The koalas, koala habitat and conservation management in the Clarke-Connors Ranges and associated landscapes

A report to the Queensland Department of Transport and Main Roads

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Koala Research CQ

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Contents

1.0 Introduction

The northern and western extent of the koala's range has contracted (Gordon *et al*. 2006, Seabrook *et al*. 2011), and with widespread declines in koala abundance across the central and northern parts of the species' range (McAlpine *et al*. 2015), there is national concern for the fate of the koala (ECRC 2011). Consequently the Commonwealth listed of the koala as *vulnerable* in New South Wales, Australian Capital Territory and Queensland under the *Environment Protection and Biodiversity Conservation Act* 1999 (TSSC 2012). Also, in 2015 the species was listed as vulnerable in Queensland under the *Nature Conservation Act* 1992 (https://www.ehp.qld.gov.au/wildlife/koalas/koala-ecology.html#conservation_status). Despite the range contractions, koalas have persisted, and maintain a widespread, but largely fragmented distribution across Queensland including Central Queensland's hinterland ranges. There have been consistent reports of koalas from these coastal ranges from about Collinsville, south through the Clarke-Connors Ranges, to the Broadsound Range (some 340 km). It is probable that, if these accounts reflect a single population, then the population represents the most extensive regional Queensland koala population. However, apart from a limited investigation by Melzer and Tucker (2011, Attachment 1), there had been no systematic studies of the koalas or their habitat in this extensive region. This lack of regional knowledge has cast uncertainty around the application of suitable conservation measures, and, consequently constrained impact mitigation around landscape management projects, as well as infrastructure, urban and industrial development.

Recently the Federal Department of the Environment and Energy declared the Eton Range Realignment Project on the Peak downs Highway a controlled action under the *Environment Protection and Biodiversity Conservation Act* 1999 due to the potential for significant impacts on koalas or koala habitat. It was agreed that residual impacts, after Queensland Department of Transport and Main Roads (TMR) impact mitigation, would be offset through two years of research relating to koala ecology and conservation management in the hills and ranges around the highway (https://www.tmr.qld.gov.au/Projects/Name/E/Eton-Range-Peak-Downs-Highway/Eton-Range-Realignment-Koala-Research-Project). The TMR funded project has facilitated the first systematic study of the koalas and their habitat.

This report provides an account of that research within a regional setting, and considers the impacts of the Peak Downs Highway within the context of the broader threatening processes that are acting on these hills, ranges and adjacent lowlands. This includes: (1) a broad account of the landscape and associated vegetation, as well as land uses; (2) a discussion of the current knowledge of the koalas and their habitat; and (3) a consideration of the threats acting on both the koalas and the habitat.

2.0 Regional overview

2.1 Location and extent of the study

The Clarke-Connors Range Study was located in eastern Central Queensland (Figure 1). Although detailed investigation was focused around the Peak Downs Highway, between Eton and Nebo with a wider investigation of koala distribution and habitat usage across the Clarke-Connors Ranges proper, the associated coastal hills and ranges around Sarina and St Lawrence were included to provide regional context. Consequently the detailed investigations and broader management considerations extended over approximately 340 km, from just south of Bowen (-22.2155, 149.2380) to about Mt Gardiner (-22.9793, 149.5868) in the Broadsound Range. The broader study covered over 15,640 km^2. Across this area there was considerable variability in the intensity of land usage and, consequently, in the threatening processes acting on koalas and their habitat. The study area was divided into three zones based on dominant land use, key threatening processes, and koala/habitat management constraints (Figure 2). These were:

- the low hills and undulating lands around St Lawrence (Zone 1);
- the coastal hills and plains around Sarina and associated beaches (Zone 2);
- the hills and ranges and adjacent lower slopes (Zone 3).

Detailed investigations were confined to Zone 3. The zones are discussed later (See *Threatening Processes*) in relation to threats and management.

The extensively developed lowlands of the eastern Isaac River basin, the agricultural and urban lands immediately around Mackay and Proserpine, and the offshore islands are not considered as part of this study area.

2.2 Desktop and field studies

Broad geographical information (geology, vegetation cover, land usages, fire history *etc*.) were derived from on line sources accessed over 2018. Individual sources are referenced where appropriate. Information on the koalas and their tree / habitat usage, and koala population estimates for Zone 1 were derived from field studies and modelling undertaken in winter (July to August) 2011 (Melzer and Tucker 2011, Attachment 1). Four TMR-funded projects provided contemporary data on koala ecology and conservation management.

Ellis *et al.* (2018, Attachment 2) collected data from radio-collared koalas and uncollared koalas caught across Zone 3 from August 2016 to August 2018. The data provided insights into koala ranging behaviour around the Nebo to Eton stretch of the Peak Downs Highway, as well as, population distribution, habitat usage and diet, chlamydial infection, general health status, genetic diversity, and group relatedness across Zone 3 of the study area.

Schlagloth (2018, Attachment 3) used koala data collected from September 2014 to August 2017, together with on-line data sourced in 2017/18, and koala habitat modelling data from Melzer and Santamaria (unpublished) to confirm the presence of koala road-kill hotspots on the Nebo to Eton stretch of the Peak Downs Highway.

Melzer and Black (2018, Attachment 4) investigated the association of koala road-kills and sightings with the Nebo to Eton stretch of the Peak Downs Highway and considered the potential for installation of wildlife barrier fencing and the availability of underpasses using existing infrastructure. They used koala data collected from September 2014 to August 2017, and field data on vegetation and landscape collected in May 2018.

Melzer *et al.* (2018, Attachment 5) undertook a snapshot study of wildlife road-kills along the Nebo to Eton stretch of the Peak Downs Highway. The objective was to place the koala road-kill data into the context of the overall impact of road-kills on wildlife generally. This small study also considered the broader benefits that may accrue from the installation of wildlife mitigation devices. Systematic surveys of vertebrate road-kills were undertaken over six days in late summer 2017 and again in late spring 2017.

2.3 Topography, geology and broad vegetation cover.

2.3.1 Topography

The study area includes coastal plains and low hills in the east, rising via an eastern escarpment (steeply in places) to ranges that reach over 800m on the Clarke Range, with a maximum altitude of 1276 m at the summit near Eungella. Altitudes decline towards the north, as well as through the Connors Range to the Broadsound Range (300-400 m) at the southern extent of the study area. In places, on the summit of the ranges, small undulating plateaus occur e.g. Dalrymple Heights – Eungella – Crediton (Willmott 2006). The western limit is defined by the broad trough of the Isaac and Bowen river valleys.

These ranges are dissected by perennial and seasonal streams that form the watershed for five major regional rivers, and a number of minor coastal streams (Figure 3).

The Proserpine, O'Connell and Pioneer rivers flow east.

Broken River rises in the high ranges of the central Clarke Range, then falls around 640 m as it flows north-west to discharge into the Bowen River, bordering the study area. The Bowen River then falls a further 98 m as it flows towards the Burdekin River.

The Connors River mostly rises in the lower altitude Connors Range, and falls just under 60m as it flows south-west to join the Isaac River. This, in turn, flows south to the Fitzroy River. Tributaries arising in the study area include Funnel Creek (with major tributary Denison Creek), Lotus Creek, Whelan Creek, Collaroy Creek, and Murray Creek). One of these, Denison Creek, also rises in the Clarke Range, and falls about 580 m to its junction with Funnel Creek.

South of the Pioneer River, numerous short streams flow east from the escarpment to the adjacent coast.

These rivers and streams dissect the ranges, carving out basins (e.g. Connors River), broad valleys (e.g. Funnel Creek/Denison Creek, Pioneer River) or narrow, steep sided valleys and gorges (e.g. Broken River).

Rainfall is strongly orographic, and patterns reflect topography. Rainfall ranges from about 1600 mm per annum in the areas of highest altitude (Eungella), declining with altitude to the north and the south, as well in the rain shadow to the west (Figure 4).

Figure 1. Location of the study area.

