River and Kings Plain, most historic records in ALA stem from 1986-1999. However, one more recent record from 2018 was recorded along Emmaville Road, very close to where the DDC found fresh koala scats during the 2021 surveys (Figure 9). This could suggest that one or more koalas have been using this area regularly. Furthermore, this emphasises the importance of promoting tools such as ALA or BioNet and the usefulness of citizen science for monitoring koala presence.

In the area of Gibraltar Ranges, no historic records exist, and the detection dog surveys did not detect signs of koalas. In Washpool National Park, which is in close proximity to Gibraltar Ranges, multiple historic records exist from 1981-1997. The 2021 DDC surveys did not find signs of koalas here in 2021. However, the field team encountered National Park and Wildlife Services (NPWS) rangers who reported to have collected a dead koala in Washpool National Park in 2018 that was hit by a car. This area has since burnt in the 2019/2020 mega bushfires which would likely have affected the presence of wildlife in this park.

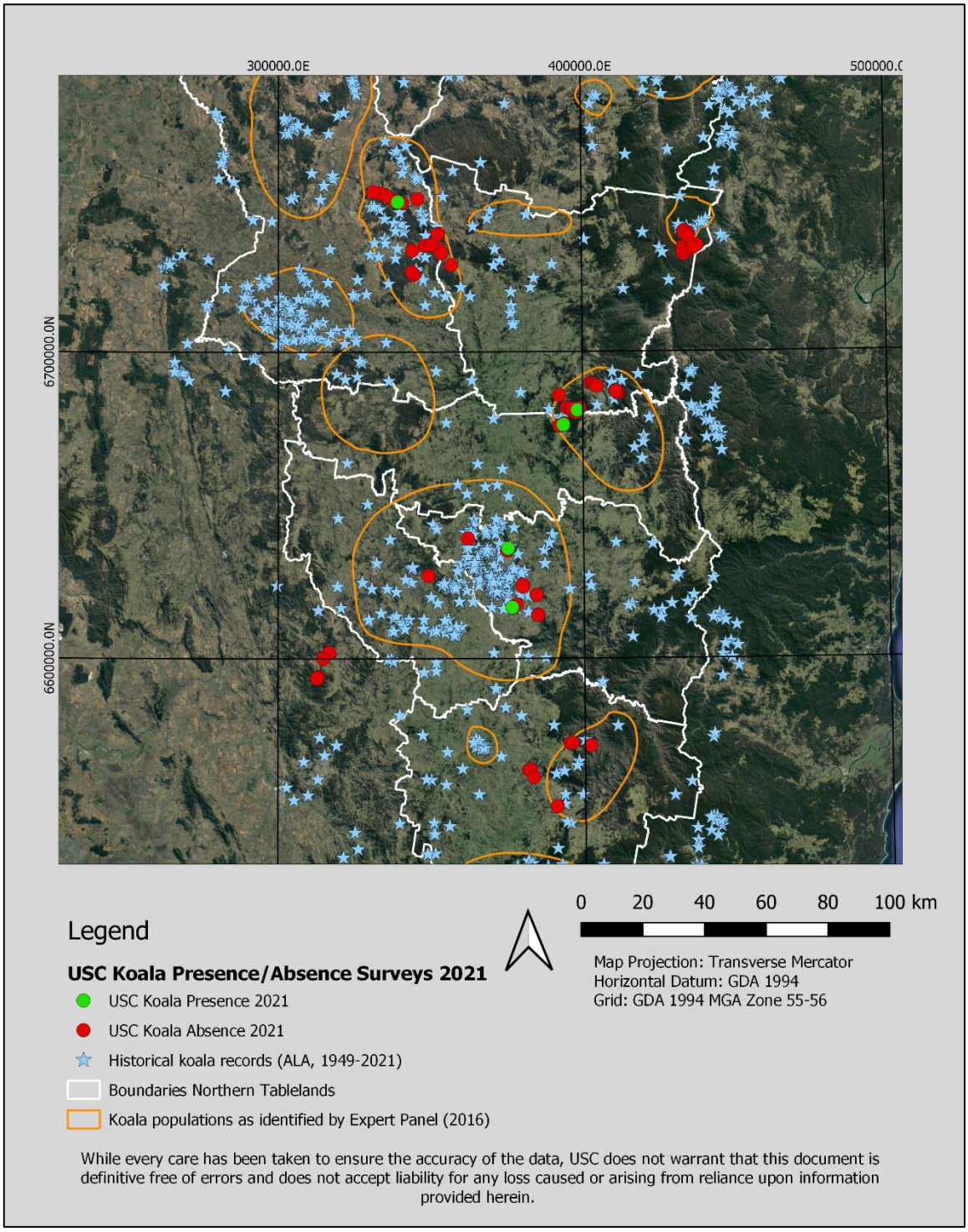

Figure 8: Koala scat presence/absence surveys and historical koala records from the Atlas of Living Australia (last updated 01/06/2021)

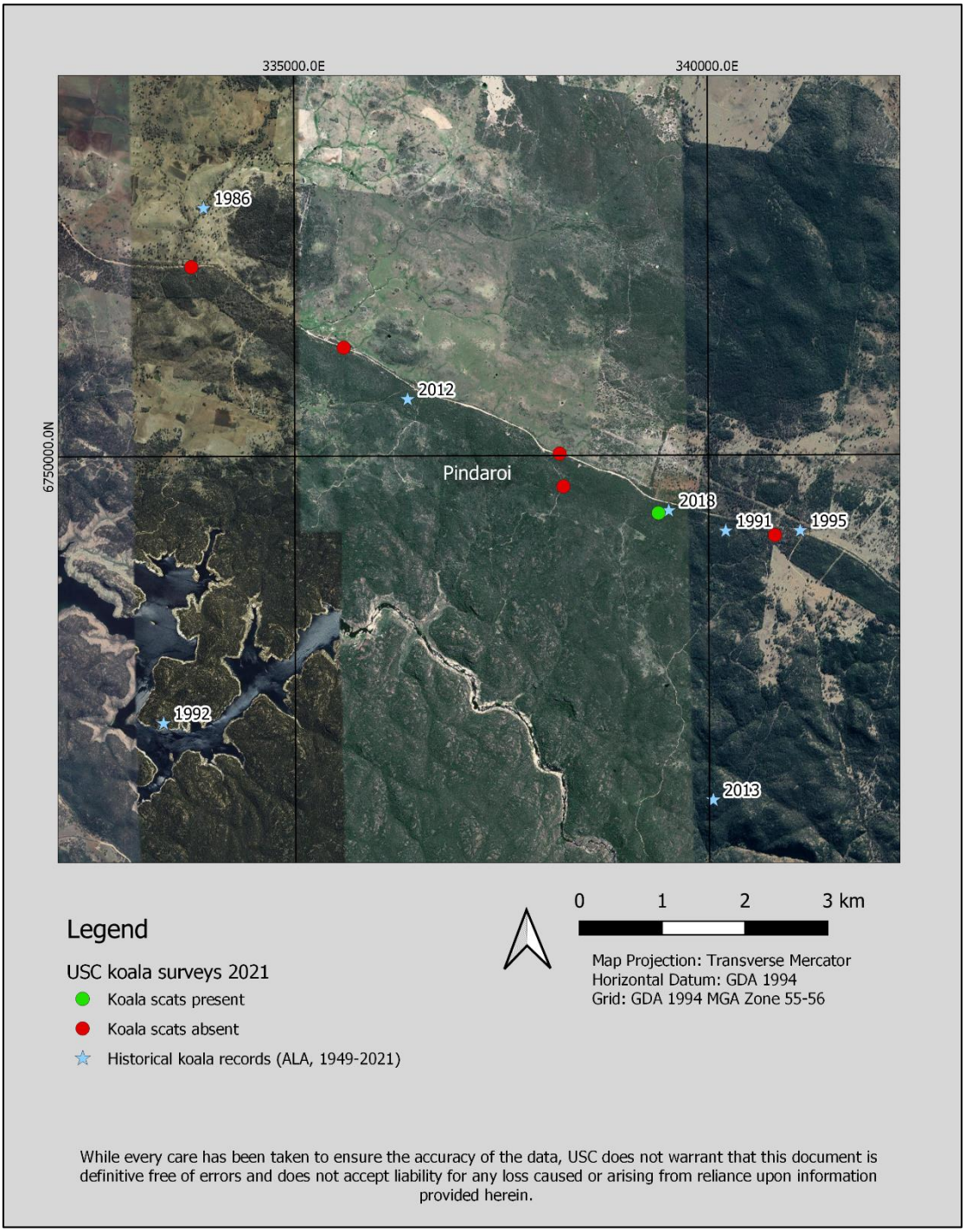

Figure 9: Koala scat presence/absence surveys and historical koala records from the Atlas of Living Australia (last updated 01/06/2021) showing the proximity of a recent record and a positive survey site on Emmaville Road

In Warra National Park and Wattleridge IPA, koala records in ALA are very scarce but few entries exist from 2013 and 2015. In both areas, the DDC found fresh koala scats. This is considered a positive sign, given that both these areas were heavily affected by the fires in 2019/2020, that at least some koalas survived and could participate in post-fire population recovery.

4.4 Scat Age and Size

Scats were found during the six presence/absence surveys ranged from scat age two (within ± 14 days) to scat age five, the oldest age category with scats being many months to years old; see Table 1 for age categories). Three of the six sites with scats (50%) had scats of more than one age present together. This suggests that 50% of the sites where scats were found exhibit ongoing use by koalas over time. None of the scats were very small, so it is likely that no scats from joeys were sampled.

4.5 Chlamydia Prevalence in Northern Tablelands Koalas

A total of 84 samples were used for the assessment of chlamydia presence in Northern Tablelands koalas, and prevalence at two koala hotspots (Figure 10). Of these samples, 77 were sampled in 2019 for the genetics pilot study and were genotyped which allowed for identification of unique individuals. An additional seven samples were collected during the 2021 presence/absence surveys which were not genotyped and may therefore include multiple samples from the same individual (though this is not very likely).

Extractions of all 84 samples were tested for presence of *C. pecorum* using the qPCR method. A total of 59 samples were found to be chlamydia negative and a total of 25 likely chlamydia positive (30%, Figure 11). Of the positive chlamydia results, six were clear positive samples, 17 suspect and two weak positive. In comparison, SNP testing of chlamydia presence (N = 77) resulted in 53 individuals testing negative for the presence of the chlamydial pathogen and 24 individuals testing positive (31%, Figure 12). The results were highly concordant (96%). This provides confidence that the chlamydia results are reliable. With the results of SNP testing for

chlamydia, all but two individuals that were chlamydia positive were located in and around Armidale. The other two individuals were located in Inverell. The qPCR revealed that two of the seven samples that were collected in 2021 tested positive for chlamydia both of which were found in Imbota Nature Reserve near Armidale. Note again that these two scat samples could stem from the same individual as they have not been genotyped.

The prevalence of chlamydia was substantially higher in Armidale and Uralla (22 out of 36 samples, 61%) than in Inverell/Delungra (two out of 41 samples, 5%) (these numbers are comparable for the SNP method). The two positive samples in Inverell/Delungra were both from male koalas and collected not far apart, between Oakwood and Cherry Tree Hill in proximity to Yetman Road. One individual that tested positive was found and showed to the DDC team by residents of Oakwood who live nearby and look out for koalas. Based on photographs taken of that male koala and notes made in the field, there were no visible external signs of disease. Again, koalas can carry the pathogen without showing pathological signs or getting sick, but still can pass it on to other koalas. Each chlamydia positive male was in very close proximity to a chlamydia negative female koala.

Of the samples collected in Armidale and Uralla, all but one of the samples that tested positive for the chlamydia pathogen stem from Armidale and surrounds. Only one of 10 samples collected in or near Uralla was positive. In Armidale, most positive samples were collected around Duval Nature Reserve, Dumaresq Dam, Toms Creek and Boorolongs Road, as well as Imbota Nature Reserve. The extremely high prevalence in Armidale is reason for concern and requires intervention.

Comparing the SNP method results for both of the koala hot spots, more male (N = 16, 34.8% of all males) than female (N = 8, 25.8% of all females) koalas tested positive for the chlamydia pathogen. However, this might relate to the bias in sexes sampled. Both Inverell/Delungra (N = 41) and Armidale/Uralla (N = 36) had a sex ratio biased towards males. In Armidale/Uralla, 13 female and 23 male koalas were sampled (sex ratio: 1:1.77). In Inverell/Delungra, 17 female and 24 male koalas were sampled (sex ratio: 1:1.41). A balanced sex ratio, close to 1:1 or with a slight bias towards females is desirable and can help stabilising declining populations.

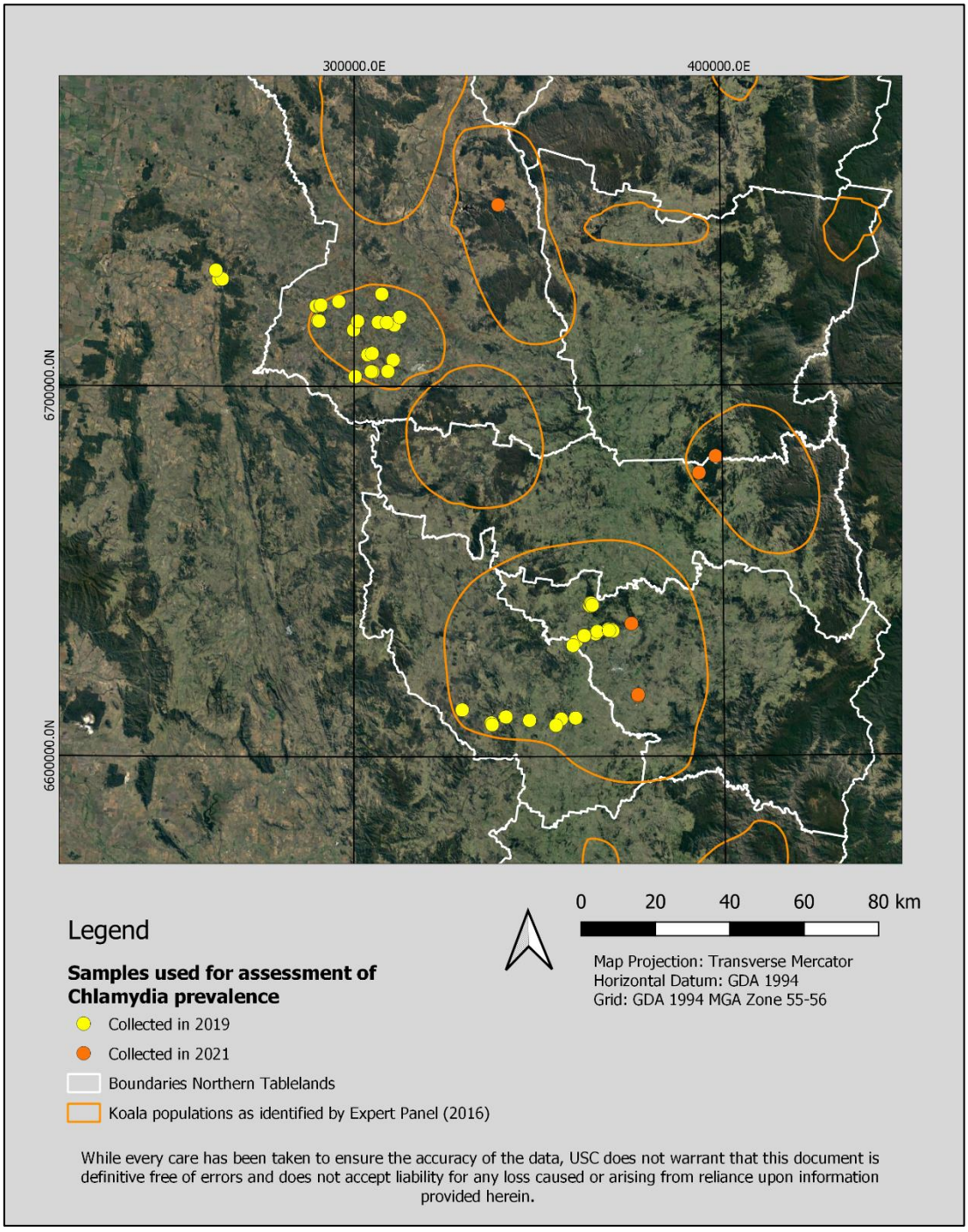

Figure 10: Location of koala scat samples (N = 84) used for the assessment of chlamydia presence and prevalence in the Northern Tablelands koalas. Samples in yellow (N = 77) were collected in 2019 and have been genotyped and identified as unique individuals. These samples were used for detection of chlamydia through specific SNPs. Samples in orange (N = 7) were added in 2021 and have been tested for chlamydia using qPCR but not SNPs. All samples have been included for chlamydia detection through qPCR.

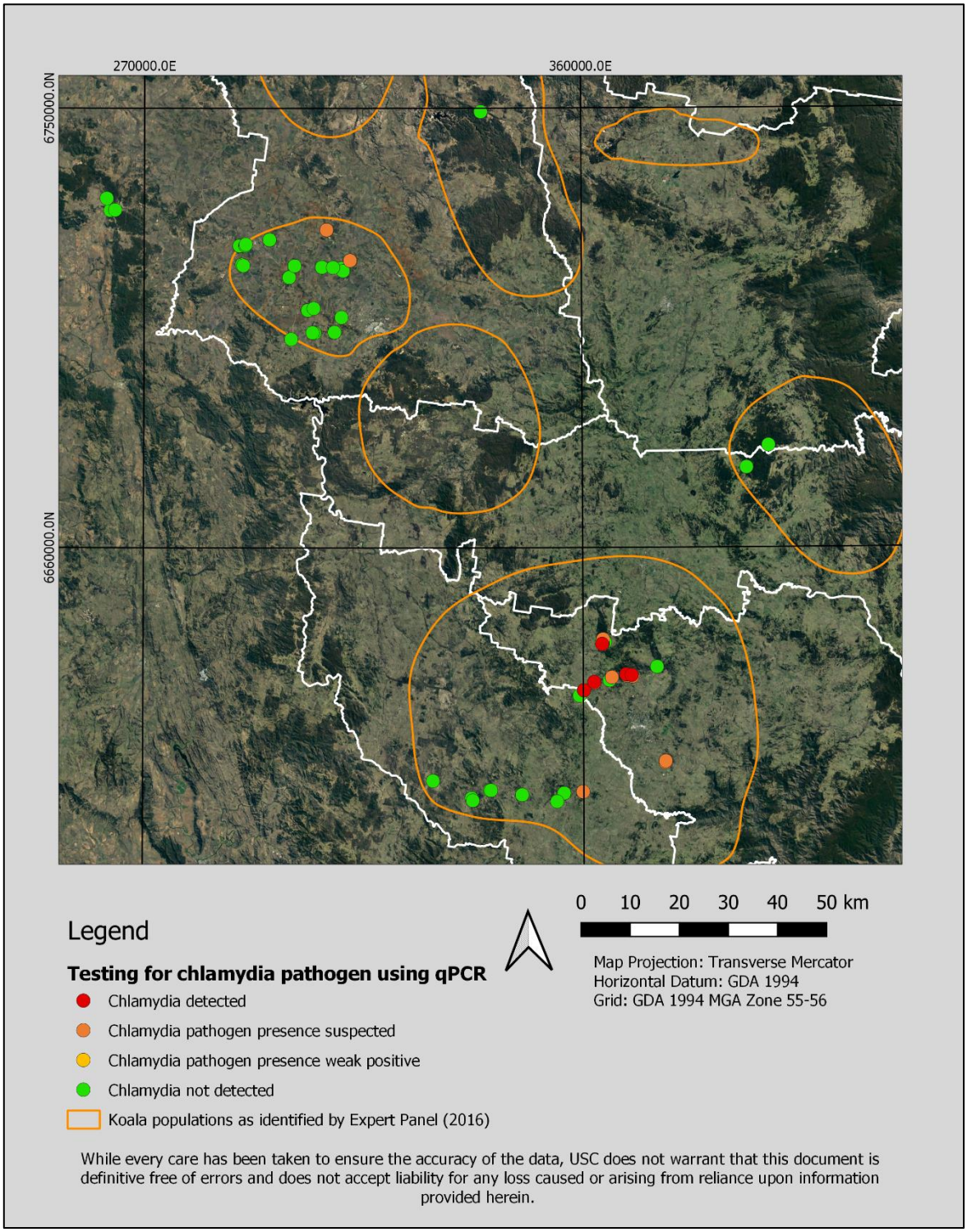

Figure 11: Location of koala scat samples (N = 84) used for the assessment of chlamydia presence and prevalence in the Northern Tablelands koalas using qPCR. Samples in which the chlamydial pathogen was detected is presented in red, where the pathogen was suspected in orange and where a weak positive signal was picked up in light orange. Samples where the pathogen was not detected are presented in green.