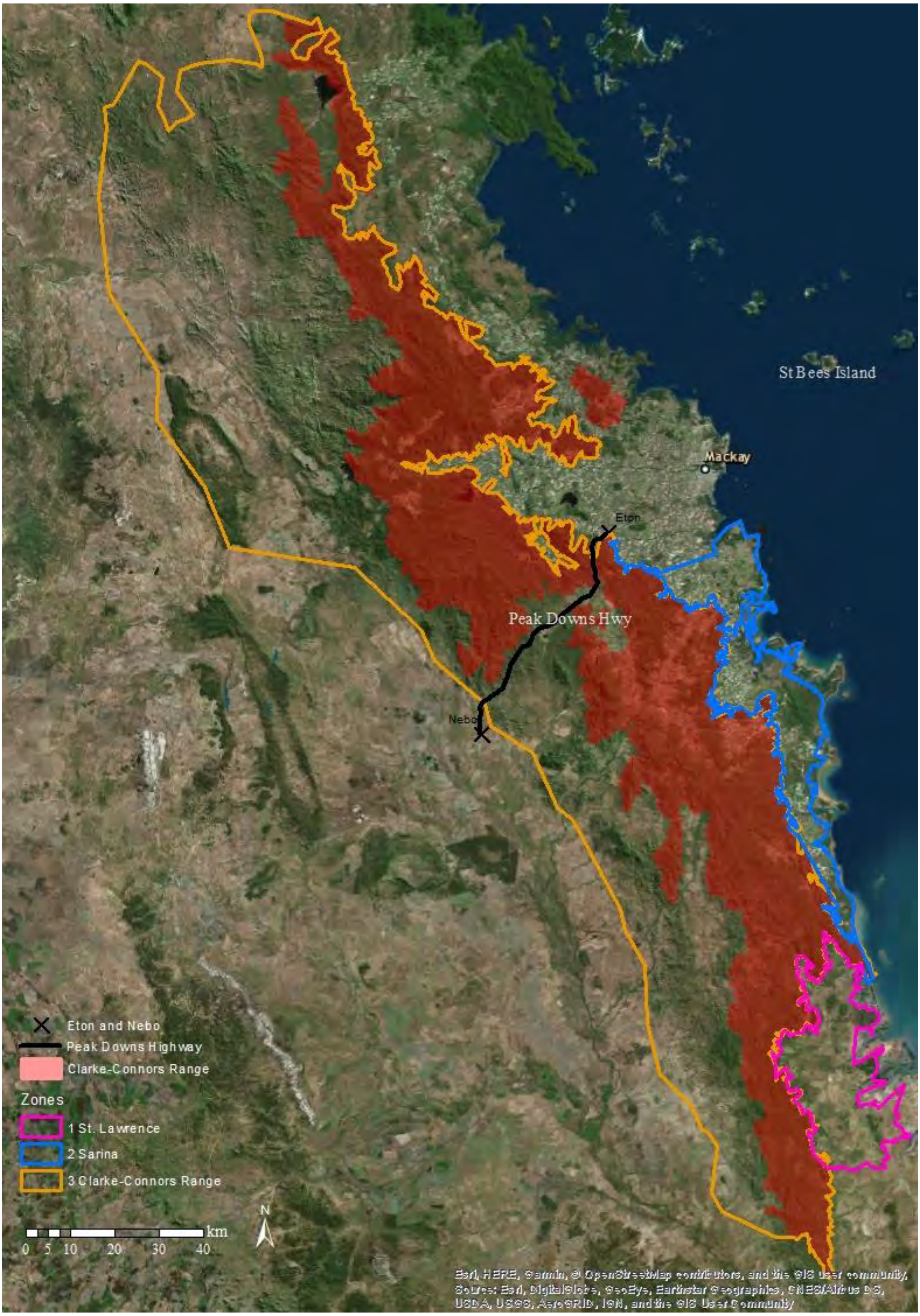

Figure 2. The study area. The area extends approximately 340 km, from just south of Bowen (-22.2155, 149.2380) to about Mt Gardiner (-22.9793, 149.5868) west of Marlborough.

Figure 3. Major drainage systems associated with the Clarke-Connors Ranges Study Area.

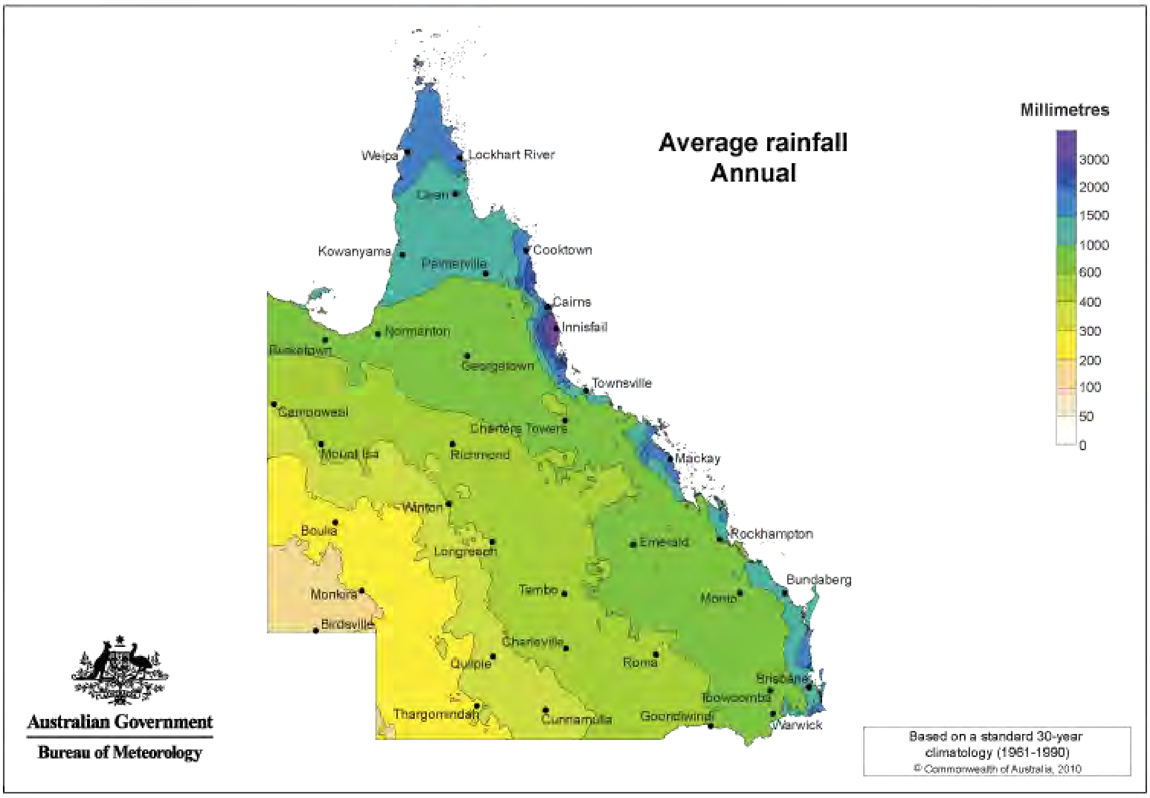

Figure 4. Queensland average annual rainfall. (Bureau of Meteorology, accessed 5/10/2018)

2.3.2 Geology

Much of the study area is dominated by coarse-grained igneous rocks (granitoid rock) especially graodiorite (Figure 5, Appendix 1). This granitic geology, with intrusions of andesite and rhyolite, has resulted in a generally rugged landscape. The greatest extent of granitic rocks in Central Queensland occurs in the Clarke-Connors Ranges. Small areas of sedimentary rock occur in the east, while elements of the Bowen Basin coal beds fall into the western portion of the study area. Soils from the granitic rocks tend to be of low fertility. More fertile soils are derived from a few restricted areas of basalt.

2.3.3 Vegetation

Broad vegetation patterns reflect the regional rainfall gradients (Figure 6, Appendix 2). Wetter forests (notophyll and mesophyll rainforests, tall open wet eucalypt forests) are prominent in the high rainfall regions of the study area (Clarke Range summit and eastern escarpment of the Clarke-Connors Ranges). Eucalypt communities dominate much of the remainder. There is a gradation from moist eucalypt forests to dry, low open woodlands with declining rainfall.

The terrain and geology of these coastal ranges has largely precluded their clearing for agriculture and their development for large-scale resource extraction. In addition, the dominant land uses of the ranges (nature conservation and rangeland cattle grazing) are largely able to occur within the existing countryside without the need for major landscape modification. Consequently, much of the ranges support remnant native vegetation – 79.25% remnant, 20.75% non-remnant (Figure 7). However, the relative proportion of remnant to non-remnant varies across the study area, and is different among the zones. Over 62% of the 107 km^2 Zone 1 is non-remnant, and 52% of the 801 km^2 Zone 2 is non-remnant. In contrast, around 16% of the 14,732 km^2 Zone 3 is non-remnant.

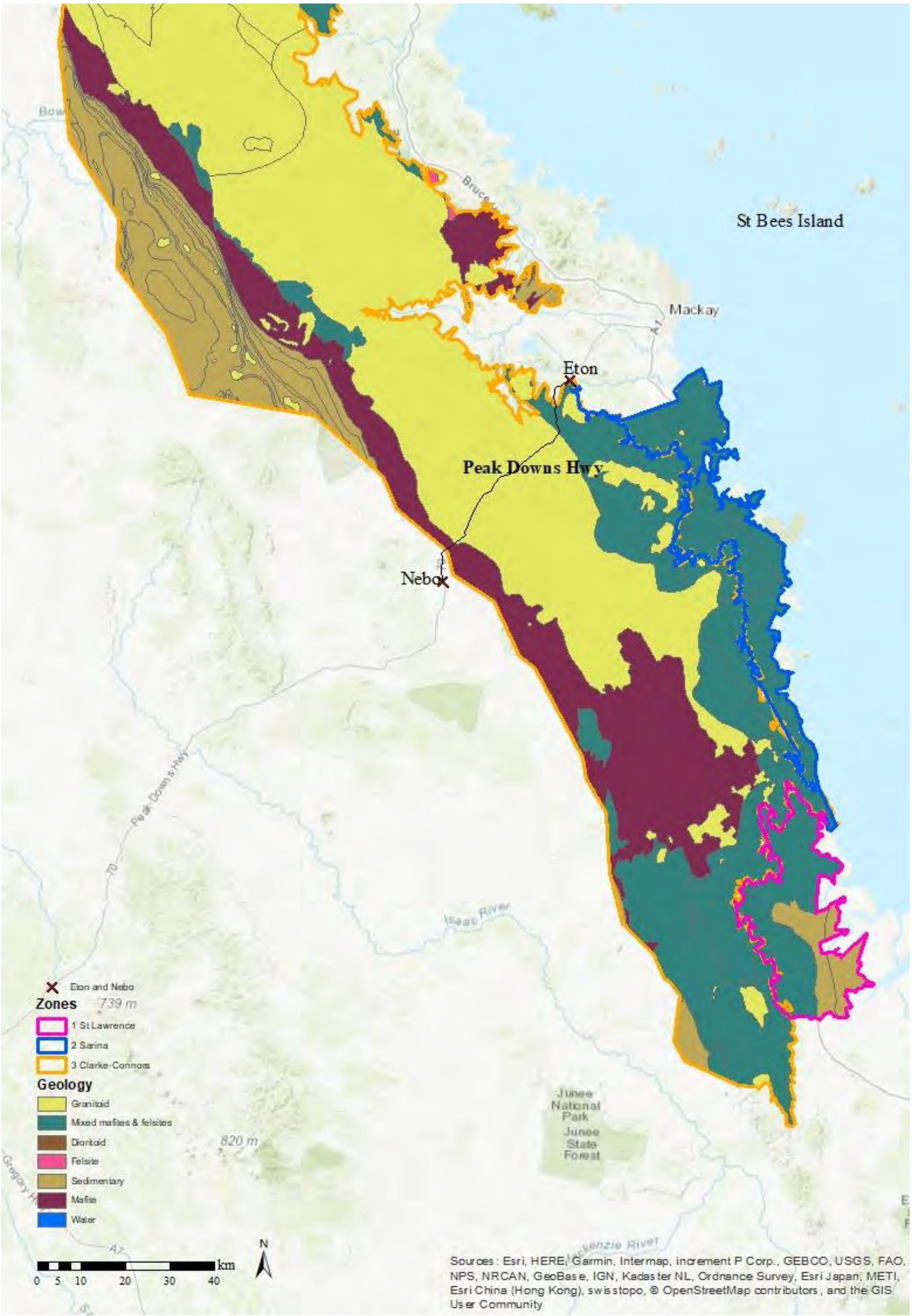

Figure 5. Parent rock type of the Clarke-Connors Range Study Area.

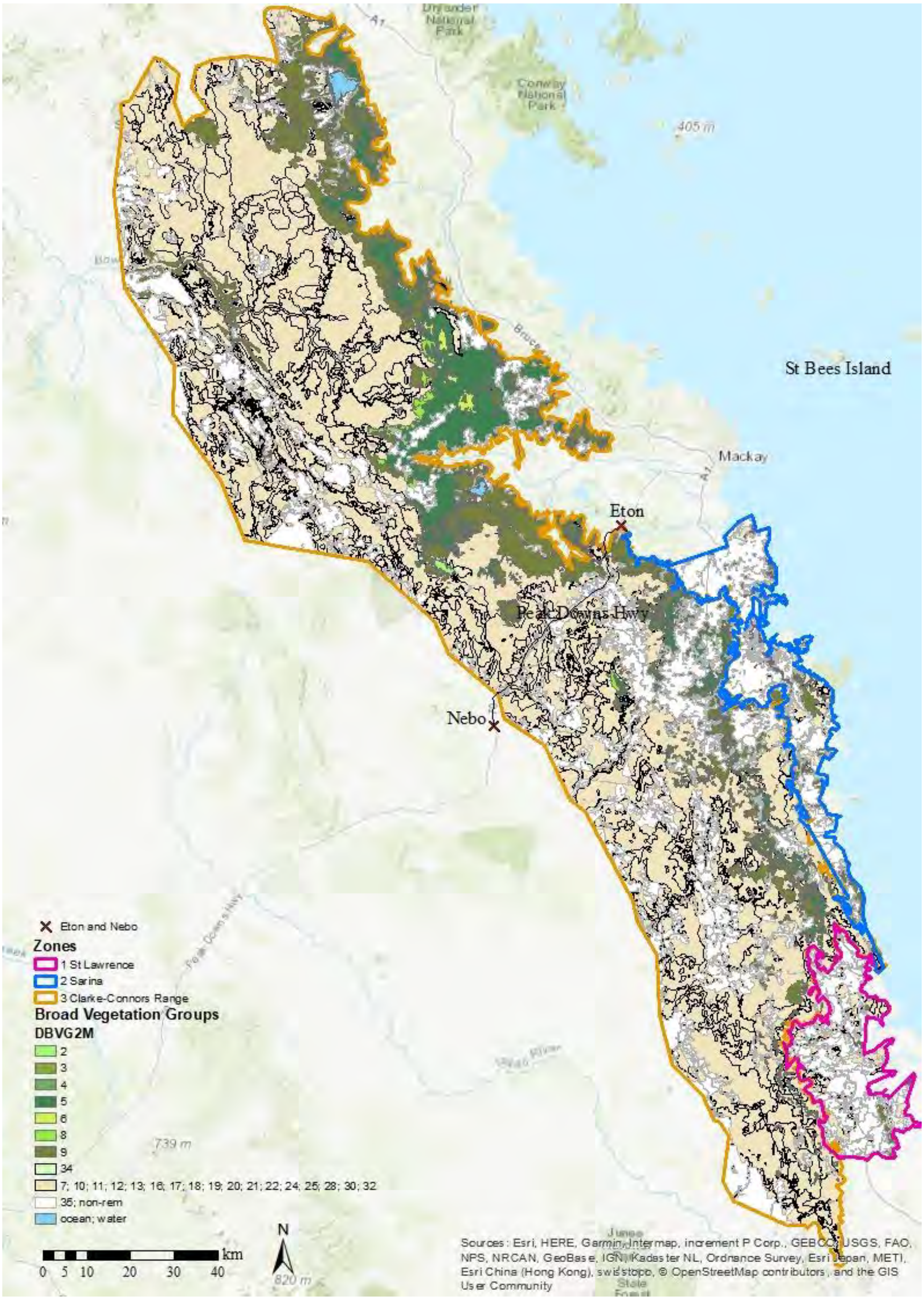

Figure 6. Distribution of wetter and dryer broad vegetation groups across the Clarke-Connors Ranges Study Area. The green spectrum map units are wetter forests, predominantly rainforest and wet eucalypt communities. The light brown units are drier forests, predominantly eucalypt communities. Detailed descriptions of the map units are in Table A2.1 in Appendix 2.

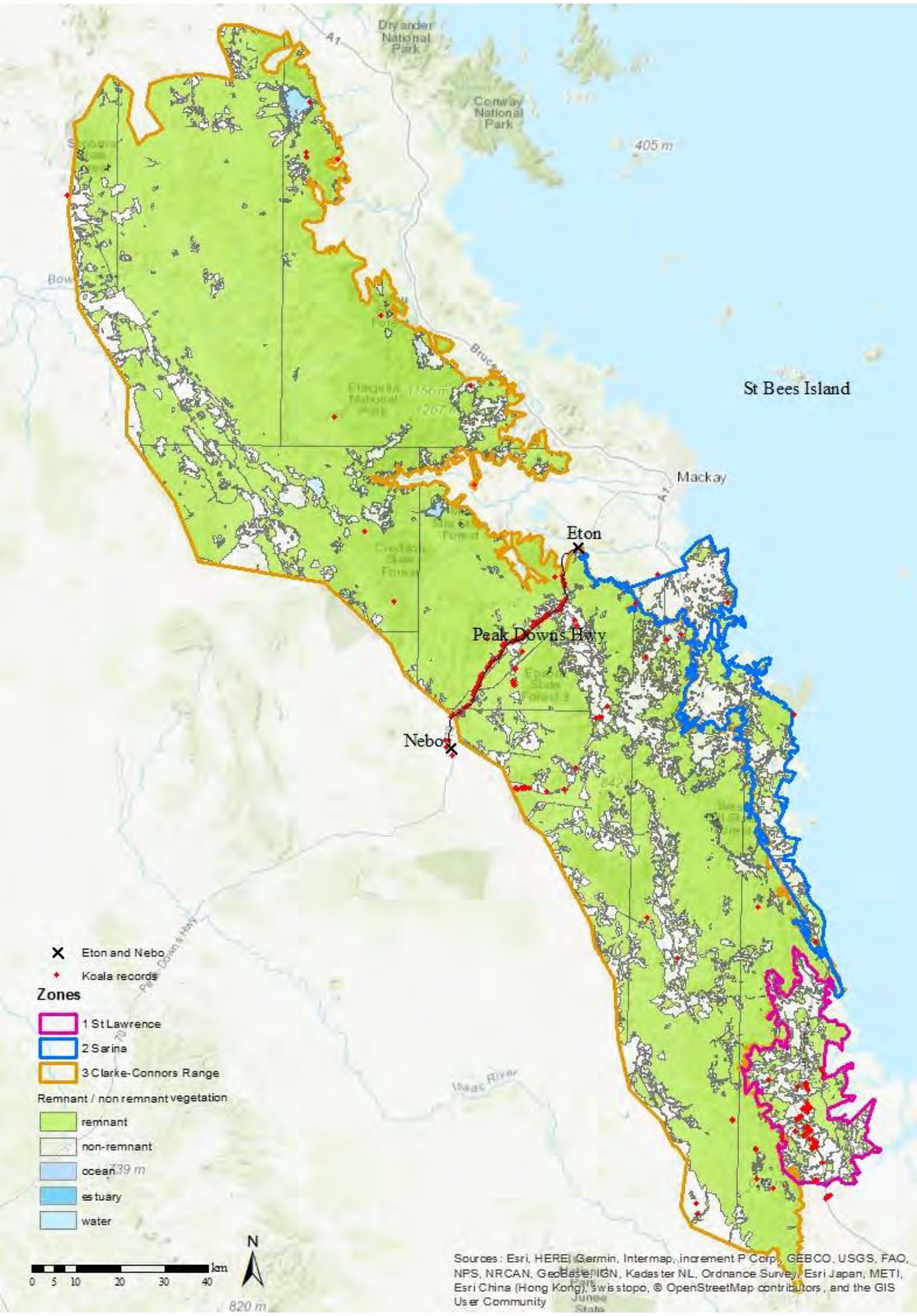

Figure 7. Extent of remnant and non-remnant vegetation within the Clarke-Connors Ranges Study Area.

2.4 Land use

The most extensive land use within the study area is rangeland grazing. Agriculture (horticulture and pasture) and conservation/production forestry are the next two largest land uses. Water storage is also significant, although much less extensive than the rangeland grazing (Figure 8, Figure 9 a). Rangeland grazing and conservation/forestry predominantly occur in the hills and ranges. Agriculture occurs on the coastal plain, river valleys and alluvial flats, as well as on the small undulating plateaus. Urbanisation is predominantly focused on the coastal plain. Linear infrastructure has a small but extensive footprint. The most important being (a) the Bruce Highway and the North Coast Rail Line running north-south along the coastal plain, as well as (b) the Peak Downs Highway and the Goonyella Rail Corridor that traverse the ranges in a roughly east – west direction. There are three major water storages (Eungella, Peter Faust and Teemburra dams) that collectively cover just over 5,000 ha, along with a number of smaller dams.