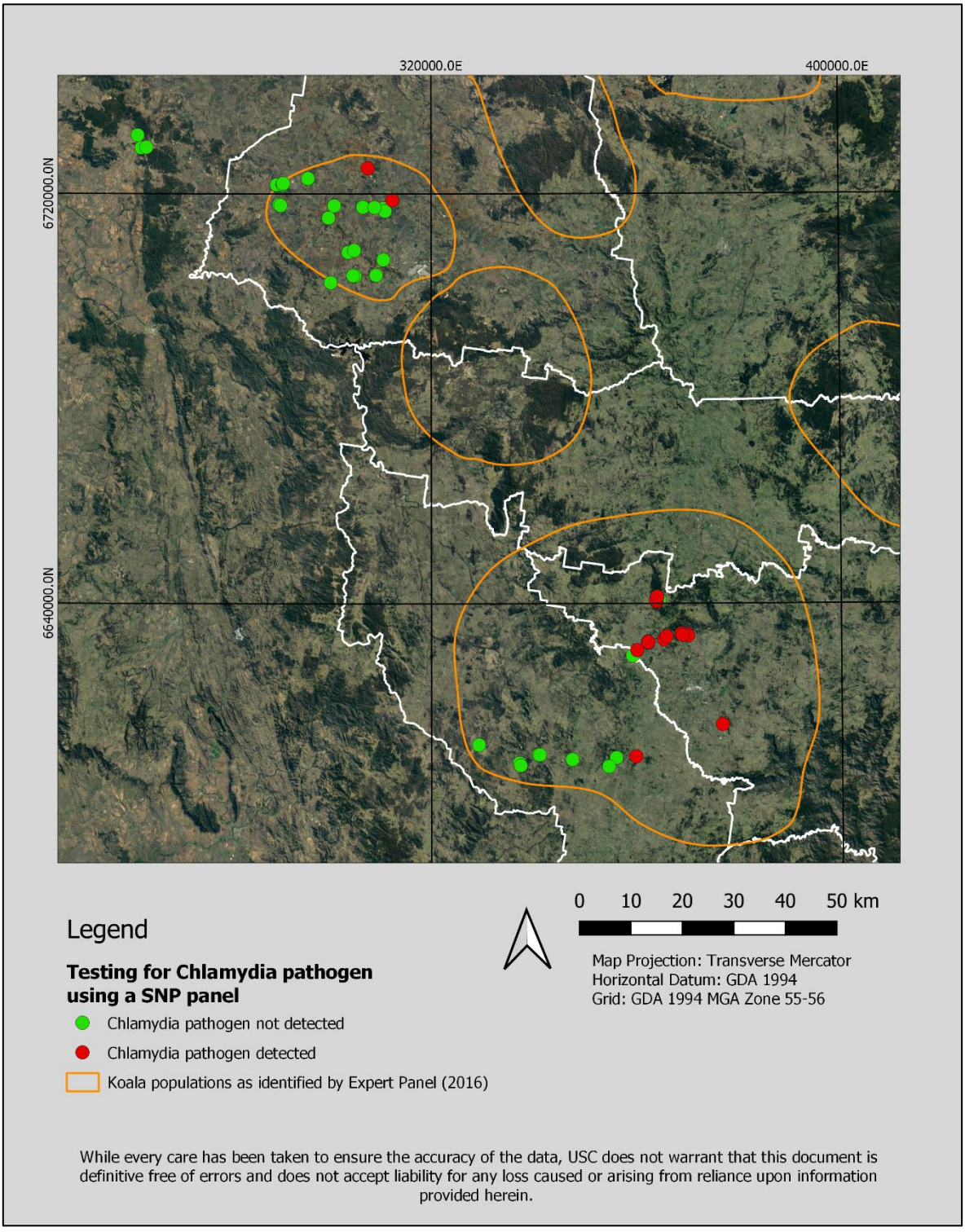

Figure 12: Location of koala scat samples (N = 77) used for the assessment of chlamydia presence and prevalence in the Northern Tablelands koalas using a panel with chlamydia specific SNPs. Samples in which the chlamydial pathogen was detected is presented in red, samples where the pathogen was not detected are presented in green.

5. Discussion of Results

5.1 *Cool Country Koala Project* 2020 - 2021 Presence/Absence Surveys

The presence/absence surveys for this project were aimed at extending the knowledge of where koalas occur in the Northern Tablelands. In autumn 2021, the DDC conducted koala scat presence/absence surveys and detected koala presence at 6 of the 100 sites surveyed (6%). However, no live koalas were sighted during the koala scat presence/absence surveys which were conducted in and around Severn River, Kings Plains, Washpool National Park, Guy Fawkes River National Park, Gibraltar Ranges National Park, Warra National Park, Wattleridge IPA, TSRs and Nature Reserves around Armidale, and Oxley Wild Rivers National Park.

A total of eight scat locations were recorded and seven genetic samples were collected**.** Overall, these findings suggest that the surveyed areas have low levels of koala density. However, scats of different sizes were found at two of the six positive survey sites, indicating the likely use of the same area by more than one individual. Furthermore, three of the six positive sites had scats of different ages present, indicating the use of the area by koalas over a period of time. It is to be noted that this years' surveys had a high level of fresh scats detected compared to other years (see in Table 2, the percent of sites with fresh scats found in this report of 87.5%, compared to other years/reports: USC 2019 = 33.3%, 2018 = 5.50% and 2016 = 18.60%; Stringybark 2016 = 2%). This could indicate that the high level of rain (La Niña) had washed or degraded the scats deposited weeks to months prior to our surveys, so that we only detected very recently deposited scats. This means this years' negative survey results are to be taken with caution, and potentially a subsample of the locations should be resurveyed to confirm whether these were true negative or low detectability of scats influenced by the heavy rains of 2021.

The results of these presence/absence surveys have expanded knowledge of koala distribution in the Northern Tablelands. Due to ongoing dog-baiting activities, some of the sites surveyed fell outside of the priority areas (Figure 2) identified by the NT KRS, although site selection was guided by historical koala sightings recorded in the ALA.

Of the priority areas that were surveyed in 2021, the Severn River area appears to have undergone the largest population reduction since ALA sightings were recorded. Some evidence of koalas was found in this area, however, the high number of negative surveys suggests that the population is likely to be small. This is particularly interesting to consider given the proximity of this area to the Delungra/Inverell priority area, where previous surveys have identified numerous koalas and ALA records are abundant. This outcome is similar to the findings in 2016, when the Ashford priority area had no signs of koalas detected. Two residents who have lived in the Severn Rivers area all their lives were encountered in independent events and asked about their recollection on koala presence and numbers. Both reported that koalas used to be abundant in the area up until 10 years ago. They mentioned that a lot of the koalas would have died of chlamydial disease, however, no evidence is available to support this hypothesis. Other known threats to koalas that could be implicated are drought, heatwaves, dieback or predation by dogs, to name a few.

All surveys conducted in 2021 occurred either at or near sites of historical records with exception of the Watson's Creek area. In comparison to historical records from the ALA, the 2021 presence/absence surveys further highlighted the reduction of koala distribution outside of koala hotspots (Armidale/Uralla and Inverell/Delungra). The fact that multiple areas of priority identified in 2016 by the NT KRS were not confirmed to be used or highly used by koalas could be indicative of a reduction in the koala populations of the Northern Tablelands in the last 10 years (note that the difference of survey method and survey time, e.g. the ALA has records that span many decades, is also a possible explanation). The DDC also found anecdotal evidence of a koala population reduction through interactions with local residents during fieldwork.

By combining the results of the 2021 presence/absence surveys with previous surveys conducted by USC and Stringybark (Table 2), some key koala hotspots in the Northern Tablelands were previously identified (Figures 13 & 14). Armidale/Uralla and Inverell/Delungra regions remain the two main areas which are important strongholds for koalas in the Northern Tablelands. The high numbers of positive survey results within these populations (Figures 17 & 18), reinforced by the numerous negative survey results outside of these areas, strengthens the picture of a patchy koala distribution in the Northern Tablelands -

and each negative survey across the Northern Tablelands reinforces the importance of the Armidale/Uralla and Inverell/Delungra koala hotspots. To add to this knowledge, this year, through the chlamydia study, we were able to identify that chlamydia is present in koalas in both these strongholds, but predominantly Armidale and surrounding areas. The presence of the pathogen does not necessarily translate into the presence of disease. Further investigation of the health of the Armidale/Uralla population is now required.

Table 2: Comparison of koala metrics calculated at sites surveyed during the NT LLS koala scat presence/absence surveys (both USC and Stringybark 2016 and USC 2018, 2019, and 2021)

	NT LLS/**USC 2021**	**NT LLS/USC 2019**	**NT LLS/USC 2018**	**NT LLS/USC 2016**	**NT LLS/Stringybark 2016**
Percent positive site	6% (6/100)	7% (9/127)	24.80% (30/121)	30.30% (81/267)	49% (N = 139)
Trees with koala scats	NA	0.5% (N = 2048)	4.90% (N = 2082)	7.20% (N = 5136)	NA
Koala sightings	0	0	0	29	NA
Activity levels	NA	0.1% (N = 2040)	4.10% (N = 2082)	6.60% (N = 4980)	6.80% 3910
Activity levels at positive sites (i.e., when koalas are present, how intensively do they use a sites)	NA	3%	15.70%	21.00%	NA
Percent of sites with fresh scats	87.5%	33.3%	5.50%	18.60%	2%
Percent of sites with medium scats	62.5%	33.3%	14.80%	41.40%	25%
Percent of sites with old scats	12.5%	33.3%	78.70%	40.00%	75%

NA = Not available in report

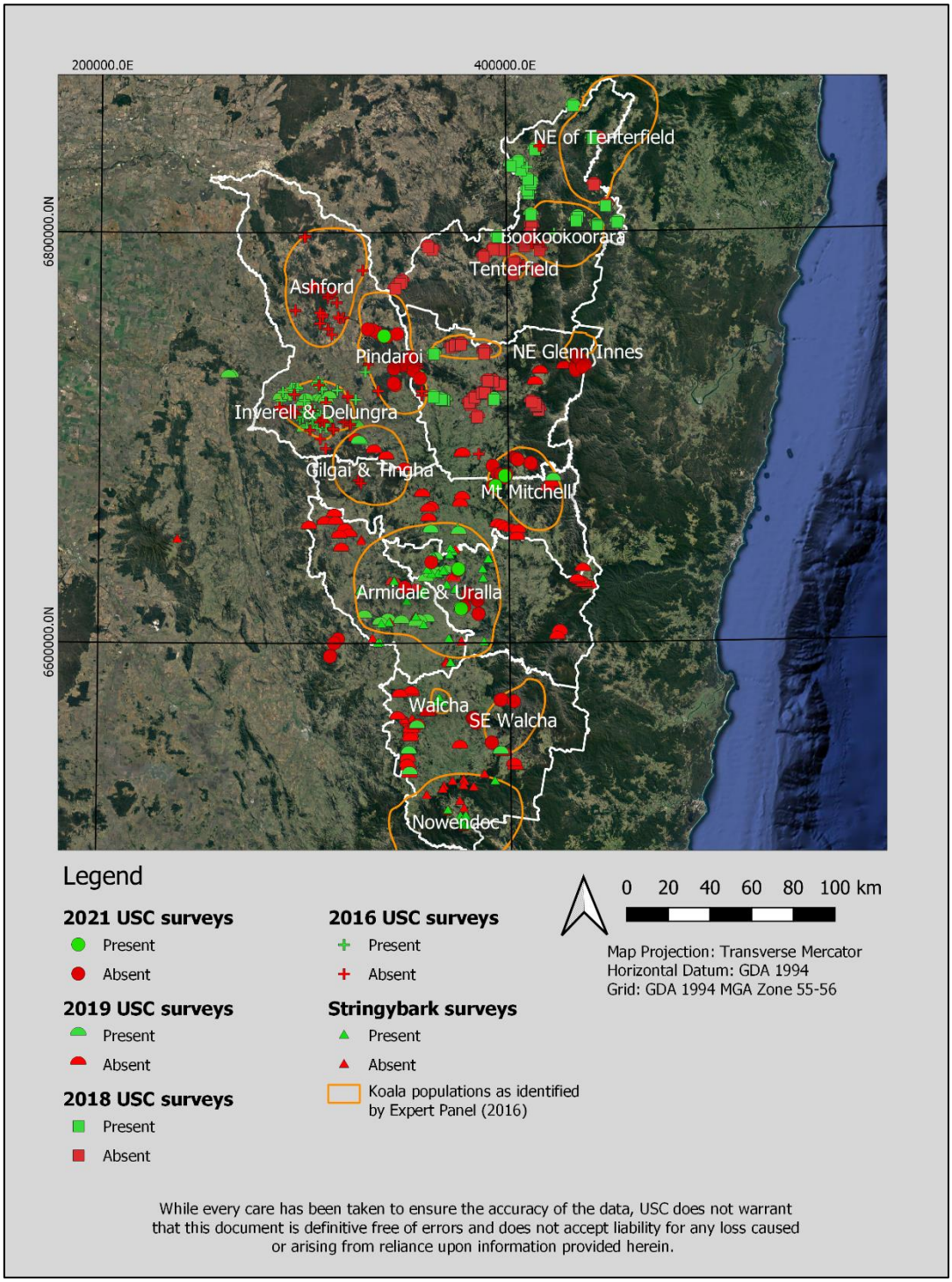

Figure 13: Koala survey sites where koala presence or absence was recorded during 2016, 2018, 2019, and 2021 koala surveying projects

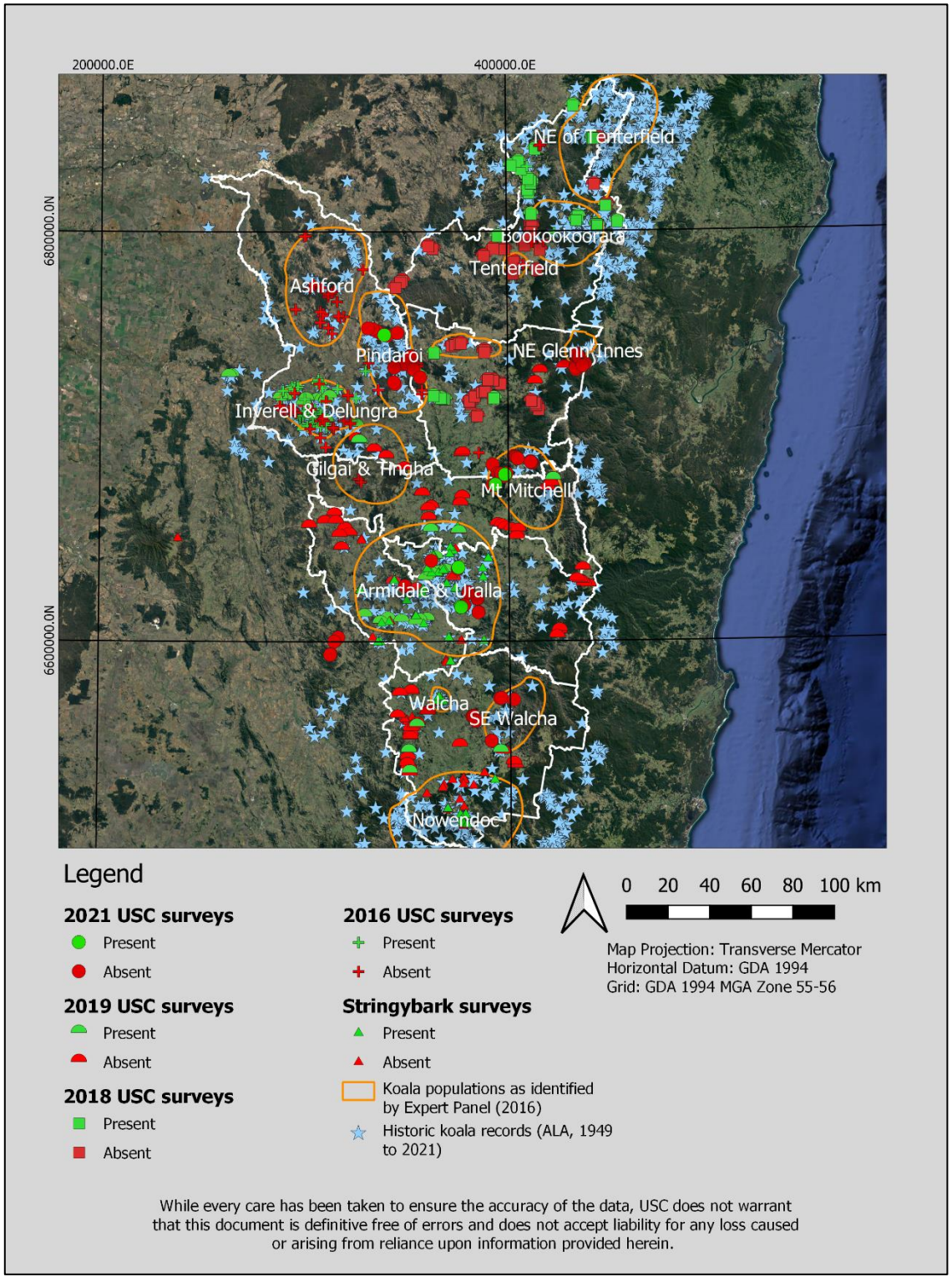

Figure 14: Koala survey sites where koala presence or absence was recorded during 2016, 2018, 2019, and 2021 NT LLS/USC/Stringybark koala surveying projects and historical data

Cool Country Koala Project 2020 – 2021: Koala Habitat and Disease Pilot Project

5.2 *Cool Country Koala Project* 2020 - 2021 Chlamydia Pilot Study

The disease pilot study was aimed at investigating whether chlamydia was detected from koala scats collected in the Northern Tablelands, as well as chlamydia prevalence, as information on whether chlamydia is present and poses a risk to the Northern Tablelands koala population is still lacking. The DDC analysed samples of 84 koalas mainly from the Armidale/Uralla and Inverell/Delungra regions for the presence of the chlamydial pathogen. Two different methods were used to improve the power and reliability of the results – a genetic test using SNP probes and a gold-standard qPCR test. The two methods were highly concordant (~96%) and results are therefore considered reliable. The DDC found an overall disease prevalence of 30-31% in the samples that were used for this first assessment. In comparison, koala populations in Redlands City Council presented a prevalence of ~37% (unpublished data). Another study found a disease prevalence of 31%, testing 160 koalas in Moreton Bay, Queensland, using the qPCR method. Most had clinically detectable chlamydia disease but not all and some diseased animals were qPCR negative (Nyari et al. 2017). A study in South Australia found a prevalence of 46.7 % in a koala population in the Mount Lofty Ranges (Fabijan et al. 2019). Therefore, overall, chlamydia disease prevalence in Northern Tablelands koalas is similar to or lower than other populations.

However, the distribution of koalas carrying the chlamydia pathogen is extremely uneven, with only two out of 24 total positive individuals being found in Inverell/Delungra and the remaining in Armidale/Delungra. This brings the disease prevalence of the Armidale koala population to 61% and thus to a much higher level than other populations. The reports from residents of Severn River, stating that chlamydia was the cause for the loss of most their koalas about 10 - 20 years ago, could be relevant. While these claims remain to be investigated, some Northern Tablelands koala populations seem to have declined (based on not all areas with past records being confirmed as currently used by koalas, through the last five years of surveys) and the impact of chlamydia could be substantial.

It is known that stress can affect an animal's immune system and can lead to pathological infections (Marsland et al. 2002), especially if the animal is already carrying a pathogen. Koalas

in the Northern Tablelands have been exposed to many stressors such as a long history of habitat loss and fragmentation, and more recently drought and bushfires. While the interaction between stress and chlamydia infection in koalas is currently being investigated (Narayan 2019), it is important to keep monitoring the Northern Tablelands key koala populations for signs of disease (external but also fertility rates). Chlamydia disease is known to affect the reproductive system of female koalas and can dramatically reduce fertility. Re-sampling of koala hot spots, and especially around Armidale, would be important to investigate consistency of trends and disease.

Both Inverell/Delungra (N = 41) and Armidale/Uralla (N = 36) had a sex ratio biased towards males (females to males 1:1.41 and 1:1.77, respectively). Note that a balanced sex ratio close to 1:1 is preferable, or with a slight bias towards female koalas, especially in declining populations. Ellis et al. (2010) found no sex bias in koalas in two regions but a male bias in south-east QLD, however, this finding could not be explained. In comparison, the sex ratio in koalas in Redlands City Council in 2021 is 0.97:1 males to females (unpublished data). To some extent, the sampling can randomly be skewed. However, because this trend was present in both regions, it could be a true trend. In and around Armidale, very few koalas were sighted (N = 2), with no sighting of a female with joey. In contrast, many more koalas were sighted in Inverell/Delungra, including five females with joeys. Therefore, we cannot conclude any effect of a biased sex ratio on the population and its growth, however, to maintain a healthy breeding population, the sex ratio should continue to be monitored to assess any trends. More specific recommendations are provided in the following section.

5.3 Management Recommendations

In this report the DDC seek to add to the recommendations included in the 2016 NT LLS, 2018 NT LLS, and 2019 NT LLS reports (and available in Appendix 4). The recommendations from these reports are still valid and should still be considered for implementation. Here, an update is provided taking into consideration the results of both the field surveys conducted in 2021 and the pilot disease study.

Recommendation 1 – Re-define distribution of koalas and koala populations compared to NT KRS "priority areas"

The 2021 *Cool Country Koala* Project surveys were conducted in areas where historic sightings existed but were not as abundant as in other priority areas that were prioritised in previous years and surveyed in 2016, 2018 and 2019. Nonetheless, with koala scats detected in only 6% of the sites, it would seem that there has been an overall reduction in koala presence in comparison to historical records (ALA). Many of the survey sites have been affected by the 2019-2020 bushfires. This catastrophic event added an additional threat for koalas in the NT, where koalas have already experienced many challenges – land clearing for agriculture and severe drought being just a couple of known examples, with the status of potential threats such as dogs and diseases remaining largely unknown.

Based on all the surveys for koala presence over the years of collaboration between the DDC and NT LLS, new maps can be established to reflect contemporary koala distribution. After five years of surveying the koala populations of NT, a new map of koala strongholds should be established, which can be used to highlight key populations to preserve and investigate connectivity between them.

There are clear koala strongholds in NT, as identified in previous reports (Armidale/Uralla and Inverell/Delungra). Every negative survey site increases the importance of these strongholds for koala survival in NT, reinforcing the need within the strongholds to: 1/ conserve current habitat, 2/ increase the extent of habitat and connectivity, and 3/ monitor koala density, sex ratio, genetic and physical health to enable early detection of any threat or population decline. In our view, the strongholds of Armidale/Uralla and Inverell/Delungra are critical to ensure the persistence of koalas in NT, and we cannot stress enough the value of these two populations for the entire Northern Tablelands region. Specific koala management plans for these two populations should be implemented.

Other important areas for koalas are likely Balala, Black Mountain, South Guyra, Walcha town, Nowendoc town, and areas around Bookookoora, though specific definitions of the boundaries for these populations require further assessment. Most of the koala populations in NT are within close proximity to urban areas, which increases threats to the koalas, but can also be of benefit,

see recommendation 2 – increasing citizen science. Furthermore, the clustered distribution of koalas in NT facilitates the implementation of intensive targeted monitoring and management strategies, that potentially would become unpractical and unaffordable were the koalas occurring across the entire area of NT at low density. Therefore, the current koala population distribution can be used to the benefit of their survival.

Recommendation 2 – Increasing community engagement to harness citizen science and empower communities to protect their koalas

The close proximity of koalas to settlements facilitates the inclusion of the community into koala conservation, a process often referred to as citizen science. The DDC already recommended the implementation of Citizen Science programs in the 2019 Cool Country Koala Project report. Specifically, the DDC presented the benefits of making the local community the guardians of their koalas. With the knowledge we gained from the pilot disease study, harnessing this powerful tool could support the monitoring of mortality and signs of disease, especially in the Armidale region. Workshops for the community and, in particular, for citizens with koalas on their property or nearby, could be held to train them to monitor koalas and recognise signs of chlamydial disease and actions to take when a sick animal is detected. This could also be advertised through leaflets or other forms of public communication and community engagement. In parallel to increasing the ability of the community to monitor the health status of their koalas, enabling their safe and prompt capture and veterinary treatment is critical to the protection of these koalas. Therefore, any such community engagement campaigns would require liaison with, and support of, local wildlife rescue groups and wildlife Hospitals.

Recommendation 3 – Monitoring of disease prevalence in Armidale

Results from the pilot disease study show that Armidale koalas present a high chlamydia pathogen prevalence. Two different methods have been used to account for potential uncertainties in tests for detecting pathogen in scats, however results from both methods lead to the same conclusion. Note again that detecting the presence of chlamydia in koalas does not

equate to them expressing signs of the disease, as there are koalas that clear the pathogen naturally themselves or harbour the pathogen chronically without disease (Robbins et al. 2019). However, the high prevalence of the pathogen in Armidale puts the population at risk because it is not yet clear from the literature what factors can trigger chlamydia pathogenicity. Therefore, even if the pathogenicity was currently low, there could be a future outbreak.

As a first step, the current status of the Armidale koala in terms of disease should be ascertained. We recommend revisiting the sites around Armidale that were positive for koala presence, and attempt to locate live koalas to check for external signs of the disease (e.g., cystitis often leads to "wet bottom", conjunctivitis). Using methods that increase koala detection efficiency, such as flying drones with thermal cameras or using detection dogs to find koalas, would be beneficial. Additionally, or alternatively, again, citizen scientists could be recruited to conduct the surveys after appropriate training.

Another issue is that, even if koalas are pathologically sick from chlamydia, external signs of the disease are not always present. Chlamydia disease can also be undetectable externally, especially at early stages or when it affects the reproductive track. Reproductive disease, in females especially, can translate to low fertility and, at the population level, low reproduction rates. Due to the potential of developing reproductive diseases, these "disease monitoring surveys" would best take place in months where females should be accompanied by their back riding joeys to assess reproduction rates. Note that specific breeding season can differ between populations, but emergence of joeys from the pouch is usually after May. From there the joey should be regularly visible. Ideally, a number of the sighted koalas should be caught by professionals and presented to a veterinary team to undergo a thorough health assessment. If pathogen presence translates to pathological disease, a substantial impact on the koala population could be expected and a plan for treatment of sick koalas should be established. Indeed, chlamydia can be responsible for population declines, but it is also a disease that can be treated if koalas receive appropriate help early (Rhodes et al. 2011b, Beyer et al. 2018).

Furthermore, it is important to collate historic and recent data on chlamydia in the Northern Tablelands koalas. Wildlife carers, wildlife groups and wildlife hospitals, as well as residents and koala ecologists, should be contacted for data and surveyed for anecdotal information. If there is a consensus in the data and reports, chlamydia might play a significant role in Northern

Tablelands koala population declines and, together with results presented here, should be considered as a threat for the two population strongholds and managed as such.

Koalas, if caught for health assessments or disease treatment, could be equipped with a prototype solar-powered Bluetooth ear tag. This ear tag can be detected with a phone App, provided that the koala is in close proximity, and can enhance community monitoring. This system is in trial in Queensland with promising results so far.

Recommendation 4 – Desktop analysis: Investigating explanations for patchy population declines and investigate future resilience of stronghold populations

There could be interesting learning to gain from comparing koala persistence across the landscape. Areas with clusters of negative sites despite high numbers of historic sightings such as Pindaroi and Ashford, Washpool National Park, Emmaville and Deepwater, could be compared to areas where koalas persisted. Models containing environmental and landscape variables could be used to investigate potential reasons for this perceived koala decline.

This analysis could be conducted as part of a PhD, which could also include other research questions around chlamydia disease prevalence, and corridor or climate refuge mapping. This PhD project could be implemented as a collaboration with other projects, organisations or universities, which would further increase collaboration.

Recommendation 5 – Resurvey positive sites to estimate changes over years since drought and fires

Since the DDC started surveying the Northern Tablelands for koala presence and absence, multiple natural catastrophes occurred that affected the local koala populations. The severe drought that lasted from 2017 to early 2020, as well as the mega bushfires in the summer of 2019 to 2020 resulted in a loss of koala habitat (Ward et al. 2020) and there is little doubt these environmental conditions would have increased stress and mortality in koalas. While specific effects of these climate change related threats on koala populations remains subject to further research, studies have previously found that drought alone can cause populations to decline by

as much as 63% (Gordon et al. 1988). Furthermore, wildlife carers shared concerns about a perceived increase in sick koalas during and since the drought period. Therefore, investigating potential effects of such events is a matter of urgency for the drought and fire affected Northern Tablelands.

Positive survey sites, where koalas and signs of koalas where previously found, could be resurveyed to understand the extent to which each population has been affected by the recent events. A selection of positive survey sites could also be chosen as "sentinel" sites, with koala density monitored on a frequent and regular basis. This approach could be combined with recommendation 3 (monitoring of disease prevalence).

Note that because of recent extreme events, habitat rehabilitation effort is needed more than ever. Survey sites visited during this survey period often contained trees that were affected by drought or fire. To sustain koala populations in the future, these habitats should be supplemented through rehabilitation and regeneration, and strategies to make landscapes more drought-tolerant investigated (e.g., selection of drought-tolerant seedlings / species, deploying drinking stations for wildlife).

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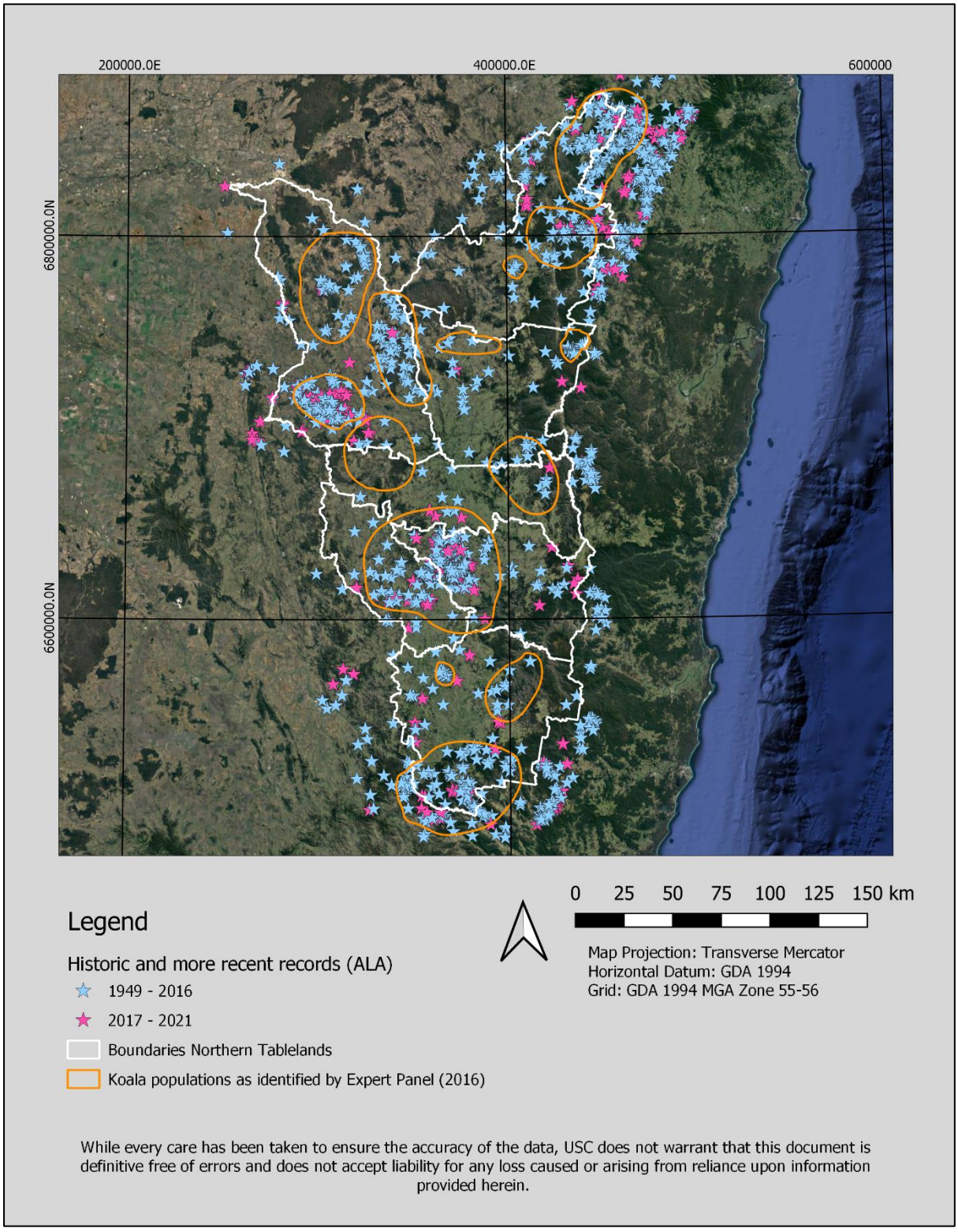
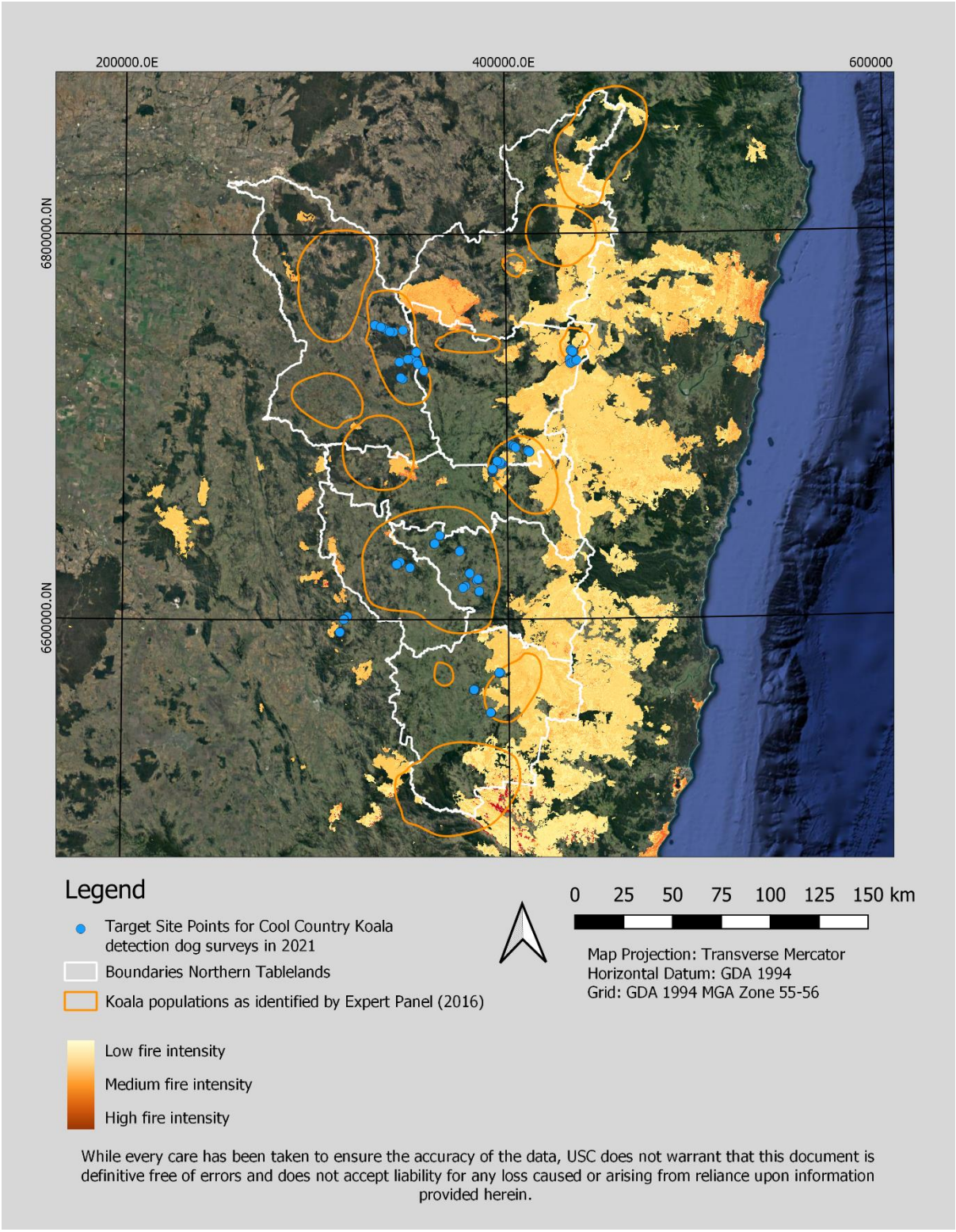
7. Appendix

Appendix 1 – Koala records in the Northern Tablelands region taken from the Atlas of Living Australia (ALA).

The map illustrates records (in blue) that have been reported up until 2016, when the Koala populations were identified by the expert panel. Since then, more koala sightings have been recorded and are presented here in pink.