Land use is not evenly distributed (Figure 9). While rangeland grazing occupies the largest relative area in all three zones, in Zone 2 intensive agriculture and urbanisation are important components. Conservation lands are not represented in Zone 1, and to a lesser extent in Zone 2 than Zone 3. State forests and production forestry are a significant element in Zone 3, and to a lesser extent in Zone 1, but absent from Zone 2. Mining and infrastructure are not significant land uses in any zone on an area basis. However, the extent, orientation and arrangement of the linear infrastructure, relative to the size of the zones is important.

2.5 Koalas of the Clarke-Connors Ranges Study Area – field study results

2.5.1 Distribution

Koalas are widespread across the study area (Figure 10). In general, the distribution of records follow road and rail corridors where access for observers and the number of observers is greatest. This is particularly evident along the Peak Downs Highway where the abundance of records reflects public interest raised by recent highway upgrades and koala awareness programs from TMR and the community.

Generally, the koalas are most often seen in the drier woodlands or open forests (Melzer unpublished; Melzer and Tucker 2011, Attachment 1; Ellis *et al*. 2018, Attachment 2), mostly on the western aspect of the ranges, although populations also extend to the coast around St Lawrence and Clairview, as well as Sarina. In the latter case, however, the populations are increasingly fragmented as coastal development expands. The Clarke-Connors koala population has been little studied apart from some audits near St Lawrence (Melzer and Tucker 2011, Attachment 1), and ecological and distributional studies focused on the Peak Downs Highway (Ellis *et al*. 2018 Attachment 2).

2.5.2 Habitat

Koala habitat has been mapped over a portion of the study area. Melzer (unpublished) classified remnant regional ecosystems in terms of their predicted value as koala habitat. The classification was based on published accounts of koala diets and tree usage in Queensland (e.g. Melzer *et al*. 2014), together with local expert knowledge derived from over 20 years of experience with regional koala populations. This expert-driven model provides a *regionally specific* indication of the likely distribution of important koala habitat across the study area (Figure 11). Highest-ranking habitat encompasses regional ecosystems where: (a) important koala food species were important components of the plant community, and where (b) they were associated with more fertile, better-watered landscape elements.

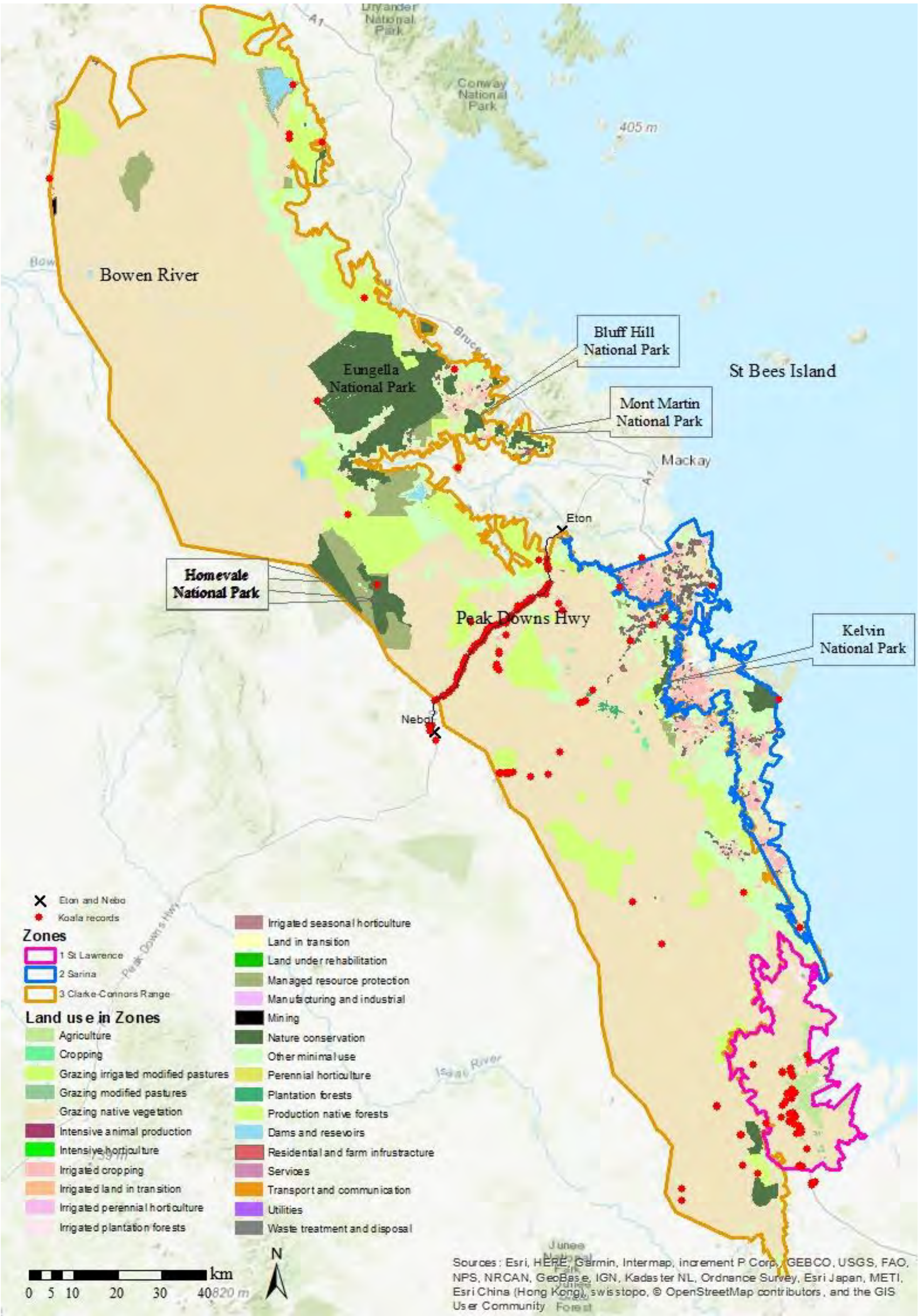

Figure 8. Land use patterns in the Clarke-Connors Ranges Study Area.

(from: Australian Land Use and Management Classification, Queensland Department of Natural Resources, Mines and Energy 2018)

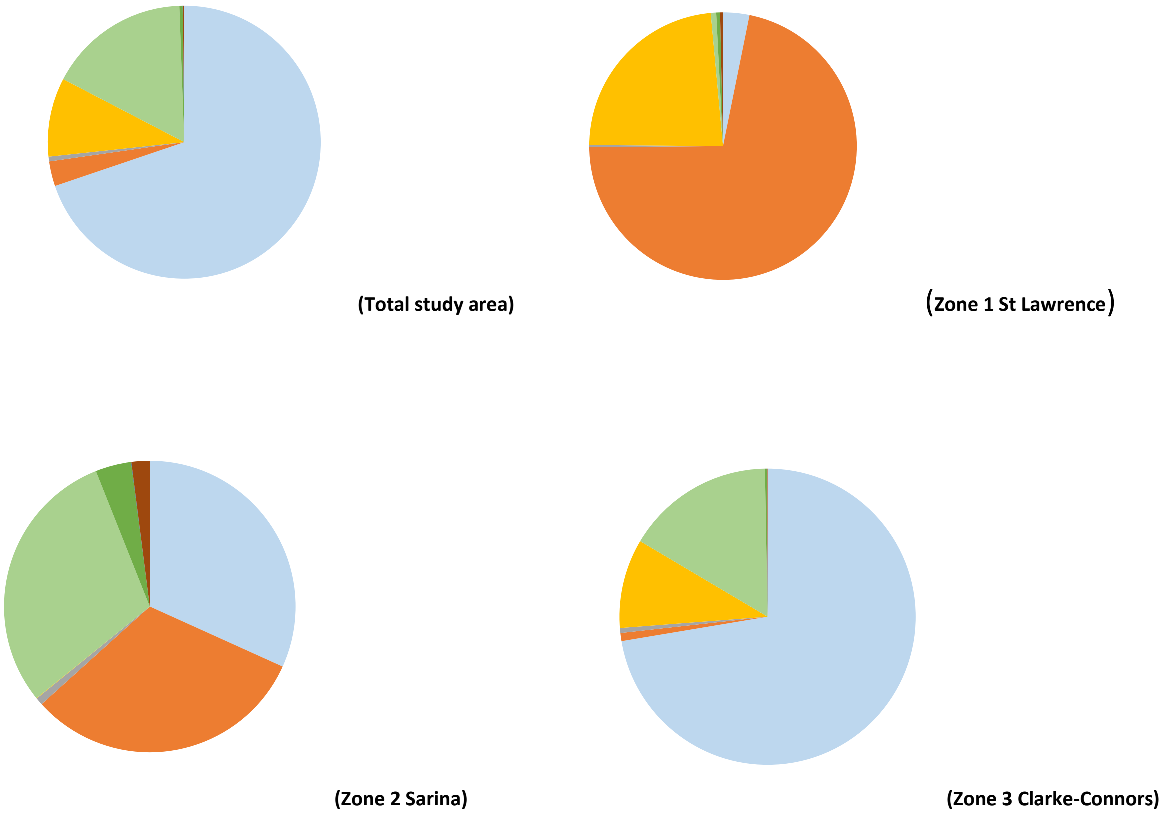

Figure 9. Relative land use (% area) in the Clarke-Connors Ranges Study Area.