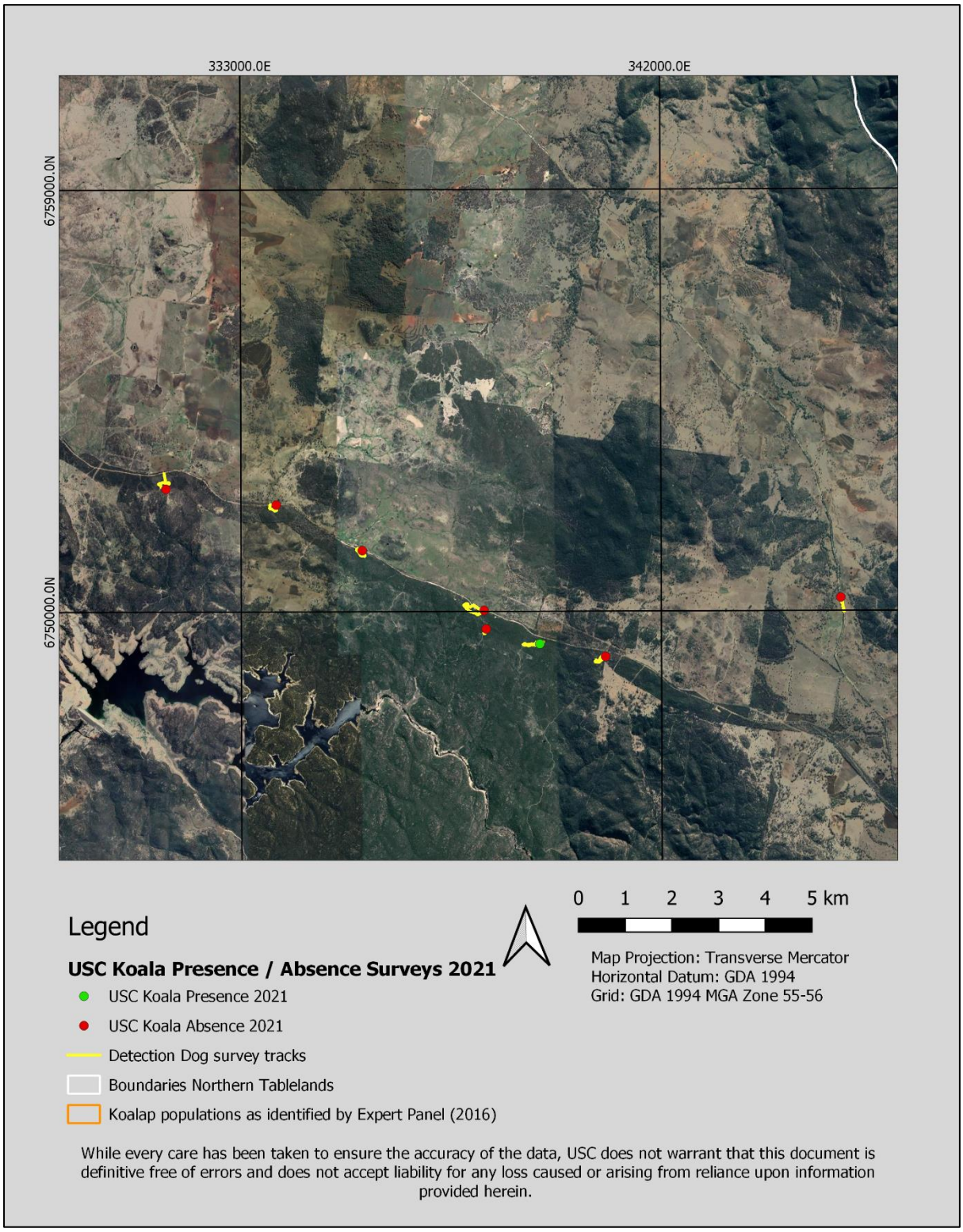

200000.0E
400000.0E
600000
6800000.0N
6600000.0N
0 25 50 75 100 125 150 km
Legend
Historic and more recent records (ALA)
1949 - 2016
2017 - 2021
Boundaries Northern Tablelands
Koala populations as identified by Expert Panel (2016)
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55-56
While every care has been taken to ensure the accuracy of the data, USC does not warrant that this document is definitive free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein.

Appendix 2 - Spread of 2019/2020 mega bushfires within 2021 survey sites

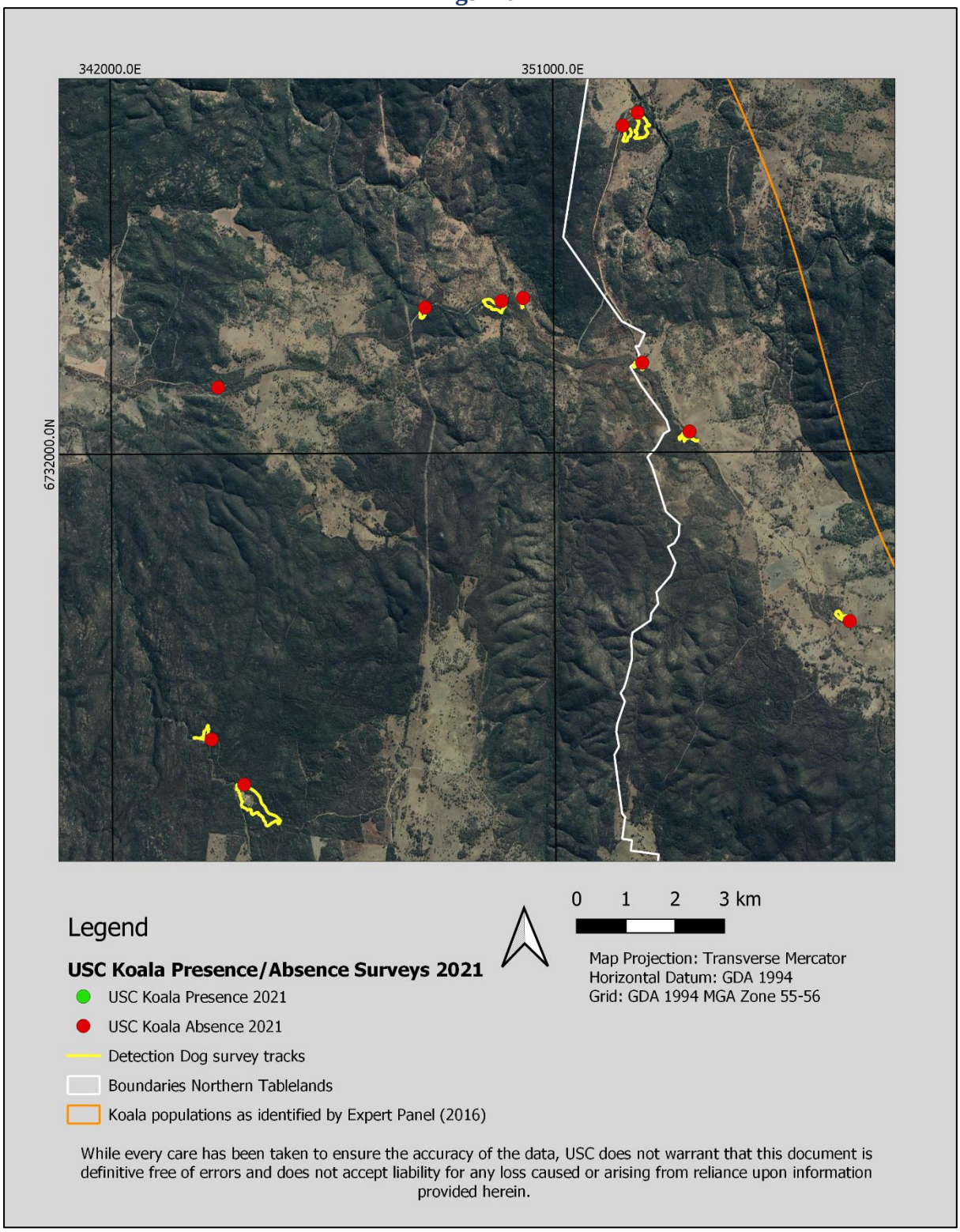


Appendix 3 - Survey start points and dog tracks close up for major survey areas in 2021

Severn River



Kings Plain


342000.0E
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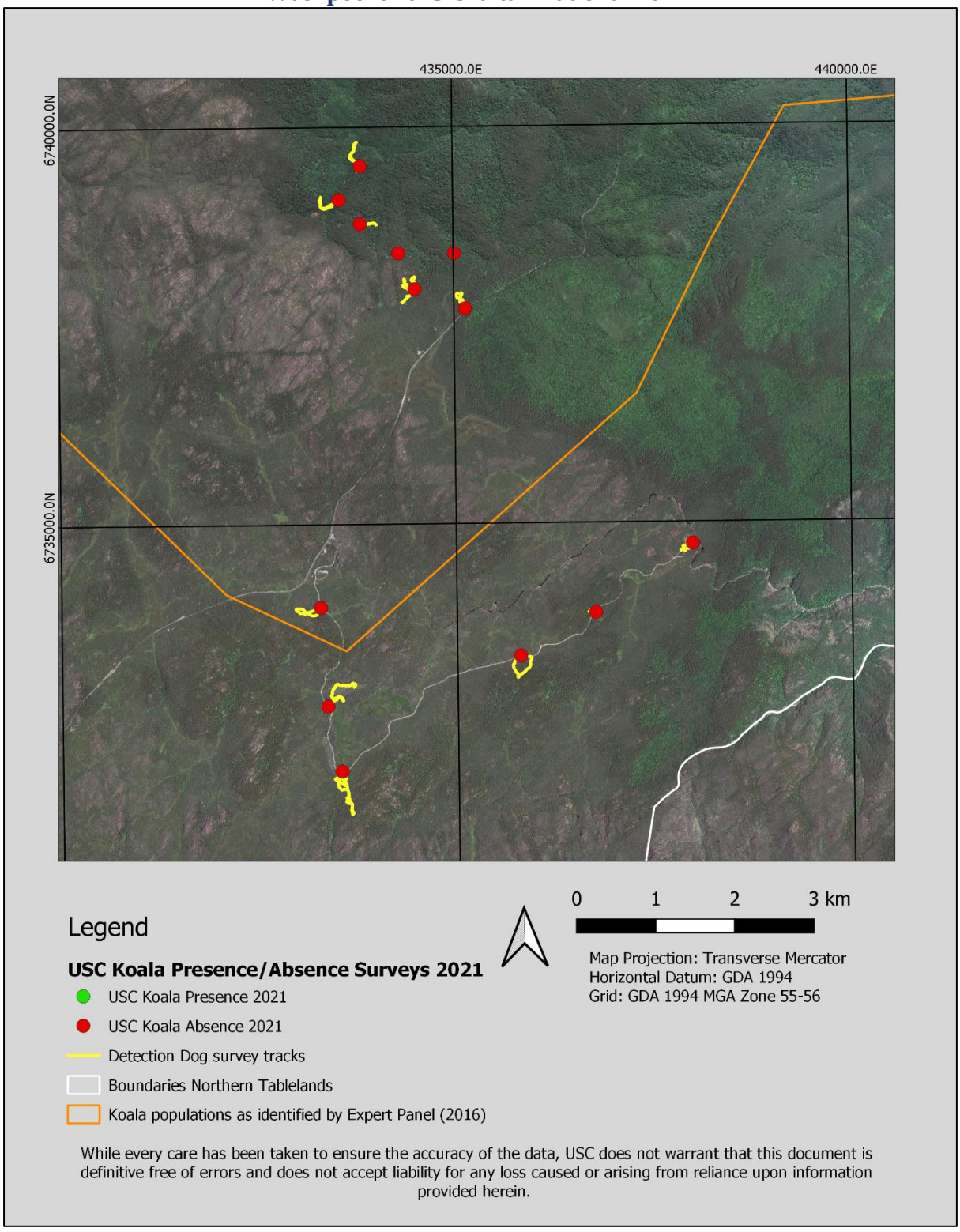
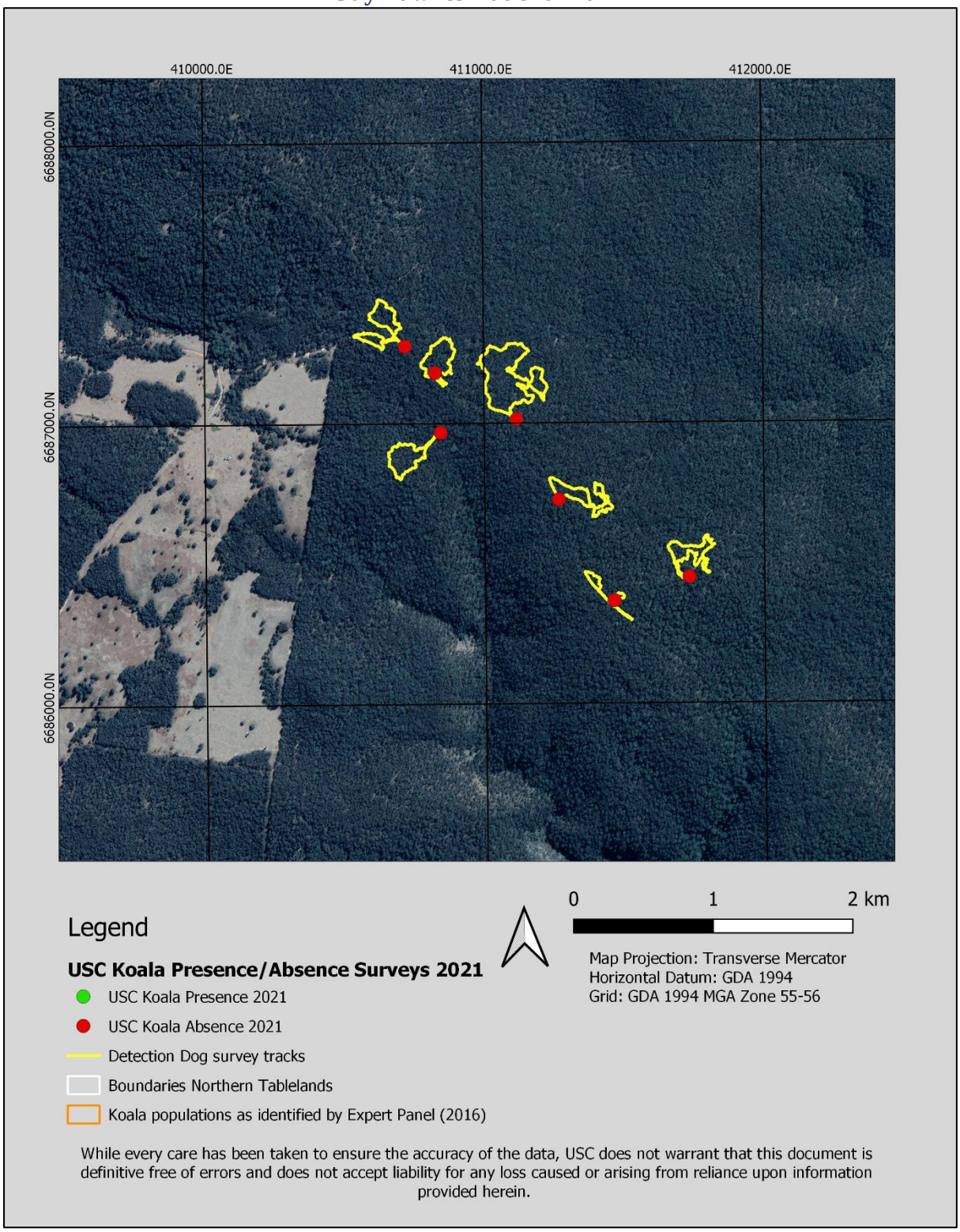
Legend
USC Koala Presence/Absence Surveys 2021
USC Koala Presence 2021
USC Koala Absence 2021
Detection Dog survey tracks
Boundaries Northern Tablelands
Koala populations as identified by Expert Panel (2016)
0 1 2 3 km
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55-56
While every care has been taken to ensure the accuracy of the data, USC does not warrant that this document is definitive free of errors and does not accept liability for any loss caused or arising from reliance upon information provided herein.

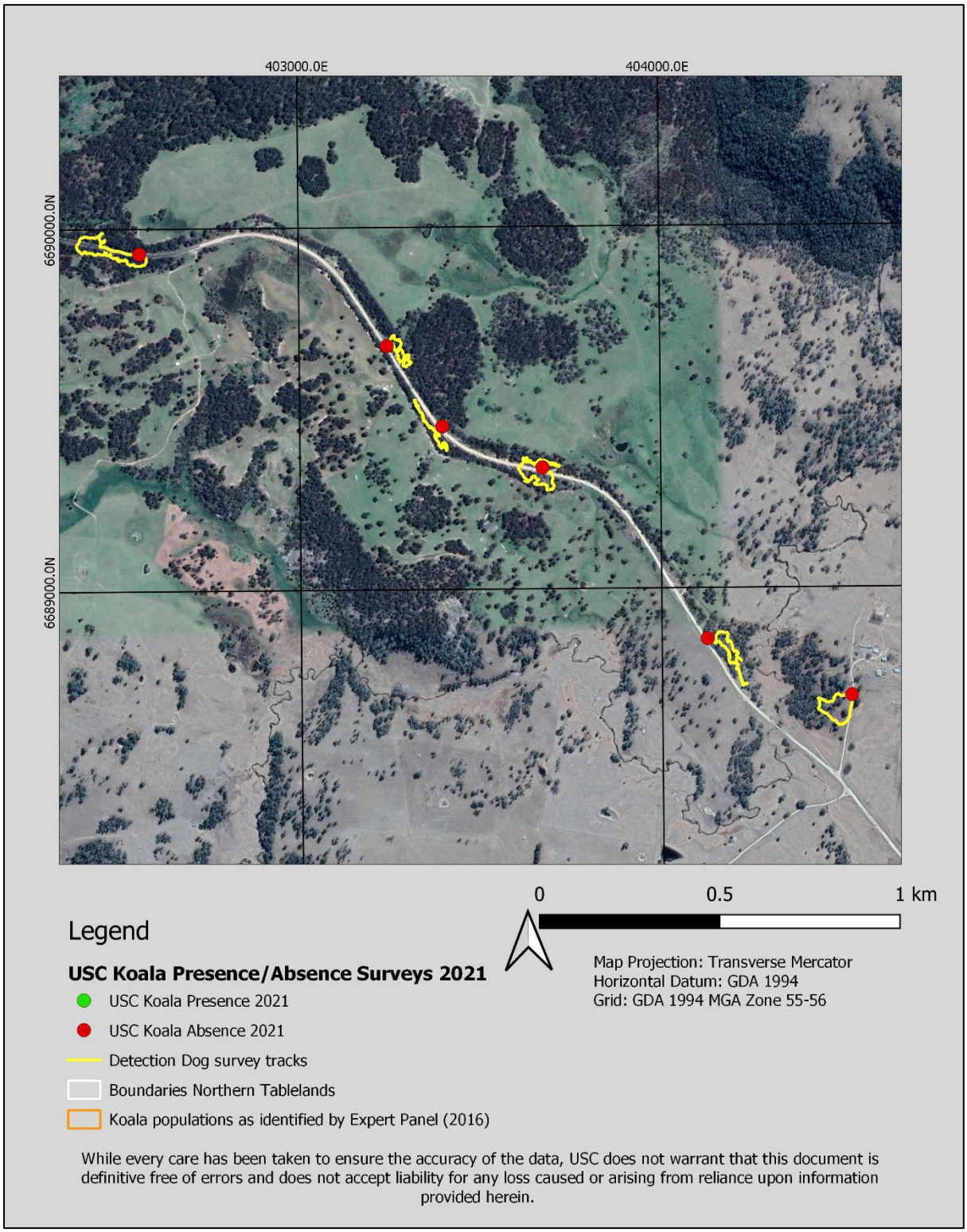
Washpool and Gibraltar National Park



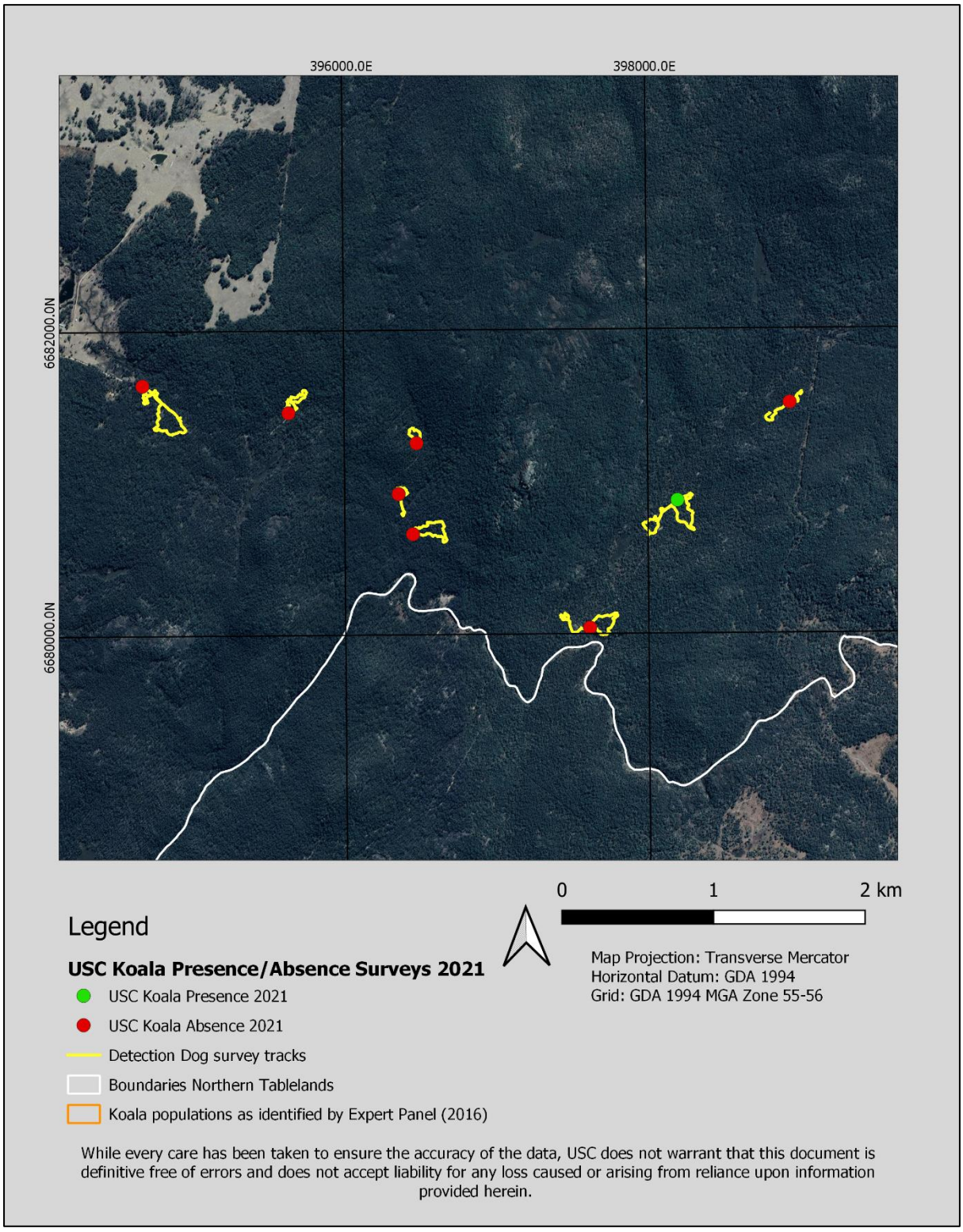
Guy Fawkes National Park



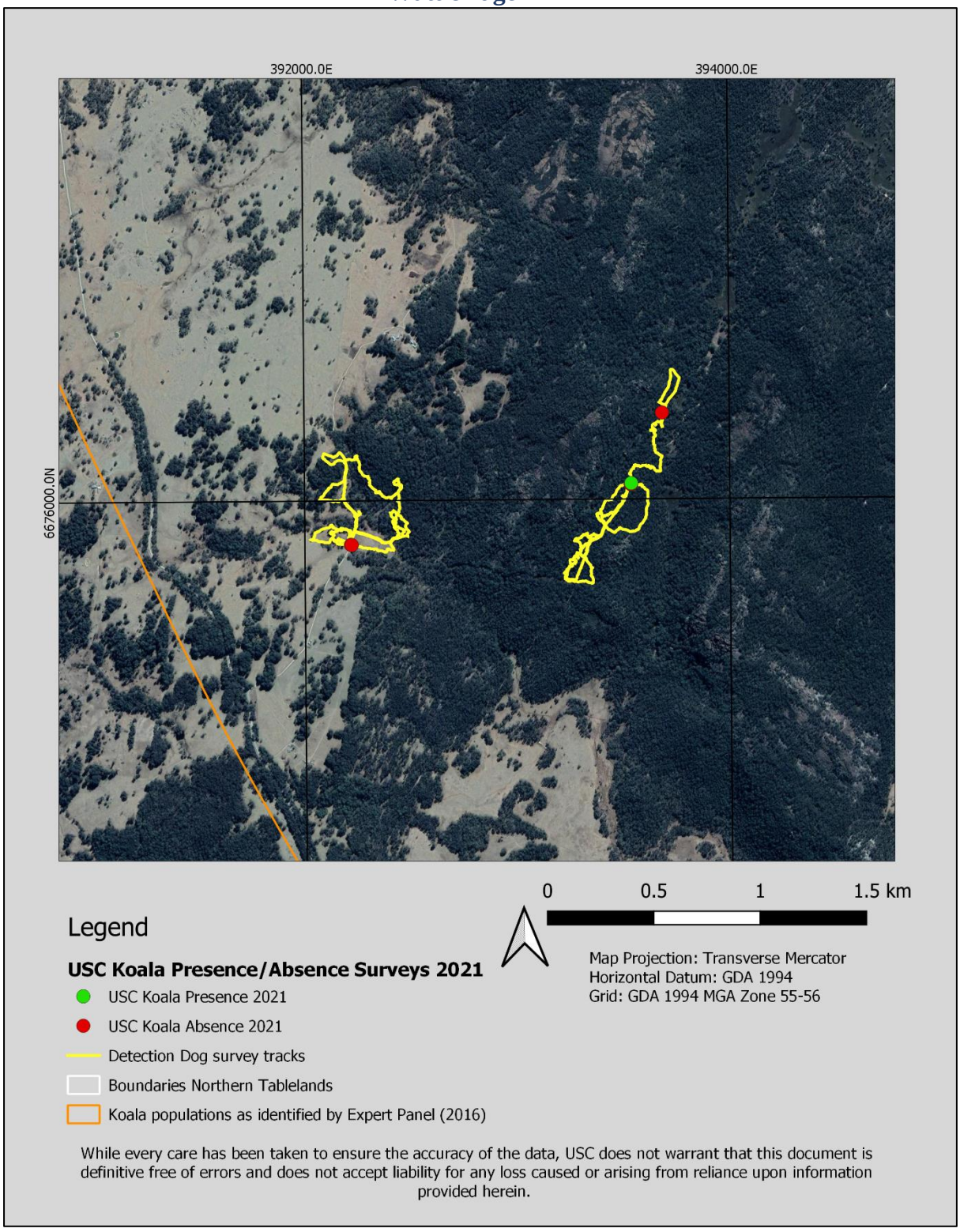
Pinkett Road TSR/Oakwood



Warra National Park

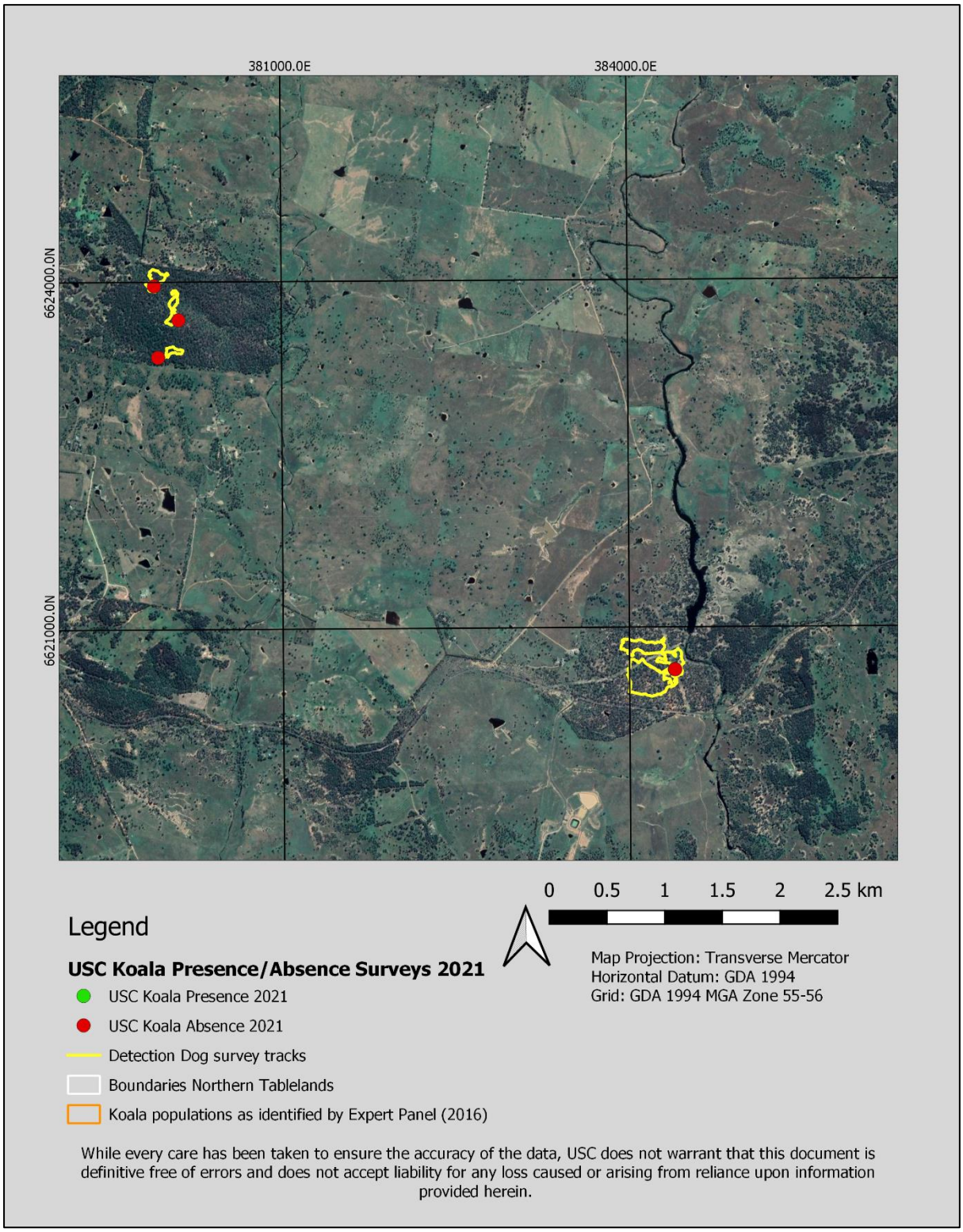


Wattleridge IPA

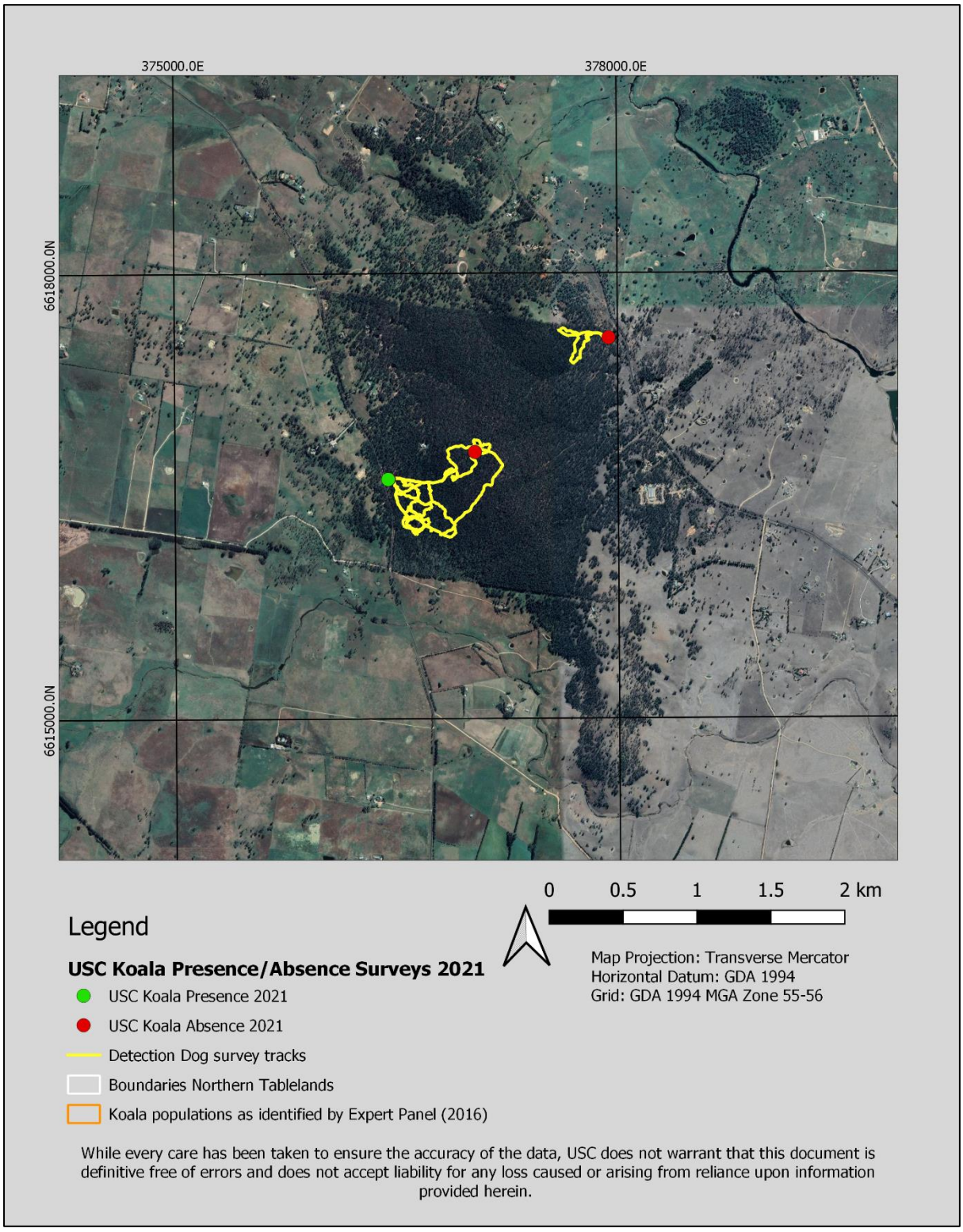


Sunnyside TSR

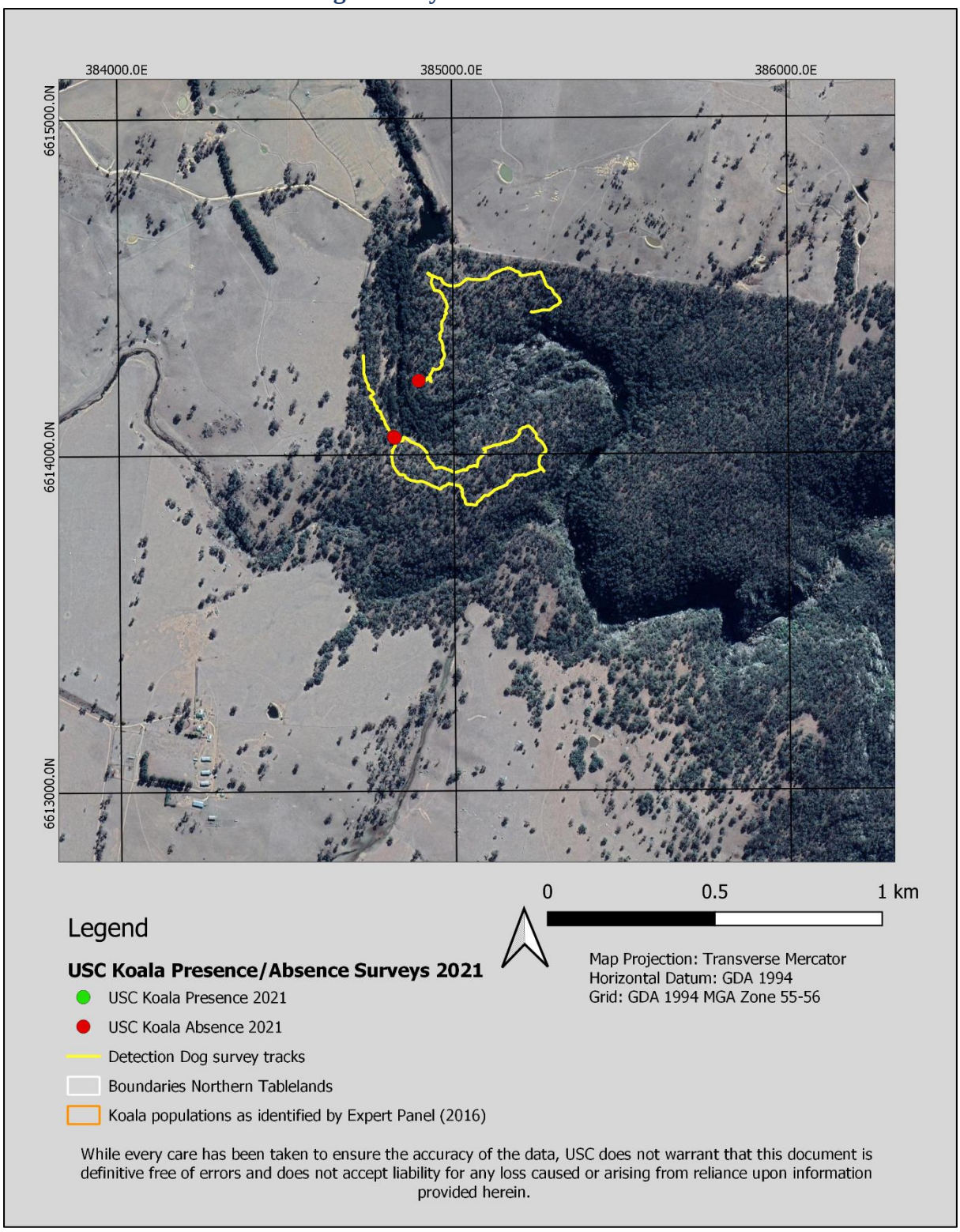
Gara TSR and Yina Nature Reserve



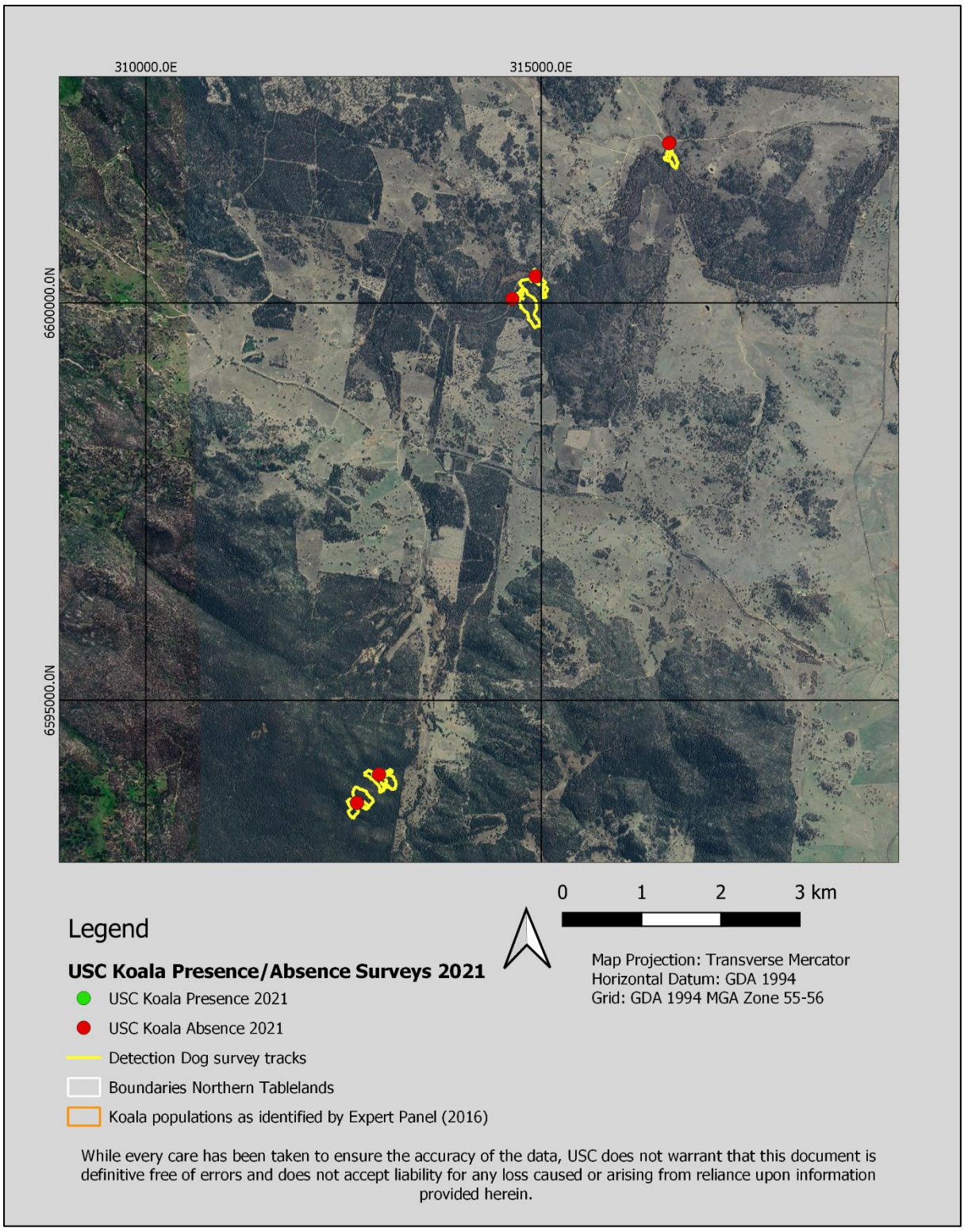
Imbota Nature Reserve



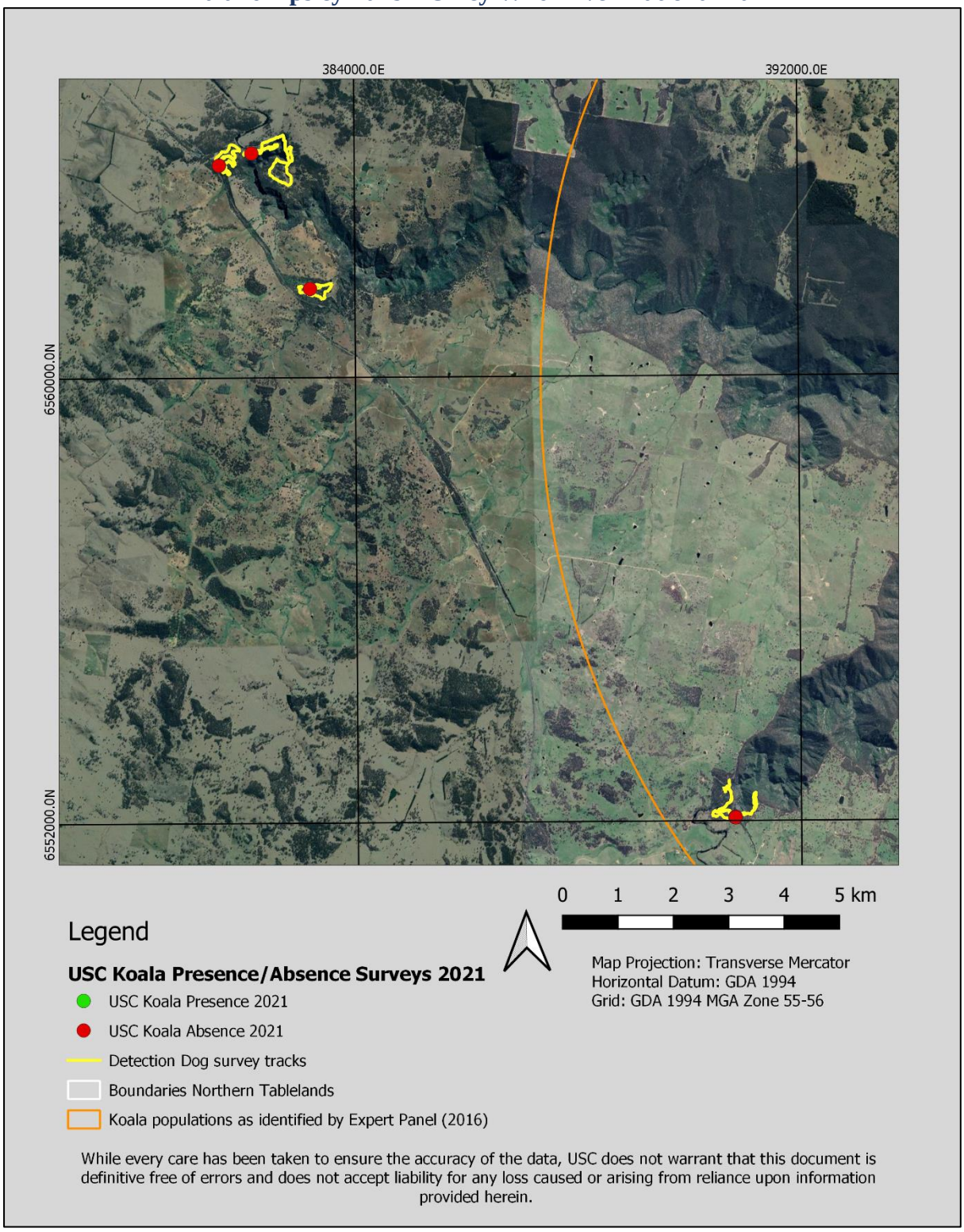
Gara Gorge - Oxley Wild River National Park



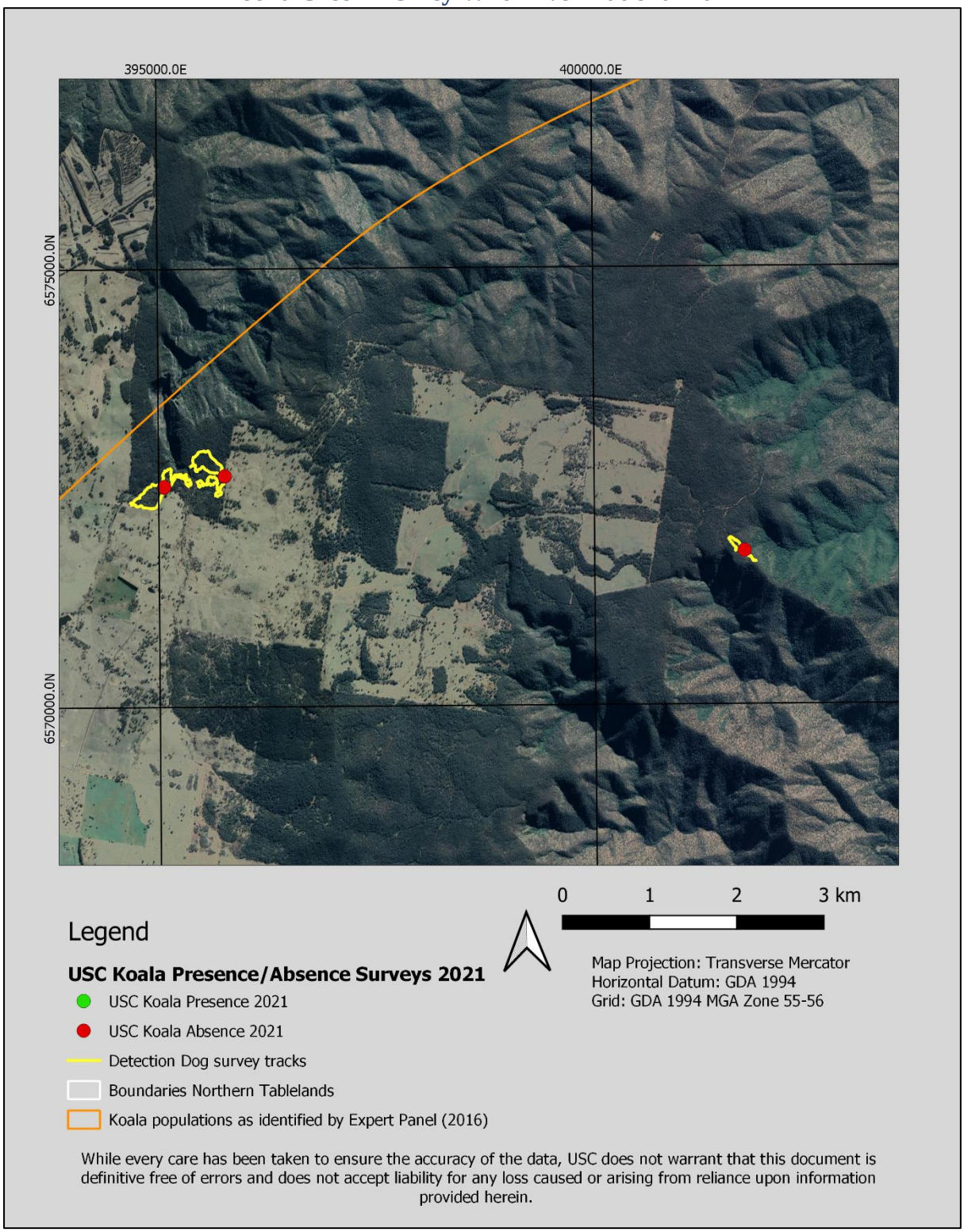
Watson's Creek



Tia and Apsley Falls – Oxley Wild River National Park



Moona Creek – Oxley Wild River National Park



Appendix 4 – Past recommendations directly lifted from previous *Cool Country Koala Project* reports

Management Recommendations from the 2019 "*Cool Country Koalas Project*"

Recommendation 1 - Prioritise habitat preservation and rehabilitation

The *Cool Country Koala Project* survey results show a reduction in koala presence in comparison to historical records (ALA). More generally, koalas have lost large parts of their habitat, especially due to clearing, including illegal clearing due to agriculture (Ward et al. 2019) and the 2019-2020 extensive bushfires (Ward et al. 2020). Official numbers on the impact of the bushfire have not been released, but Government and trusted websites have quoted, for NSW alone: more than 8.4 million hectares have been destroyed including at least 1.3 million hectares of koala habitat burnt, while others quoted as much as 30 per cent of koala habitat, and a fifth of the NSW koala population, have been lost.

This new situation increases the importance of protecting remaining koala habitat as well as continuing efforts in habitat rehabilitation. The *Cool Country Koala Project* confirmed multiple koala hotspots throughout the Northern Tablelands region. Therefore, especially considering the loss of prime koala habitats and populations in the 2019-2020 bushfires across wide ranges of NSW, the importance of the Northern Tablelands region for koalas needs to be re-evaluated.

Large koala habitat rehabilitation programs are currently being developed/delivered, and the Northern Tablelands should be part of these initiatives. For example, WWF's "Towards Two Billion Trees" program, which is very focused on helping private individuals and farmers, plant trees. The NSW Government has announced, in March 2020, $150,000 in funding to a wide range of organisations for koala habitat rehabilitation, including Lismore City Council, Friends of the Koala, Far South Coast Landcare Association, Border Ranges-Richmond Valley Landcare Network and Bangalow Koalas. The Federal Government has announced $50m for wildlife impacted by bushfires. It is recommended that NT LLS, in partnership with other local organisations, approach such rehabilitation programs and secure funding for the region.

Note - The reasons behind the decline of some koala populations in Northern Tablelands are unknown, they may be linked to several factors including climate change. This could be investigated, although the current dataset might not be large enough to identify factors of decline.

Recommendation 2 – Update the mapping of current population distribution

From the *Cool Country Koala Project* as a whole (2016, 2018 and 2019 surveys), new data has become available for current koala distribution in the Northern Tablelands. Some hotspots have been confirmed, while key areas mapped by experts in 2016 are no longer sustaining populations known historically (e.g. Ashford). Potential new koala populations have been underlined, such as south west of Walcha and north of Tenterfield. Some further surveys may be required to confirm hot spots and populations especially in areas that 1080 baiting prevented surveys in the past.

It is critical, post the 2019-2020 bushfires, that the Northern Tablelands koala populations are updated in State mapping, recognised as significant for the preservation of NSW koalas, and attract funding (State and Federal) that has been in the past focusing on more coastal koala populations.

Predictions are of an increase in bushfire extent and intensity, therefore updated koala maps can inform fire-fighting prioritisation and koala rescue (see "Other Considerations" below).

Recommendation 3 - Ongoing monitoring of the regional population through scientific surveys

The *Cool Country Koala Project* surveys have underlined that the distribution of koalas in the Northern Tablelands is patchy. Furthermore, some koala populations in areas with historic records seem to have largely declined, such as was the case in Ashford. This underlines the importance of confirming current regions with koala hotspots, such as Armidale/Uralla and Delungra/Inverell regions. This means that koala priority areas, as underlined in the NT KRS in 2016, that have not yet been surveyed, or where surveys covered a small part of the priority areas, need to be surveyed.