Rangeland grazing | Agriculture | Water storage | Forestry
Conservation | Residential | Mining | Other

Schlagloth (2018, Attachment 3) and Melzer and Black (2018, Attachment 4) looked for associations between koala sightings and plant community/landscape features around the Peak Downs Highway between Nebo and Eton. Both studies confirmed that the occurrence of koala-vehicle interactions was unevenly distributed along the highway. Schlagloth (2018, Attachment 3) associated the likelihood of koala-vehicle interactions with regional ecosystems containing *Eucalyptus tereticornis*, *E. drepanophylla*, and *E. platyphylla* – all important food species regionally. Conversely, he found that the likelihood of fewer koala-vehicle interactions was associated with regional ecosystems that contained few, and sparsely distributed koala food species.

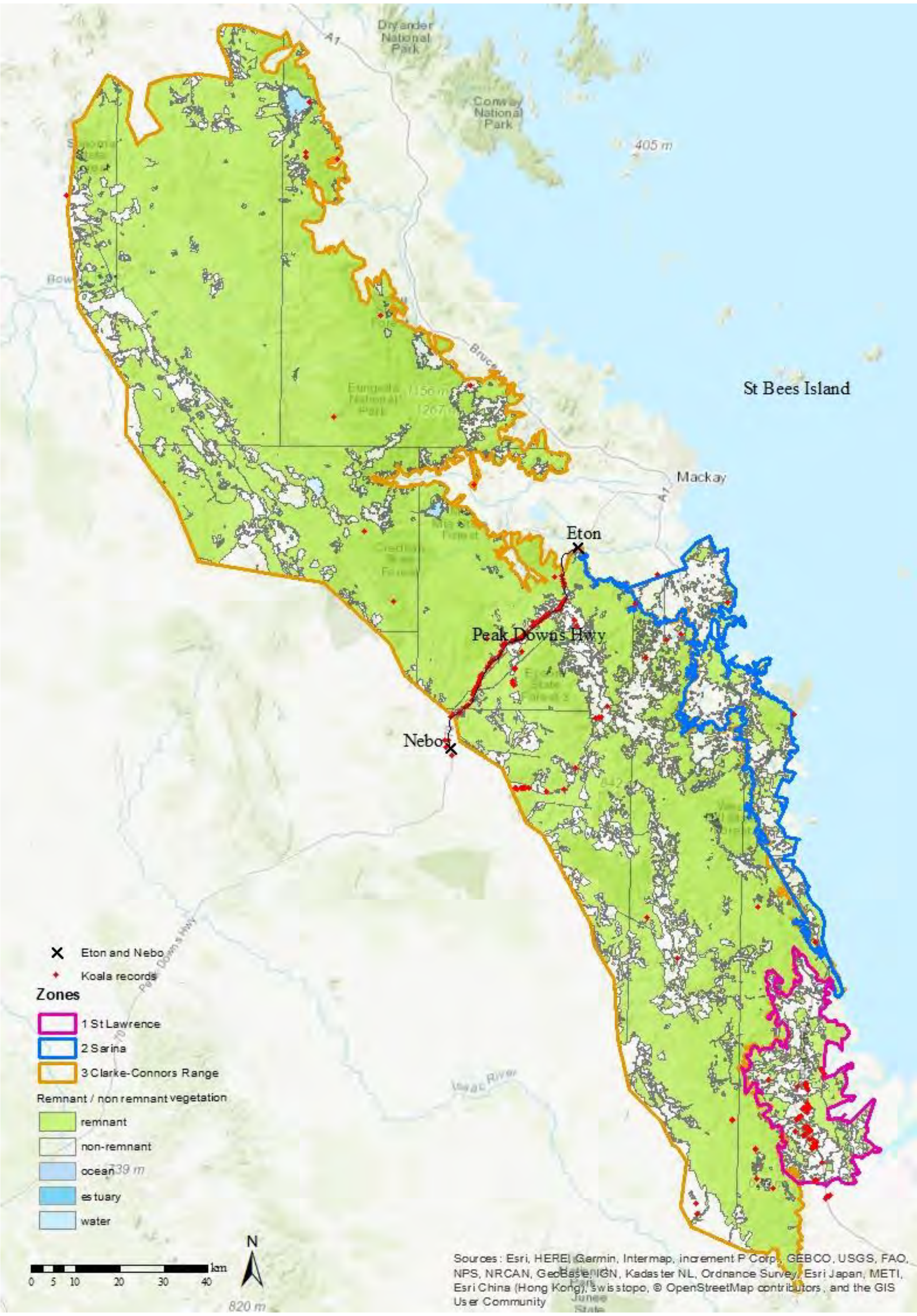

Figure 10. Koala records within the Clarke-Connors Ranges Study Area. Data from 2014 to 2018.Records represent road and rail kills, as well as field sightings. Distribution of records predominantly follow road and rail corridors where access facilitates observation.

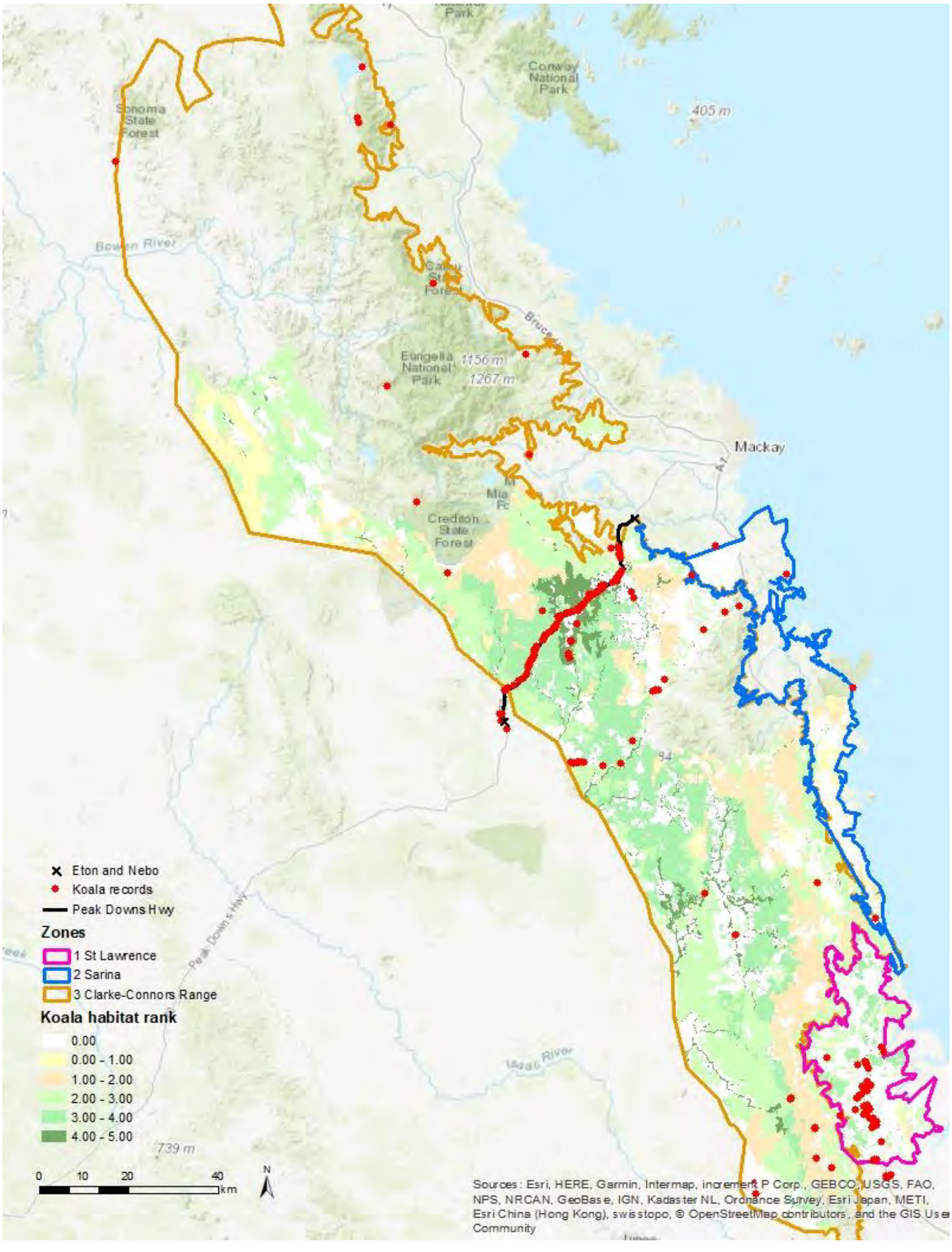

Figure 11. Model of koala habitat importance in the Clarke-Connors Ranges Study Area. High value koala habitat is ranked 3 to 5. The increasing green palette reflects predicted increasing importance as koala habitat. (Mapping is incomplete in the northern portion of Zone 3 and in and around Zone 2).

Melzer and Black (2018, Attachment 4) associated koala records along the Peak Downs Highway with:

(1) streams and associated alluvia where the dominant vegetation included *E. tereticornis* and *E. platyphylla*;

(2) ridges supporting *E. drepanophylla* open forest/woodland, where the ridge immediately abutted streams or alluvia; as well as

(3) mid-lower slopes dominated by *E. drepanophylla*, where the slopes were dissected by minor drainage lines fringed by *E. tereticornis* +/- *E. platyphylla* on banks or adjacent minor alluvia.

Conversely, koala sightings were absent from *E. drepanophylla* open forest/woodland on the upper slope or crest of ridges and on hills.

Melzer and Tucker (2011, Attachment 1) focused on habitat-based sighting of koalas, rather than road interactions. They systematically surveyed the forest and woodlands around the Bruce Highway from about the junction of the Bruce Highway and the St Lawrence Connection Road (-22.3721, 149.4693) south to Granite Creek (-22.612, 149.5387) locating 55 koalas, and noting the tree species and the plant community they were located in. They found that, in these coastal low hills and undulating plains, koalas were associated with alluvial and gently undulating plains with associated low hills and rises supporting woodlands with *Eucalyptus crebra*, *E. platyphylla*, and *E. exserta*, as well as *E. tereticornis* in places.