The DDC recommend scientific surveys of priority areas that have not been surveyed yet, in particular the priority area south-east Walcha towards Oxley Wild Rivers National Park and north-east Glenn Innes towards Washpool National Park. Furthermore, it is recommended that surveys are conducted within previously surveyed priority areas that have gaps in the landscape, where no surveys have occurred. This would in particular apply for the north-east of Tenterfield, the area around Severn River near Pindaroi, the area near Mt Mitchell around Warra National Park and the area south-west of Nowendoc. Refer to Figure 19 for reference. With one more year of *Cool Country Koala Project* surveys, all priority areas may be able to be checked.

Recommendation 4 - Ongoing monitoring of the regional population through broad and targeted Citizen Science programs

Longitudinal monitoring of koalas can enhance our understanding of factors affecting the distribution, population trends and specific threats to local koala populations (main threats likely vary between populations). Longitudinal monitoring can be conducted by training members of the public to support koala monitoring. Acknowledging budget constraints, we recommend recruiting the local community to become the guardians of their koalas. Increasing the community awareness of threats to koalas and involving them in active monitoring could improve the detection of emerging hotspots of mortality and disease, which would allow an early intervention in the management of these threats.

In the Northern Tablelands, it is recommended that data collection be promoted through a combination of the following:

- Encourage broadscale reporting to ALA throughout the year: this will continue building the current distribution across the whole of Northern Tablelands

This will be best achieved as a coordinated approach with other Northern Tablelands partners to promote the use of ALA and increase sighting reports. To maintain enthusiasm, this might require continuous communication from NT LLS, with or without external inputs, to increase koala knowledge and the importance of reporting sightings, through flyers and community events.

- Targeted citizen science program in koala hotspots of Armidale/Uralla and Delungra/Inverell regions

Both hotspots occur in areas relatively developed/occupied by humans. This can be both seen as a threat and an opportunity. Events or citizen science programs may include annual phone-in or online surveys encouraging the reporting of sightings at a particular time of the year, such as a "Koala-thon", a specific weekend each year. These could coincide with national events, using the general heightened enthusiasm for koalas and transforming it into action: *Koala Month* is September, while *Wild Koala Day* is 3rd May each year.

Recommendation 5 - Expand genetic sampling of koalas in the Northern Tablelands

The DDC were able to show successful sampling and genotyping of koala scats collected in the Northern Tablelands. Genetic analyses of individuals and populations provide valuable information such as identifying isolated koala populations, risks of inbreeding depression and disease hotspots. Disease mapping of the two hotspots could be conducted from the scats already available from the 2019 genetic surveys.

Increasing the sampling size and the spread of sampling across the Northern Tablelands landscape would contribute to a better understanding of the Northern Tablelands koala population dynamics and inform the development of conservation strategies, including but not limited to:

1) strategic placement of revegetation projects to reinstate genetic connectivity across the landscape,
2) identification of disease hotspots to enhance the delivery of disease treatment/vaccination to minimise decline of local populations,
3) identification of locations with high inbreeding to inform the possibility of genetically rescuing these (introducing new genes) to reduce the risk of inbreeding depression (the rise of health defect from close relatives mating with each other).

5.4 Other considerations

Plan koala management response to bushfire

The 2019-2020 bushfires have highlighted the difficulty in preventing high intensity (crown) fires, especially considering the prevailing conditions of drought and high temperatures – conditions that are worsening with climate change.

Parts of the Northern Tablelands region have not been impacted by the 2019-2020 bushfires (Figure 20), while some parts have been affected at different fire intensity, therefore a review of fire management and risk to koalas from future bushfires is recommended. Understanding where koalas have survived in the fire footprint, and whether these populations are able to deal with the conditions in post fire habitat could help prepare for future fire events. Planning, and setting aside funding, for an emergency response to bushfires affecting koala populations could help koalas to persist in Northern Tablelands into the future.

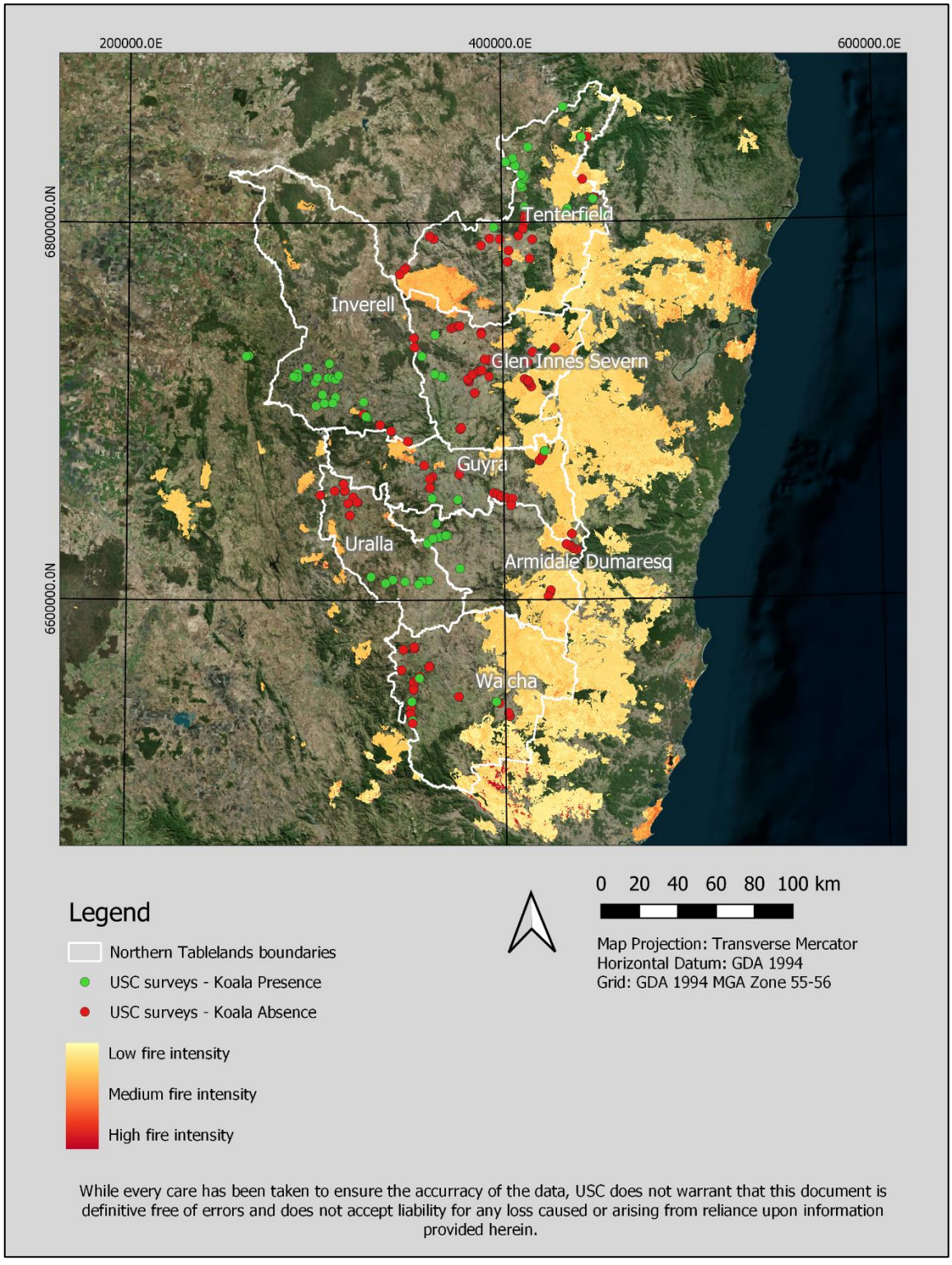


Figure 20: Extent of the 2019 – 2020 fire compared to koala survey sites where koala presence or absence was reported during 2016, 2018, and 2019 NT LLS/USC surveys

For example, during the 2019-2020 bushfires, USC was deployed to locate and rescue koalas through flying drone-mounted thermal camera and deploying detection dogs to:

- locate koalas in burnt areas,
- assess koala health and available habitat,
- rescue koalas when necessary and bring them to veterinarians/wildlife hospitals,
- collected fresh koala scats for health analyses including stress, disease and microbiomes.

A critical part of success in rescue work is to establish a strong network with clear lines of communication, and building trust, before the emergency occurs. In collaboration with welfare and emergency wildlife rescue partners (Ifaw and Vets for Compassion), USC is developing a first responders emergency plan. As part of this plan, further reflections that NT LLS might want to consider, are needed on the following possibilities:

- rescue a percentage of koalas pre fires, and how to 1) work with emergency services to do it safely and 2) determine koala populations to be part of this rescue attempt (for example, if a Northern Tablelands hotspot was predicted to be affected by high intensity fire),
- coordinate with fire fighters to add koalas to the list of assets to be protected during a fire – this has occurred in the past. Of course, human lives and properties were ranked above koalas, however koala populations were also integrated in the fire-fighting planning,
- work closely with state licensing to organise broad-scale permits in advance to access areas as quickly as possible post fires to rescue any survivors,
- what steps to consider in order to prioritise post fire rescue. For example, the following could be undertaken:
    - *prioritise areas of high koala density* to maximise rescue effort benefits in terms of number of koalas, or
    - *prioritise covering a large geographical extent* to protect koalas in several places and allow for recolonisation from multiple populations sources as well as the preservation of more genetic diversity.

Continue to support the koala network on the Northern Tablelands

Because many of the threats to koalas are anthropogenically mediated (i.e., vehicle and dog injury, tree clearing), an educated and empowered community can act to protect koalas. It is recommended that NT LLS continues its efforts to promote threatened species on the Northern Tablelands and to engage landholders to be involved in their protection.

The critical role of wildlife rescuers and koala carers has been publicly recognised during the 2019-2020 bushfires. They are a critical part of the koala network because of their knowledge, their passion and their constant work rescuing, rehabilitating and releasing koalas. In times of bushfires, their already busy schedule might be stretched beyond capacity and they should receive emergency help.

In preparation, NT LLS should develop ways to:

- Communicate effectively: have contact list ready and updated.
- Recognise and support rescuers/carers effort and investment in the wildlife of Northern Tablelands all year round – for example, several Councils in Queensland now offer "carer grants", these enable wildlife rescuers/carers to claim petrol and consumables they buy for the wildlife in their care.
- Have emergency funds for disasters emergency relief or be part of a larger emergency network to gain access to these funds rapidly when they are needed.

Management Recommendations from the 2018 "*Cool Country Koalas Project*"

The surveys conducted by USC in 2018 found that koalas are present in the surveyed regions (Tenterfield/Glen Innes), but in low or medium abundance. Historical records indicate a long-term presence in the region and koalas are dispersed widely throughout the landscape, typically in low density with some localised medium to high density populations (see newly recognised population north of Tenterfield).

The longer-term management of NT koala population should make provisions for local and regional changes in the landscape as a result of land-use practices, anthropogenic threatening

processes and climate change. Habitat loss was identified as the key threat to the persistence of the KMA4 - Northern Tablelands koala population (NSW 2008). As such, the primary management strategy to conserve this population was the restoration of habitat on public and private lands. Undoubtedly there are a suite of other threatening processes impacting on the Northern Tablelands koalas, resulting in the premature mortality of animals, such as wild and domestic dog trauma, vehicle strikes, trauma from livestock, and disease. However, the general paucity of data on which threats rank higher for each priority area koala population makes targeted management uncertain. As such, the impact for population viability of targeting other potential threats are less certain than the restoration and enhancement of habitat in the region.

The 2016 NT LLS reports (USC/Stringybark) contained many recommendations to NT LLS. In this report, USC seeks to add to the 2016 recommendations, and provide management actions that can be potentially more targeted and therefore easier to implement. However, and before any other actions – NT LLS priority should be to work with Local Councils and State Government so that the approach to koala conservation in the NT is coordinated and strategic.

We provide the following recommendations based on the results of this and past research in the region:

Recommendation 1 - Prioritise habitat rehabilitation

Typically, better quality habitat for koalas occurs in lower elevation alluvial soils on the plains that have been historically cleared for agriculture and grazing. This is consistent with the majority of the koala records and populations identified by the expert panel as west of the mountainous regions. There are multiple on-ground actions that can enhance habitat and linkages between populations, and has the dual benefit of enhancing the climate change proofing of the region:

- Trees on farms program

A program to reduce salinity on rural properties in the Gunnedah region (to the south-west) through tree planting was also successful in restoring koala habitat in the area (Lunney et al 2012). Koalas can relatively quickly make use of regrowth vegetation (Cristescu et al. 2013), providing primary habitat and /or linkages between patches of habitat.

- Landcare grants/Nature Assist/Nature Refuge grants to encourage, with financial incentives, the restoration and enhancement of koala habitat on private tenure.

- Local council bushcare groups and other community rehabilitation groups to coordinate the rehabilitation of strategic linkages between townships and rural areas of koala habitat

- Community koala tree program to provide koala food and habitat trees to local residents.

- Community participation such as a propagators group could collect local providence seed and propagate preferred koala food and shelter tree species.

Recommendation 2 - Conserve habitat in Travelling Stock Routes

- Travelling Stock Routes (TSR) provide important remnant habitat and linkages in the landscape, and may often be the only patches of vegetation in areas of significant farming practices. They should be considered as unofficial reserves and managed as such, in isolation to the usual management practices on rural holdings.

Recommended management actions include:

  - weed control of invasive species such as Coolatai Grass and Ox-eye Daisy
  - reduce grazing pressure,
  - reinstall TSR fencing,
  - plant out native species,

- remove rubbish,
- control feral animals such as pigs, goats and deers.

- A review of all TSR survey data available should be conducted, and TSR with high conservation values should be identified. Management plans should be developed to preserve significant species, including koalas, on these high conservation value TSR.

- During this review, NT LLS should also identify well managed TSR to be used as case study for other landholders. This for example could showcase landholders with sound management plans of the TSR that demonstrate grazing and conservation of TSR can both work together.

- If there are information gaps, an additional survey of TSR and how they are treated across NT LLS should be conducted, as our personal observation is that some TSR are appropriated by landholders for private use.

Examples of suggested management recommendations for specific survey sites (sites are mapped in Appendix 2)

- Reduce livestock grazing pressure in over-grazed TSRs, e.g. site 2018-11-07-ba10.
- Reinstall TSR fencing where it has been removed/taken down by neighbouring landholders for grazing purposes, e.g. site 2018-11-16-ba2.
- Consider those TSR sites which are of high conservation value to be managed for conservation, e.g. 2018-11-14-ba1.
- Undertake tree plantings on good condition TSR sites with wildlife corridor potential, e.g. 2018-11-07-ba1.
- Manage understory weeds such as Coolatai Grass and Ox-eye Daisy (*Hyparrhenia hirta* and *Leucanthemum vulgare*) which are an emerging threat to good condition TSRs, e.g. 2018-11-16-ba5.

- Manage feral animals, such as goats, deer, pigs, that overgraze TSRs, e.g. 2018-11-14-ba9.
- Discourage the dumping of rubbish in TSRs, e.g. 2018-11-08-ba1.
- Stop the practice of tree clearing in or adjacent to TSRs of high conservation value, e.g. 2018-11-13-ba1.
- Undertake plantings of TSR sites that are susceptible to eucalyptus dieback, e.g. 2018-11-04-ba5.

Recommendation 3 - Ongoing monitoring of the regional population through targeted and Citizen Science programs

The longitudinal monitoring of the regional population is needed to understand factors affecting the distribution, abundance and viability of the regional population. Data collection can be targeted to understand particular aspects of koala biology or ecology, or more general and passive in nature. Data collected through incidental reporting, while somewhat biased, can provide compelling data on the trends and threats to koalas in the region – this is especially relevant in koala hotspots (Delungra/Armidale) that coincide with human populated areas. Citizen scientists are often a cost-efficient way to gain a greater understanding of the threats to koalas that are reported as sick, injured or orphaned and needing treatment and rehabilitation. It is a pro active monitoring that if the community is engaged can provide real-time monitoring of population status as well as monitor the success of management actions.

- Identification of source populations that are healthy and in relative abundance to ascertain the strategic management of these key populations.

- Gather baseline population data on the Delungra and Armidale populations, currently hotspots of signs of koala activity and likely two of the source populations in the region. Further in-depth investigation of the dynamics and ecology of the Delungra and Armidale populations will allow for a more targeted approach to the management of koalas in these areas.

- Monitoring of 'insurance' or source populations at a frequency to allow the detection of critical population changes and threats that may negatively impact on the viability of the local and regional koala populations

- Ongoing engagement of the community in koala citizen science programs to get the community actively engaged in koala conservation while providing incidental population data that may otherwise not be reported. These may include annual phone-in or online surveys encouraging the reporting of sightings at a particular time, community-based surveys, etc.

- Improve community awareness of threats to koalas and improve detection of emerging hot spots of mortality and disease in local populations for active management of threats.

- Identify appropriate partners to facilitate the collation of data obtained via citizen science programs for dissemination to regulators and local environmental groups to actively manage emerging threats and support strategies to conserve the koala and habitat in the region. For example, the Armidale Regional Council is actively encouraging their constituents to report koalas: "We urge people who have seen a koala to please register the details on Armidale's Koala Sightings Register. The sightings are then transferred to Bionet, the NSW Wildlife Atlas record of threatened wildlife that assists ecologists in researching and monitoring threatened wildlife on a national scale." This could be extended across NT Councils. Armidale Regional Council register is available at the following link:

https://epathway.newengland.nsw.gov.au/ePathway/Production/Web/CustomerService/DynamicPages.aspx?CustomerServiceId=42500&PageIndex=0&js=657262340

Recommendation 4 - Update government mapping to reflect current population distribution

As data become available, regulatory maps need to be updated to reflect changes in population distribution and emerging important populations. This ensures that strategies to restore koala habitat, for example, are based on the most up to date information about key populations and their distribution in the landscape and where habitat and linkages need to be restored and enhanced.

- Amend maps to acknowledge newly identified high density populations (e.g. NW of Tenterfield).

- Review the expert panel assessment of populations based on current survey data.

- Ensure any survey contractor reports raw data to Bionet as per NSW licencing conditions.

Recommendation 5 - Gain support of local and state government to assist in local on-ground management actions

- Promote the NT koala populations so that the NT koalas are "put on the map" and become a priority when State Government in particular releases funding. Due to its geographical position, NT koala populations might be less subject to some threats that are high in other KMA (habitat loss and associated anthropogenic threats on the Eastern coast, climate change to the west of NT). This could mean NT populations could potentially act as insurance population and climate refuge. This requires further research but is important as if this is the case, NT is critical for long-term survival of koalas as a species in NSW.

- Seek grants to promote state and local government involvement in on-ground activities that will engage the community and landholders

Recommendation 6 - Scoping an emergency plan document for hotspot populations

The koala observed in the NT through the 2016 surveys showed no signs of the common koala disease chlamydia. It is less risky and would provide better outcome to monitor population and detect early change of this healthy state. This can be done through citizen scientists (see recommendation 3).

NT LLS might wish to investigate an emergency plan in the event of a chlamydia outbreak. At minimum, if NT LLS is able promote the importance of NT koala population (see recommendation 5), funding in an emergency might be easier to access. The emergency plan should describe cost-effective ways to monitor population hotspots, threshold for management actions as well as which actions should be considered (catching/treating koalas). Research project could also be investigated through partnership with universities and interest groups – for example, whether Drinky Bill water delivery stations can deliver vaccine to wild koala populations in the future.

Recommendation 7 - Spatial analysis as a tool to predict koala current and future landscape use and as a tool to communicate with other stakeholders

Mapping corridors and climate refuge could be investigated, especially as collaboration with other projects or universities.

Recommendation 8 - Continue support the koala network on the Northern Tablelands

Many of the threats to koalas are anthropogenically mediated (i.e., vehicle and dog injury, tree clearing) which also means that an educated and empowered community can act to protect koalas. Therefore, NT LLS effort to promote threatened species on the NT and engage landholders to be involved in their protection is critical and should continue. For example, NT LLS should endeavour to pursue these current efforts:

- promote the visibility of the koalas on the NT through social media engagement, including Northern Tablelands Threatened Species Network Facebook page and You Tube channel,

- capitalise on any koala story to develop media releases in order to keep koalas at the front of people minds,

- deliver workshops and public events, with the aim of being practical and breaking all barriers to foster permanent behaviour changes.

A very engaged and committed part of the public are the wildlife rescuers and koala carers. They are a critical, if often extremely busy and already at capacity, part of the network. NT LLS should develop ways to:

- Communicate effectively (for example, carers often cannot go to workshops as they have responsibilities to their animals in care). Long-term rescuers/carers are often very knowledgeable in the local populations, and the value of this on-the-ground experience should not be underestimated.

- Support rescuers/carers effort and investment in the wildlife of NT – for example, several Councils in Queensland now offer "carer grants", these enable wildlife rescuers/carers to claim petrol and consumables they buy for the wildlife in their care.

Management recommendations from 2016/2017 "*Cool Country Koala project*" -northern section

Summary of Threats to the Survival of the Koala

Threats to koala populations have been well-documented throughout their geographic range and include the following (Obendorf 1983, Martin and Handasyde 1999, Dique et al. 2003, Rhodes et al. 2011, Denner and Young 2013, Burton and Tribe 2016, McAlpine et al. 2017):

- habitat loss, fragmentation and degradation (including dieback, grazing and weed incursion);
- vehicle strike;
- disease;
- predation (including wild and domestic dog attack); and
- extreme weather events (bushfires, droughts, heatwaves).

Although the general threats are known, what is lacking and generally difficult to ascertain is the relative importance of these threats across the landscape.

As discussed in Section 4, some areas of the Northern section of the Northern Tablelands appears to experience relatively high levels of koala activity, particularly in the Inverell/Delungra priority area. In comparison, Ashford priority area experienced very low koala activity and, based on historical records and community engagement, it appears that this area has seen a large decline in koala presence, possibly since 2010. None of the threats measured in this project were able to explain this difference.

This study has found evidence that predators such as domestic and wild dogs occur within the priority areas on the Northern Tablelands, although the threat of dog predation is difficult to quantify in koala populations. This is because the density of dogs does not necessarily represent the level of threat. In a research project in Moreton Bay Railway Link, where 500 koalas were radio-tracked for up to five years, it is thought that one individual was responsible for most of

the mortalities attributed to dog attacks (124 koalas killed, Jon Hanger, personal communication).

Tree dieback and grazing activity were light at the majority of survey sites. It has to be noted that dieback can be spatially limited, and therefore easily missed in the field (Andrew Davidson, personal communication).

Most sites had at least one species of weed, or introduced species, present. However, the impact of these infestations on koalas is unlikely to be significant because the infestations were rarely considered high enough to prevent regrowth. Personal observations from the USC team also seems to indicate that presence of weed does not always prevent koalas using sites (unpublished data).

Although only a small number of individual koalas were observed during the study, none presented external signs of poor health or disease (i.e. *Chlamydiosis*).

Our models of koala presence/absence as a function of threats (grazing frequency, grazing intensity, presence of weeds, dieback and wild dogs), showed that no threat was significantly associated with the absence of koala (all P-values > 0.5).

As such, the general recommendations (see "Recommended Management Actions") of this study are more based on the perceived conservation status and threats to koalas on the Northern Tablelands, which has been inferred from known koala threats, rather than on threatening processes observed/quantified during this project.