From radio-collared animals, Ellis *et al.* (2018, Attachment 2) obtained 98 diurnal and 36 nocturnal observations of tree usage in eucalypt open forests and woodlands with *E. drepanophylla*, and or *E. crebra*, *E. tereticornis* and, to a lesser extent, *E. populnea*.

Collectively, the reports indicate that eucalypt forests and woodlands associated with the lower, better-watered parts of the landscape, supporting plant communities with important koala food species, are the main koala habitat in the study area. Importantly, Melzer and Tucker (2011, Attachment 1; Table 2) and Melzer and Black (2018, Attachment 4; Table 1 - Hamdenvale cluster) also associated koala records with non-remnant wooded landscapes where koala food species were prominent.

2.5.3 Population

There has been only one estimate of population density size in this region (Melzer and Tucker 2011, Attachment 1). They undertook a systematic survey of woodland near the St Lawrence stretch of the Bruce Highway (Zone 1, Figure 10; Melzer and Tucker 2011, Attachment 1; Figure 3). An estimated density of 0.12 koalas/ha (12.1 koalas /km^2) was derived from records of 55 koalas over 64 km of linear searching. The estimate was calculated using a *Density-from-Distance* approach (Buckland e*t al.* 2015). This density was then applied to the mapped area of suitable koala habitat in the local region, giving a population estimate of 1,440 koalas around the St Lawrence stretch of the Bruce Highway. This estimate falls within the range of published population densities in mainland central Queensland (0.01 to 2.5 koalas/ ha, Melzer and Houston 2001). Estimates of the mean population of koalas in the northern Brigalow Belt North and the Central Mackay Coast bioregions (Queensland Government 2018) are just over 15, 000 and about 8,800 animals respectively (Adams-Hoskings *et al*. 2016).

Recent field inspections of properties near Nebo (Melzer pers. obs.) returned a moderate number of koala sightings, suggesting that the regional population there will also be quite high. However, systematic assessment over the majority of the study area is lacking. Given the extensive area of potential koala habitat, and the extent of koala sightings within the study area, it is likely that a significant proportion of the region’s expected population occurs within the greater Clarke-Connors Ranges.

2.5.4 The koalas

Size

The koalas captured by Ellis *et al.* (2018, Attachment 2) were typical Queensland koalas. Mature males weighed between 9.3 and 5.5 kg (N=11, X=7.4, sd=1.4). Mature females weighed between 4 and 7.1 kg (N=16, X=5.7, sd=0.9). This generally falls within the reported mass of Queensland koalas, although the males may be slightly heavier than the statewide estimates (males 4.2-9.1, X=6.5, females 4.1 – 7.3 X=5.1; Van Dyck and Strahan 2008).

Sex ratio

There was an apparent female bias in the sex ratio of mature animals (percentage males to females: 40.7:59.3). This is usual and reflects the larger male range areas than female koala range areas (Melzer and Houston 2001), and the territorial behaviour of mature mainland males that result in lower densities of males in the landscape.

Body score and health

Twenty seven mature, sub-adult and juvenile koalas were caught from August 2016 to August 2018 by Ellis *et al*. (2018, Attachment 2) and given a health assessment. This included the collection of swabs for chlamydial infection testing (polymerase chain reaction PCR Jackson *et al*. 1999; Devereaux *et al*. 2003), physical examination for symptoms of poor health and the overt manifestation of chlamydial infection (keratoconjunctivitis, urinogenital cyctitis), and also an assessment of body condition using a koala body condition index (Ellis and Carrick 1992). This index uses the amount of muscle around the scapula as an indicator of koala health. The index is scored from 1 to 10, with 10 being excellent muscle or fat condition and below 5 being very poor condition. Overall the sample population was in good condition with no animals scoring 5 or below (adult males 6 – 9, X=7.1, SD=0.98, N-11; adult females 5.5-8, X=7.1, SD=0.76; N=16; juvenile and sub-adult 7-10, X=8.6, SD=0.9, N=8). Only one animal showed overt sign of possible chlamydial infection with some minor urino-genital staining. This was the only animal to test positive for *Chlamydia* in a PCR test.

Reproductive rate

Of the 17 females caught by *Ellis et al*. (2018, Attachment 2), almost 50% (8 animals) had dependent young. Although this will be an underestimate of the true reproductive rate due to seasonality factors, the indication is that there is no impediment to reproduction.

2.5.5 Habitat and tree use

Ellis *et al*. (2018, Attachment 2) were able to fit radio-collars to 10 koalas. These koalas were tracked between August 2016 and May 2017, providing data on ranging behaviour and tree usage. Both male and female koalas undertook relatively long distance movements, at times through steep and rough terrain. Of the animals that could be located, movement distances of up to 10km were recorded. Four female koalas did not exhibit this long distance ranging behaviour, allowing home range areas to be estimated (1.5, 3.1, 5.8 and 113 ha). These are comparable to ranging areas for female koalas in south east Queensland, but smaller than those for Springsure in central Queensland (Melzer and Houston 2001) – possibly reflecting differences in the methods for calculating the area applied in each study. This long distance ranging over rugged landscapes is not unusual. It has also been recorded from koalas in the Minerva Hills, Springsure (at least 20 km, Melzer 1995), and on St Bees Island, Mackay coast (Ellis, Tucker, Melzer pers. obs.).

Melzer and Tucker (2011, Attachment 1) undertook diurnal observations during their survey of koalas in Zone 1. Fifty-five koalas were located in six tree species, most frequently (about 91%) in *E. crebra* and *E. exserta* (Figure 12). However, koalas used different trees by day and by night (Melzer *et al.* 2011). Day trees most likely provide shade, as well as protection from predation. Night tree usage was associated with feeding (Pfeiffer *et al*. 2005) and, presumably, social engagement (Melzer *et al*. 2014).

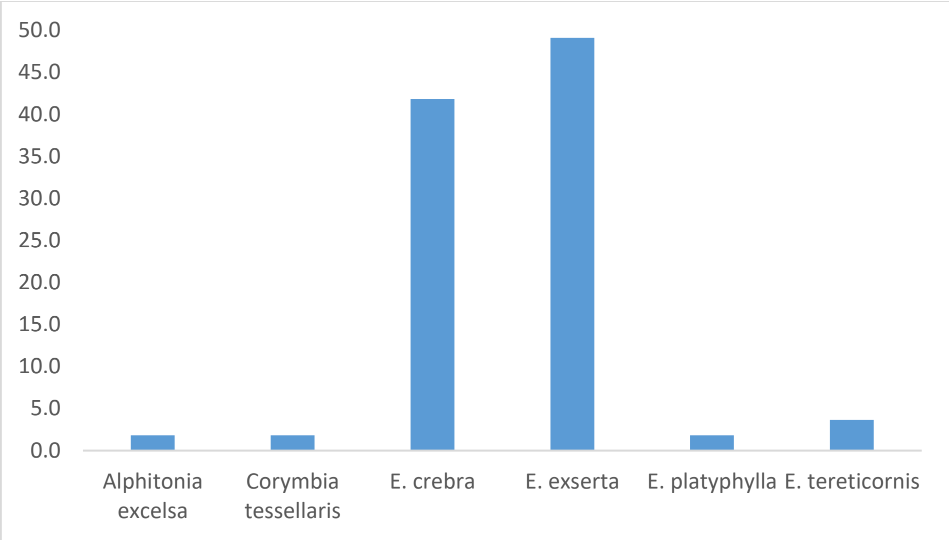

Figure 12. Relative frequency (%) of diurnal tree use among koalas around St Lawrence, Zone 1, Clarke-Connors Study Area. (**N=55, data collected winter 2011, from Melzer and Tucker 2011**)

Ellis *et al.* (2018, Attachment 2) made observations by day and by night to account for these differences (Figure 13). They caught and fitted radio-collars to 10 koalas. Tracking the collar signal allowed them to locate the animals, and identify what tree that animal was using. During the day, koalas were observed in *E. crebra or E. drepanophylla* on 36% of observations, and *E. tereticornis* on 33% of observations. Other species made up the balance of observations, with *Corymbia* species the highest representation of these at almost 8%. By night observations indicated a clear preference for *E. tereticornis* (75%), with *E. crebra or E. drepanophylla* (25%) being the only other species with significant representation. As a result of this preference for *E. tereticornis* at night, the overall proportional use of *E. tereticornis* and *E. crebra or E. drepanophylla* was relatively similar (41 and 33% respectively) with koalas spending some 25% of their time in a range of other species including *Corymbia* and *Acacia* species.

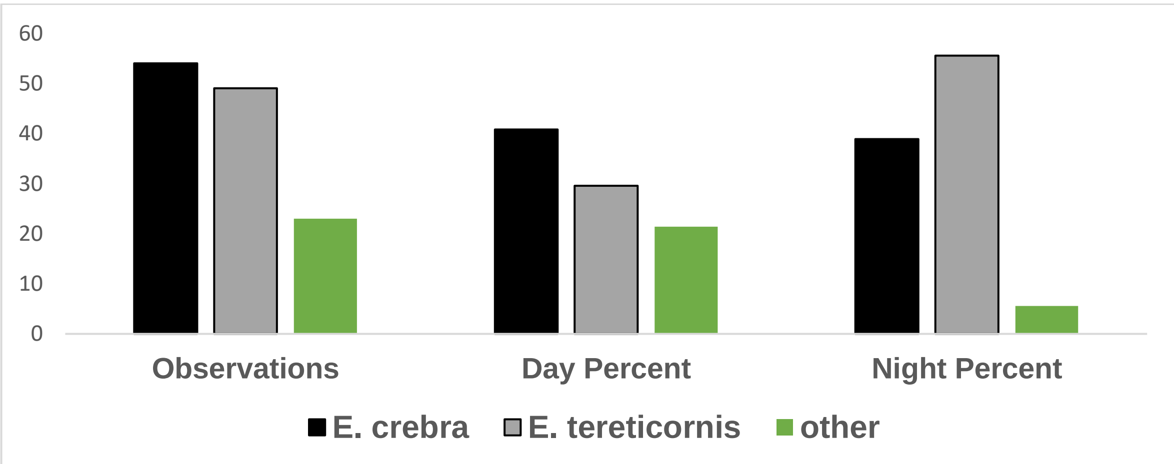

Figure 13. Diurnal and nocturnal tree use in Zone 3 of the Clarke-Connors Ranges Study Area. (**from Ellis *et al*. 2018**)

2.5.6 Diet

Ellis *et al.* (2018, Attachment 2) were able to infer major dietary selection through nocturnal observation of radio tracked koalas. Repeat observations of the koalas suggested that *E. tereticornis* and *E. crebra* or *E. drepanophylla* were the probable diet species in the study area. Very rarely other species were observed to be used by koalas at night, but too infrequently to be considered likely food sources. Koalas were also observed to use *C. intermedia* and *C. erythrophloia* during the day, as well as being observed in *E. orgadophylla*, *C. tessellaris*, *E. populnea,* and a range of other species in low numbers (Table 1). By day, koalas were seen in seven eucalypt species as well as a few other non-eucalypt species. The picture by night was markedly different. The koalas were seen almost exclusively in *E. drepanophylla*/*crebra* and *E. tereticornis*.

While direct nocturnal observations can provide a good indication of food tree selection (Melzer 1995, Tucker 2009; Woosnam-Merchez *et al*. 2013; Ellis *et al*. 2013), there may also be some discrepancies (Melzer *et al.* 2011). Consequently, faecal pellets were collected for later, detailed quantitative analysis of dietary choices (Ellis *et al*. 2018, Attachment 2). Many tree species, especially eucalypts, have a chemically resistant cuticle on the leaf surface. Fragments of these cuticles pass through the koala's gut with the surface detail intact. This surface detail includes leaf surface cell patterns that are diagnostic for the species from which they came. An analysis of the content of the faeces allows a determination of the species eaten and of the relative species composition of the dietary choice (Ellis *et al*. 1999). For example, table 3 in Melzer *et al.* (2014) shows the frequency of occurrence of food species in the diet of koalas from 11 sites across Queensland. In all cases one to three species accounted for the majority of the diet, with up to 14 species being present is small to trace amounts.

Table 1. Diurnal and nocturnal observations of tree use by 10 koalas in the Clarke-Connors Range Study Area (Ellis *et al.* 2018).

Species	Total N°	%	Diurnal N°	%	Nocturnal N°	%
E. crebra / E. drepanophylla	54	40.3	40	40.0	14	38.9
E. tereticornis	49	36.6	29	29.6	20	55.6
E. populnea	3	2.2	2	2.0	1	2.8
Corymbia intermedia	2	1.5	2	2.0	0	0
Corymbia spp.	6	4.5	6	6.0	0	0
Other species	20	14.9	19	19.4	1	2.8
Total	**134**	**100**	**98**	**100**	**36**	**100**

2.5.7 Genetics

To understand the potential impact of an activity and/or environmental pressures on the Clarke-Connors koalas, it is necessary to know whether the extensive population is a single body of animals or consists of two or more distinct types. This is tested by examining the genetic similarity of animals from across the species range in the study area. Ellis *et al*. (2018, Attachment 2) analysed tissue samples from 54 koalas collected from across the extent of the study area. DNA was extracted and amplified from a small tissue sample. Genetic diversity was analysed to calculate the number of alleles and the observed and expected heterozygosity (GENALEX 6.5). Genetic diversity statistics were then calculated, and compared with three other Queensland regional populations (Mt Byron, near Esk; Oakey; St Bees Island). There was similarity amongst the four populations, although St Bees Island had the lowest diversity; probably reflecting its isolation and relatively small founder population.

In general, the Clarke-Connors Range koala population appears to be a single relatively homogeneous genotype. However, there was an enclave of a distinct genetic character in the general Nebo area (Figure 14). Given that there are no ecological barriers between this enclave and surrounding population, it is unlikely that this represents a distinct management unit. At this stage it is not clear what this variation represents. More study would be required to: (a) eliminate the possibility of an effect of differential sampling intensity across the study area (the enclave may have been sampled more intensively than the surrounding study area); (b) map the limits of the distribution of HapType 1; and (c) identify the significance of the variation.

At this stage, it is concluded that: (1) the highway has not interrupted gene-flow in the past, and (2) the Clarke-Connors Ranges koala population is a single genotypic management unit (Ellis *et al*. 2018, Attachment 2).

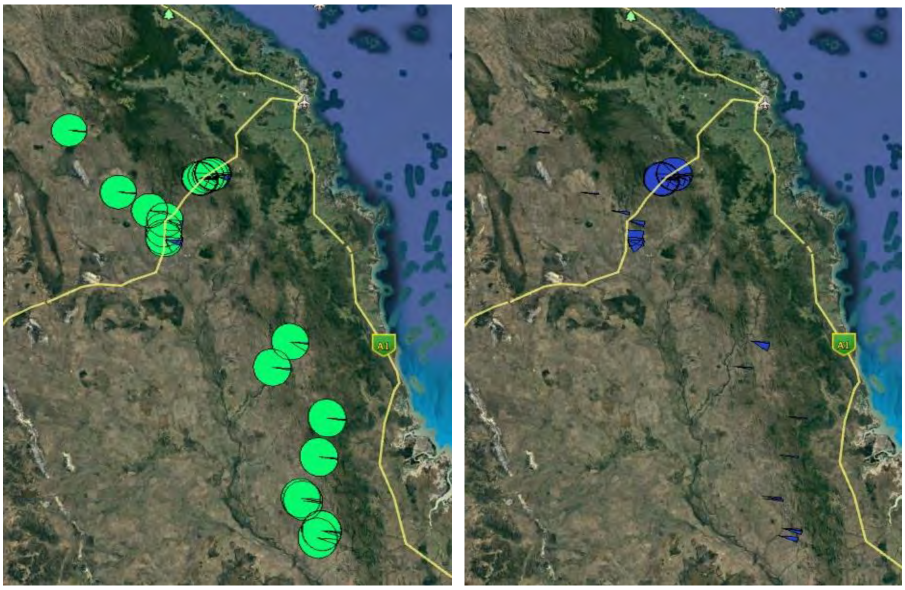

Figure 14. Distribution of Haptype 0 (left) and Haptype 1 (right) in the Clarke-Connors Ranges. The pie charts and slices represent the koalas analysed. The relative size of each piece represents the proportion of each haptype present in the koala sampled.

3.0 Threatening processes

The National Koala Conservation and Management Strategy (Natural Resource Management Ministerial Council 2009) listed seven overarching threat classes or management issues. These were:

1. Habitat loss, fragmentation and degradation;
2. Over-browsing;
3. Natural disasters;
4. Disease;
5. Vehicle collisions;
6. Predation;
7. Climate change.

Each is discussed below in relation to the Clarke-Connors Ranges Study Area. The drivers of many elements of these umbrella threat classes are directly or indirectly a consequence of human land uses. It is clear, however that the pattern of land use and of threats from human activity are unevenly distributed across the study area. Three zones were defined based on (a) the degree of clearing and landscape fragmentation, (b) differences in land use, and (c) the spectrum of management/remedial responses that can be applied in each zone.

3.1 Habitat loss, fragmentation and degradation

Habitat loss has been a major factor in the decline in koala abundance and distribution since European settlement (Melzer *et al.* 2000), but especially with the advent of broad acre clearing techniques from the 1940's. The resulting habitat fragmentation challenges the survival of remaining koala populations (McAlpine *et al*. 2006). In Central Queensland, koala habitat has declined. The percentage loss varies with local government area (LGA):

- 30 to 37% Isaac LGA;
- 38 to 60% Central Highlands LGA;
- 43 to 58% Livingstone LGA;
- 80 to 89% Rockhampton LGA.

(Melzer, Santamaria unpublished)

Mackay LGA has not yet been fully mapped.

The differences are largely a reflection of the extent of remnant vegetation, predominantly determined by the extent of rangelands and low productivity lands or land tenures that preclude development. For example, in Livingstone LGA, the Shoalwater Bay Military Training Area precludes development of extensive remnant vegetation. In the Isaac LGA the terrain of the Clarke-Connors Ranges and most of the study area preclude clearing or more intensive development.

Most of the study area retains a cover of remnant vegetation. However, this varies across the study area, and Zones 1 and 2 have greater extent of clearing than Zone 3 (see sections 2.2.3 *Vegetation* and 2.4 *Land Use* for further discussion of these zones). In Zones 2 and 3, incremental, small losses will continue through property management activities, local industrial and resource projects, and state infrastructure maintenance and upgrades. There is one exception to this. The proposed construction of a dam on the Connors River would see the loss of at least 1,915 ha of koala habitat, largely fringing a perennial stream (http://statedevelopment.qld.gov.au/assessments-and-approvals/connors-river-dam-and-pipelines.html). In Zone 1, these small losses have a higher likelihood of impacting koala population viability as the habitat has been subject to greater fragmentation than in Zone 3. In Zone 2, the likely losses are relatively greater as the landscape is highly fragmented, and the regional population is predicted to grow by nearly 22% over the next 20 years (http://www.qgso.qld.gov.au/subjects/demography/population-projections/tables/proj-pop-lga-qld/index.php). This growth would see increased development of land for housing as well as increased urban threats. These include increased traffic flows, increased dog activity, and the degradation of habitat remnants through weed invasion, inappropriate fires, and greater dog and human activity.