The recommendations were developed in conjunction with other similar documents produced for koala conservation in New South Wales, including:

- New South Wales Government 2016. Report of the Independent Review into the Decline of Koala Populations in Key Areas of NSW. NSW Chief Scientist and Engineer. December 2016.
- North West Ecological Services 2016. Gunnedah Koala Conservation Plan for the Landcare and Community Groups, prepared for North West Local Land Services.
- Hawes, W., Hunter, J, Lechner, A. & Ede, A. 2016. Northern Tablelands Koala Recovery Strategy 2015-2025. The Envirofactor Pty Ltd, Inverell.

However, below we give some specific recommendations for the two priority areas surveyed through this project, Inverell/Delungra and Ashford, in addition to the general ones.

Recommended Actions for the Priority Areas of the Northern Tablelands Cool Country Koala Project (Northern Section)

Inverell/Delungra Priority Area

During the *Cool Country Koala Project* (Northern Section), we clearly found the Inverell/Delungra priority area to be a koala hot spot. As a consequence, on-ground actions should be targeted and prioritised in this area where the local population of koalas can be supported and increased immediately.

Recommended actions in the Inverell/Delungra priority area are:

Rehabilitation:

Trees on Farms program and other collaborative initiatives (with Landcare groups for example) should be implemented so that the total amount of available habitat is increased. The Inverell/Delungra priority area is highly fragmented with a low proportion of remnant (i.e. native) PCT remaining (72.5% is cultivated land). Despite this, the area already supports a healthy, breeding koala population. By providing more habitat, we expect that the carrying capacity of the landscape would increase and so would the koala population size.

In addition, the local koala population would benefit from the protection of the remnant habitat.

Engagement:

The community should receive a high level of engagement, such as environmental talks from NT LLS, to increase awareness of the significance of their koala population and promote specific behaviours that strengthen koala conservation efforts.

Particular consideration should be given to the possibility of recruiting a "Koala Champion" in this area to create and support a local Koala Action Group. This group could be in charge of encouraging the community to report koala sightings to the Atlas of Living Australia (ALA),

maintaining a Facebook page where the community could upload pictures, organising tree planting days and generally raising the profile of koalas in the area.

Road signs:

Travellers should be notified that they are entering a special koala hot spot, so they can decrease their speed and increase their level of vigilance. Signs can be as simple as koala zone signs (preferably ones with a koala on the ground, not in a tree, and with a direct action message, see examples Figure A1) or can be an interactive sign with the speed of the driver or with the number of koalas hit in the region for the year (toll).

Figure A1: Example of simple koala signs that show a koala on the ground and have a suggestive message

Disease

Signs of disease, especially *Chlamydiosis*, should be monitored. This can be achieved by:

- being regularly in touch with the wildlife carers in the area, to inquire whether sick animals have been admitted from this area,
- if a Facebook page is created where members of the public upload their sightings, monitor the pictures for clinical signs of the disease,
- scat monitoring (collection of fresh scats by members of the public and analyses for the presence of Chlamydia).

Monitoring of *Chlamydiosis* would permit an early intervention by the NT LLS and other stakeholders to treat/control the disease in case of an outbreak.

Heat wave

If a heat wave occurs in the area, NT LLS should encourage members of the public to provide water bowls for koalas. Koalas have now been proven to drink water when freely available (Sydney University, unpublished data), and this might be increasing their survival when they are suffering heat stress (North West Ecological Services 2016).

Ashford Priority Area

The Ashford priority area, albeit clearly identified as a potentially significant population based on past records, provided very few signs of koala presence during the 2016 survey. However, no threats recorded during the same survey could explain the population crash which, based on interviews with members of the public during the survey, occurred a few years prior. Anecdotal evidence suggests a heat wave could have been involved (Andrew Davidson, personal communication).

As a consequence, the Ashford area would benefit from a follow up survey based on a questionnaire, for example through a letter drop (Note: this could also be part of USC final community talks). The questionnaire needs to be developed with input from researchers/statisticians with knowledge of community surveys (for example, Dan Lunney, Office of Environment and Heritage NSW, could be approached), so that answers provide quantifiable and robust data.

Areas of interest for the questionnaire:

1. Have you seen a koala in Ashford?
2. Can you circle on the map (provided) where your sighting(s) occurred?
3. How long ago did you see your last koala in Ashford?
4. Is there a moment in time where you saw sick or dead koalas in Ashford?

5. Was there any other change in the environment at the time you noticed sick/dead koalas, or when you stopped seeing koalas in Ashford?

The Ashford priority area, because of the very low koala presence, is not an area where rehabilitation and further work promoting "Trees on Farms" program is considered a priority. In addition, the Ashford priority area presents low fragmentation (90.3% is remnant vegetation).

If the reason(s) for the population crash can be elucidated, directly managing the threats, not habitat rehabilitation, would be the highest priority.

Additionally, the Ashford priority area might present an interesting subject for a student project (Honours for example), where the temperature and precipitation records for the area, from the Bureau of Meteorology, could be data-mined for anomalies. This could be compared to the Atlas of Living Australia records and the questionnaire, to determine whether any specific meteorological event coincides with the koala population crash.

Recommended Management Actions

On Ground Actions

A. Curb habitat loss, increase habitat extent and connectivity

A1. Decrease/prevent habitat clearing in key areas for koala conservation (see 5.3.4 Research)

A2. Increase the extent of koala habitat by supporting tree planting campaigns and promoting natural regrowth (and associated benefits for the land in general)

A3. Increase the extent of protected koala habitat through: land acquisition, legislative protection and voluntary protection

A4. Engage with neighbouring Councils/State, environment groups and bushcare and habitat rehabilitation groups on koala corridor projects

B. Identify koala road mortality hotspots

B1. Compile available data from all koala Hospitals on road mortality

B2. Interview wildlife rescue teams (e.g. WIRES, Northern Tablelands Wildlife Carers (NTWC)) and local veterinarians

B3. Map koala mortality based on B1. and B2.

B4. Map koala habitat (a first approximation could be by mapping PCT used by koalas from the present surveys, but consider employing an expert to perform a habitat mapping exercise) and underline where koala habitat is divided by roads

B5. Rank koala mortality risk based on B4., as well as road speed and traffic, which influence koala mortality (Jones et al. 2014). B5. is useful as there might be zones of high risk, i.e. where koala habitat is divided by high traffic roads, but that was not picked up by B3. if koalas incidents went unreported)

B6. Use B3. and B5. to establish where new koala infrastructure might be needed (see examples Figure A2). Koalas have been proven to use underpasses (Dexter et al. 2016) although not rope bridges (Goldingay and Taylor 2017). Koala fencing is often used to guide koalas to the underpass (Koala Conservation Unit 2012)

Figure A2: Koala exclusion fencing and fauna underpass with koala furniture. (Pictures from Koala Conservation Unit 2012)

C. Audit and prioritise work on koala infrastructure

C1. Map all current koala infrastructure in the NT (e.g. koala fencing, underpasses, koala signs)

C2. Assess state of all current koala infrastructure in the NT

C3. Prioritise koala infrastructure repairs from C2. and new infrastructure needs from B6.

D. Control predation

D1. Target wild dog control to key areas for koala conservation (see 5.3.4 Research)

E. Improve fire Planning

E1. Review recommendations for control burns in koala habitat

E2. Plan control burns to decrease risks of wild fire in key areas for koala conservation (see 5.3.4 Research)

F. Support Wildlife Carers

F1. Subsidise carers and rescuers (grants)

F2. Organise workshops for carers and rescuers to disseminate knowledge about rescue/care/treatment of koalas

F3. Support carers and rescuers to attend koala conferences to stay updated with latest rescue and rehabilitation research findings (grants)

Legislation and Regulatory Controls

- Develop/support legislation:
  - to protect koala habitat (i.e. Land Clearing laws)
  - to properly offset cleared habitat
  - to decrease carbon emissions, climate change and increase renewable energies (climate change will negatively impact koalas (Adams-Hosking et al. 2011))
  - to control domestic dogs
- Enforce legislation

Community Engagement

- Foster a community that is: informed, engaged, active on the ground for koala conservation
- Promote responsible dog ownership

Research

Koala distribution

- Extend koala presence/absence field surveys to all priority areas and corridors from the NT KRS
- Model koala habitat
- Ground truth the model
- Map genetic connectivity at the landscape level

Koala health

- Map koala health (diseases) at the landscape level
- Map koala genetics (diversity, inbreeding, effective population size…) at the landscape level

Map key areas for koala conservation

- Use koala habitat, health and genetics to rank populations and establish key areas for koala conservation

Koala threats

- Research how climate change will affect NT, map potential climate refuge and investigate connectivity between current koala populations and climate refuges
- Investigate research opportunities to assess the impact of wild dogs, and wild dog baiting, on koala populations
- Investigate research opportunities to assess which weeds (and at what density) impact negatively on koala populations
- Investigate research opportunities to identify and quantify threats across landscape

Division of Responsibilities

Local Land Services

Loss, modification and fragmentation of habitat

- Organise/promote tree plantings (Trees on Farms program)
- Collaborate with other stakeholders to build a strategic corridor network

Vehicle strike

- Participate (with Councils) in mortality hotspot mapping

Predation by wild or domestic dogs

- Continue implementing 1080 baiting

Intense prescribed burns or wildfires that scorch or burn the tree canopy

- Work with other agencies (especially National Parks) to develop fire regime prescriptions for different plant community types
- Work with other agencies to develop guidelines for implementing control burns in koala habitat

Koala disease

- Support research into koala health mapping

Heat stress through drought and heatwaves/Human-induced climate change

- Support legislation on carbon emission, climate change, renewable energies
- Support research on impact of climate change on koala and mitigation measures

Inadequate support for fauna rehabilitation

- Investigate grant opportunities (with Councils) for wildlife carers/rescuers

Lack of knowledge

Poor understanding of sources of trauma and mortality

- Interview wildlife carers and veterinarians, and mine wildlife Hospital datasets, to quantify disease in koalas coming into care
- Encourage the reporting of dog attacks on koalas

Poor understanding of population distribution and trend

- Facilitate the development of accurate, scientifically-tested koala habitat mapping for the Northern Tablelands
- Monitor koala trends in key areas for koala conservation

Poor understanding of animal movements and use of habitat

- Investigate research opportunities to assess animal movements if this information is required for management
- Extend research into koala Activity Levels (see 4.3 Activity Levels) in different habitats (by including more plant community types for example)

Getting the community engaged in koala conservation

- Distribute educational material to the public about:
    - The importance of koala conservation on private land
    - Rehabilitation programs
    - Koala food and shelter tree species on the Northern Tablelands
    - Reporting koala sightings
    - Reporting sick and injured koalas to wildlife carers
    - Facilitating koala movement across private land and creating "koala-friendly" properties
    - Controlling weeds on private land
    - Options for managing wild dogs on private land
    - Providing watering points for wildlife on private land
    - Opportunities for private conservation initiatives
- Offer expert advice to the public about koala conservation, whenever possible
- Develop and maintain strong relationships between land managers, policymakers, researchers, wildlife carers, veterinarians and other community groups on the Northern Tablelands
- Conduct koala field days to educate and engage the public in koala conservation

In addition:

- Allocate funding to implement these measures

- Monitor and evaluate the effectiveness of these measures

Councils

Loss, modification and fragmentation of habitat

- Modify the planning scheme to require a Koala Plan of Management for development in priority areas where koala scats were located. The KPOM needs to ensure a maintained or improved outcome in terms of extent of koala habitat
- Modify the planning scheme to include assessment of potential barriers to koala movement in the development application process.
- Require koala bridges/overpasses/culverts/ladders to mitigate the impacts of potential barriers
- Implement a policy for replacement/offset of cleared native vegetation for development impacts that do not require a full impact assessment
- Identify Council land that can be regenerated for koalas as a response to developments that do not have space to plant trees
- Protect Council land that has high koala activity from development
- Connect fragmented habitat patches where koala scats were found on Council land (aiming to increase the abundance and diversity of koala food and shelter trees)
- Rehabilitate degraded koala habitat where koala scats were located on Council land (aiming to increase the abundance and diversity of koala food and shelter trees)
- Conduct an audit of existing fencing within each Council area and identify areas where fencing prevents koalas from accessing food trees
- Prepare a tree replacement policy for Council parks and streets that include more koala food and shelter trees
- Manage weeds on Council land to control weeds that threaten regeneration of trees and shrubs, provide a fire hazard or could disable a koala

Vehicle strike

- Identify koala road and rail mortality hotspots on Council land and target these areas for mitigation measures, such as:

  - Exclusion and guiding fences along roadways and railways
  - Koala bridges, culverts and underpasses
  - Koala ladders
  - Speed limit reductions
  - Koala signage (make it bright or flashing, include local koala death toll)
  - Road markings and traffic calmers
  - Improved street lighting
- Audit the state of existing infrastructure on Council roads

Predation by wild or domestic dogs

- Educate the Public about the impact of domestic dogs on koalas
- Modify the planning scheme to apply domestic dogs control limitations/land covenants on land where koala scats were found
- Enforce domestic dog control
- Investigate the usefulness of workshops on koala aversion training for domestic dogs
- Conduct wild dog trapping and/or baiting on Council reserves

Intense prescribed burns or wildfires that scorch or burn the tree canopy

- Manage fire breaks on Council land to prevent the occurrence of uncontrolled fires

Koala disease

- Support research into koala health mapping

Heat stress through drought and heatwaves/Human-induced climate change

- Support legislation on carbon emission, climate change, renewable energies
- Support research on impact of climate change on koala and mitigation measures

Inadequate support for fauna rehabilitation

- Investigate grant opportunities (with State) for wildlife carers/rescuers
- Issue a levy to ratepayers and developers to assist with expenses of koala carers

Lack of knowledge

Poor understanding of sources of trauma and mortality

- Share Council database

- Encourage the reporting dog attacks on koalas

Poor understanding of population distribution and trend

- Facilitate the development of accurate, scientifically-tested koala habitat mapping for the Northern Tablelands

Poor understanding of animal movements and use of habitat

Getting the community engaged in koala conservation

- Create incentives for landholders to engage in private conservation (e.g. grants, subsidies)
- Offer expert advice to the public regarding koala conservation, whenever possible

In addition:

- Allocate funding to implement these measures
- Monitor and evaluate the effectiveness of these measures

State Government

Loss, modification and fragmentation of habitat

- Strengthen legislative and regulatory controls on vegetation clearing
- Require a Koala Plan of Management for development on State and Crown land in areas known to have/had a resident koala population. The KPOM needs to ensure a maintained or improved outcome in terms of extent of koala habitat
- Include assessment of potential barriers to koala movement in the development application process on State and Crown land and require koala bridges/culverts/overpasses to mitigate the impact of potential barriers
- Formulate a tree replacement/offset policy for small development impacts not requiring a full impact assessment on State and Crown land
- Identify State and Crown land that can be regenerated for koalas as a response to developments that do not have space to plant trees
- Protect State and Crown land that has high koala activity from development

- Connect fragmented habitat patches where koala scats were found on State and Crown land (aiming to increase the abundance and diversity of koala food and shelter trees)
- Rehabilitate degraded koala habitat where koala scats were located on State and Crown land (aiming to increase the abundance and diversity of koala food and shelter trees)
- Prepare a tree replacement policy for State roads that include more koala food and shelter trees
- Manage weeds on State and Crown land, to control weeds that threaten regeneration of trees and shrubs, provide a fire hazard or could disable a koala

Vehicle strike

- Identify koala road and rail mortality hotspots on State and Crown land and target these areas for mitigation measures, such as:
    - Exclusion and guiding fences along roadways and railways
    - Koala bridges, culverts and underpasses
    - Koala ladders
    - Speed limit reductions and enforcement of speed limits
    - Koala signage (make it gory, bright or flashing, include local koala death toll)
    - Road markings and traffic calmers
    - Improved street lighting
    - Evaluation of the design of road and rail networks

Predation by wild or domestic dogs

- Conduct wild dog trapping and/or baiting in State forests and reserves

Intense prescribed burns or wildfires that scorch or burn the tree canopy

- Manage fire breaks on State and Crown land to prevent the occurrence of uncontrolled fires
- Include protection of koalas and their habitat in State Bushfire Risk Management Plans
- Investigate the possibility of detecting/catching koalas ahead of prescribed burns
- Investigate the possibility of detecting/catching and treating injured koalas post prescribed burns

Koala disease

- Support research into koala health mapping

Heat stress through drought and heatwaves

- Investigate the possibility of installing water points on State and Crown land

Human-induced climate change

- Strengthen legislative and regulatory controls on decreasing carbon emissions and promoting renewable energies

Inadequate support for fauna rehabilitation

- Develop grants for wildlife carers (with Councils)
- Subsidise petrol for wildlife rescuers

Lack of knowledge

Poor understanding of sources of trauma and mortality

- Make information about koalas coming into care and their treatment publicly available

Poor understanding of population distribution and trend

- Invest in accurate, scientifically-based koala habitat mapping and allocate funds to Councils to contribute to the mapping

Poor understanding of animal movements and use of habitat

- Invest in accurate, scientifically-based koala habitat use mapping
- Investigate the feasibility, and information gained for management, of koala radio-tracking

Getting the community engaged in koala conservation

- Offer expert advice to the public regarding koala conservation, whenever possible
- Create incentives for Councils to support private conservation (e.g. grants, subsidies)

In addition:

- Allocate funding to implement these measures
- Monitor and evaluate the effectiveness of these measures

Private Landholders

Loss, modification and fragmentation of habitat

- Protect existing and potential koala habitat on private land
- Plant koala food/shelter trees to replace trees that are cleared on private land
- Rehabilitate degraded koala habitat where koala scats were located on private land (aiming to increase the abundance and diversity of koala food and shelter trees)
- Encourage natural regrowth (for example, by fencing creeks)
- Engage in private conservation
- Consider barriers to koala movement on private properties and create "koala-friendly" properties
- Examine fencing and identify areas where this prevents koalas from accessing food trees
- Manage weeds on private land to control weeds that threaten regeneration of trees and shrubs, provide a fire hazard or could disable a koala
- Collaborate with neighbouring properties to create strategic koala corridors

Vehicle strike

- Drive responsibly in koala habitat areas and obey all koala speed signs, traffic markings, etc.
- Have wildlife carers phone number stored in mobile phone/vehicle

Predation by wild or domestic dogs

- Restrain domestic dogs
- Support 1080 baiting

Koala disease

- Know koala signs of disease
- Report signs of disease when logging koala sightings to the Living Atlas database
- Contact wildlife carers when diseased koala is identified

Heat stress through drought and heatwaves

- Deploy water bowls for wildlife during drought and heatwaves

- Participate in water stations on farm program

Human-induced climate change

- Support climate change policies

Inadequate support for fauna rehabilitation

- Take injured/diseased koalas to veterinarians or wildlife carers
- Support wildlife carers

Lack of knowledge

Poor understanding of sources of trauma and mortality

- Report koala attacks and deaths to Council, Wildlife carers or NT LLS
- Report diseased koalas to Council, Wildlife carers or NT LLS

Poor understanding of population distribution and trend

- Report koala sightings to the Living Atlas database and take photos of koalas sighted

Poor understanding of animal movements and use of habitat

- Report koala activity in specific tree species (especially feeding)

Getting the community engaged in koala conservation

- Read educational material distributed by NT LLS
- Liaise with other private landholders, policymakers, researchers, wildlife carers, veterinarians, Landcare groups and other community groups
- Participate in koala field days
- Promote koala conservation via social media and through the community

End of report