Loss of habitat is managed through legislation, regulation and planning. Further habitat loss in the study area, at least, should be contained through the Queensland Vegetation Management Act 1999, the Planning Act 2016, and associated regulations, policies and codes of practice (https://www.qld.gov.au/environment/land/vegetation/monitoring). However, in Zones 1 and 2, planning, regulation and implementation are more complex than in Zone 3. In South East Queensland, this legislative and regulatory complexity combined with competing interests among departmental, industry and community sectors contributed to a failure to adequately protect koala habitat or arrest a steep decline in regional koala populations. As part of a new approach, the keystone element is the adoption of a strategic and coordinated approach to koala conservation initiatives (Queensland Government undated, Rhodes *et al.* 2017).

It is likely, given the lessons from South East Queensland, that an integrated approach to koala conservation management would be required for Zones 1 and 2. This is because of the density of anthropogenic threatening processes (*e.g*. roads, rail, urbanisation, agriculture) combined with the relatively small extent of the zones, and projected population increases for Zone 2.

An emerging threat to the study area's koala habitat is the population growth and range expansion of three species of exotic deer (*Cervus elaphus* (red deer), *Cervus timorensis* (rusa deer), *Axis axis* (Chital); Figure 15) (Department of Agriculture and Fisheries 2018). Feral deer trample understorey plants, including seedlings, browse on tree seedlings, and ringbark small trees (https://www.daf.qld.gov.au/__data/assets/pdf_file/0016/73510/IPA-Red-Deer-Factsheet.pdf). Over time they have the capacity to interfere with the natural regeneration of eucalypt communities and degrade koala habitat.

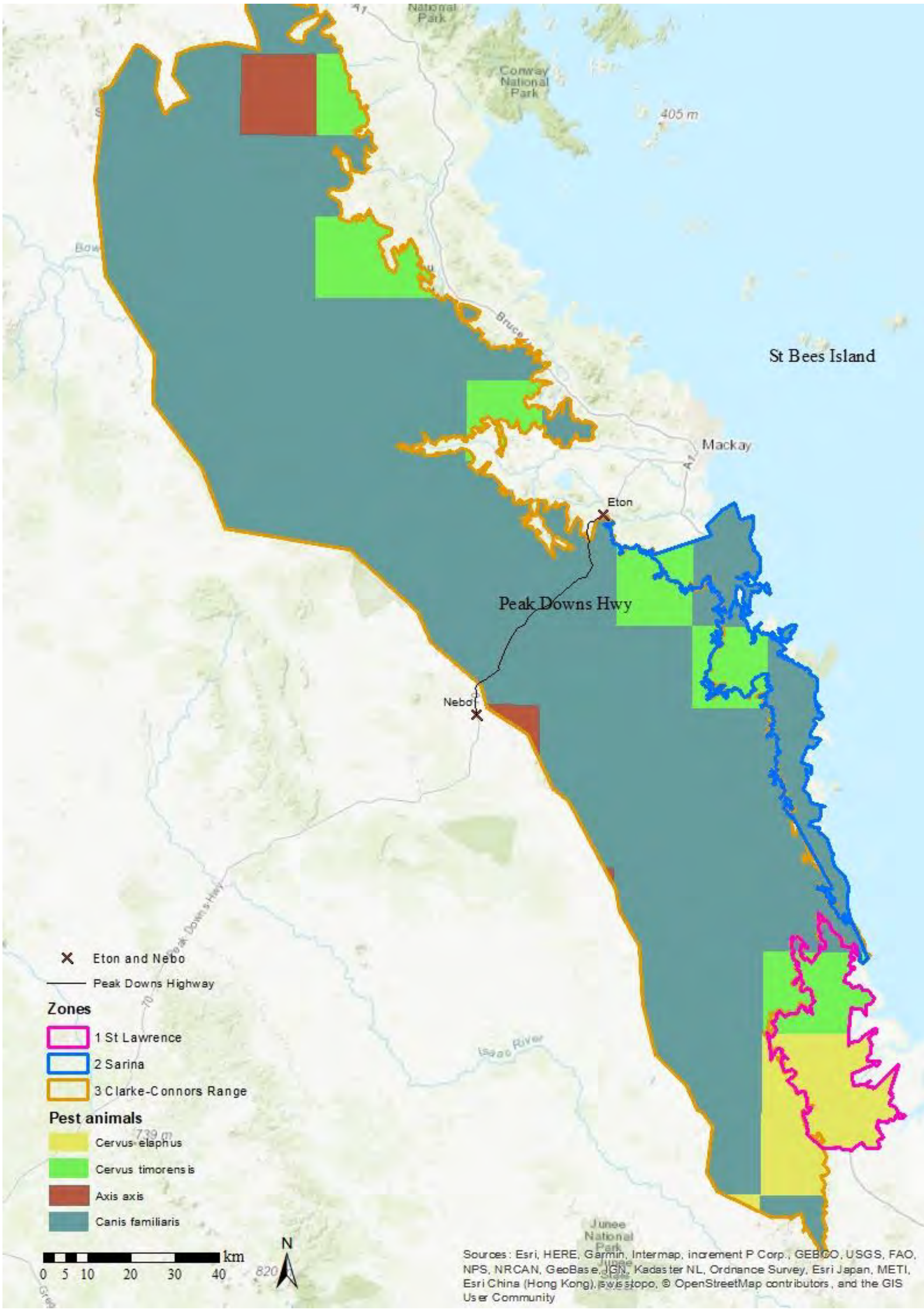

Figure 15. General distribution of *Cerves elaphus* (red dear), *Cerves timorensis* (rusa deer), *Axis axis* (chital) in the Clarke-Connors Ranges Study Area (From Department of Agriculture and Fisheries 2018).

3.2 Over-browsing

Over-browsing by koalas is linked to overpopulation and overutilization of habitat in Victorian and South Australian koalas. Commonly, this has occurred where the koala population is unable to, or does not disperse from a habitat patch. Commonly this is an island or a habitat fragment surrounded by cleared lands. There are no recorded cases of Queensland koalas overexploiting habitat, or of populations increasing unchecked to the point where resources are exhausted.

Over-browsing is not considered a threat to koala habitat in the study area.

3.3 Natural disasters

Under the natural disasters banner the national strategy includes consideration of the impact of fire and drought. The threats from both will increase under developing climate variability scenarios.

Drought

In the Clarke-Connors Ranges Study Area drought is not considered a major threat. Rather, the region is seen as a refuge from drought although some parts of the area may be drought affected (*See Threatening Processes- Climate change below for a broader discussion*).

Fire

Some parts of the Clarke-Connors Ranges Study Area burn each year (Department of Natural Resources Mines and Energy 2018). The area burned per year in the decade from 2006 to 2016 is shown in Table 2. The area burned peaked during 2008/09 and again in 2013/14. Broadly, burn area increased during the La Nina years 2007/09 and 2010/12. Burn areas were lower during the La Nina years 2006/07, 2009/10 and 2015/16 (http://www.bom.gov.au/climate/enso/index.shtml). Presumably, this tendency reflects growing conditions and fire fuel load accumulation.

Table 2. Area (km^2) burned annually from 2006 to 2016 within the Clarke-Connors Ranges Study Area

(Derived from Department of Natural Resources Mines and Energy 2018)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Burning (km^2)	6,679	4,350	14,719	12,499	9,522	10,487	11,117	17,590	14,082	4,954	4,841

The pattern of burning resulted in a landscape-scale mosaic. Not all areas burned in any one year (Figure 16). Large areas have remained unburned for at least a decade. The landscapes subject to fire are predominantly dry eucalypt woodlands and open forest. These form the bulk of the koala habitat in the study area. These are fire-adapted ecosystems and require periodic fire for the maintenance of their structure and composition. The threats to koalas and koala habitat arising from the burning of these systems relate to (a) the timing of the burn, and (b) the landscape context, both in conjunction with fire intensity.

Timing

Hot fires, or dry season burning, even of moderate intensity, can scorch the eucalypt canopy. Even if koalas are not directly affected by flames, the scorching or desiccation of the canopy eliminates food, moisture and shelter resources within the burned area. Dry season burning, especially in time of drought, can result in large areas of otherwise suitable habitat being unviable, and depletion of the local koala population. In the Clarke-Connors Ranges, such burning risks the landscape’s role as a drought or climate refuge.

Landscape context

In fragmented landscapes, each isolated patch is at risk from local or chance impacts (fire, flood, storm, inappropriate land management). Local extinction of plants or animals is possible (Mac Nally and Bennett 1997, McAlpine *et al*. 2006). Within the study area, the mosaic burn pattern in Zone 3, and the long unburned portions of the landscape provide the opportunity for koalas to re-establish in patches where the resident animals may have been lost. However, in Zones 1 and 2, the fragmentation of the available habitat raises the likelihood of incremental loss of isolated koala populations with inappropriate burning, and with limited opportunity for recolonization. This is particularly the case along road reserves, and adjacent to sensitive infrastructure, where prescribed seasonal fuel reduction is implemented in conditions that result in canopy fires, or scorching.

3.4 Disease

Chlamydial infections have been considered the most significant disease affecting koalas and have been associated with declining populations in the Darling Downs and more recently in South East Queensland. However, the frequency of Chlamydia in healthy and unstressed koala populations is usually low. This seems to be the case in the Clarke-Connors Ranges Study Area. Ellis *et al*. (2018) was able to identify chlamydia in one of 27 animals sampled from across the study area (see *The Koalas – Body Score and Health* above for details). All koalas had high body score indices and, with one exception, there was no indication of disease or poor health. Since then three cases of apparent chlamydial infection have been reported from within the study area (Ian Gottke pers. com. October 2018). Despite these cases, it is clear that the instance of Chlamydia in the area is low and not of concern.

3.5 Vehicle collisions

<u>The problem</u>

Injury and death of koalas due to road and rail vehicles is an issue throughout the koala's range, and across the study area. This is particularly a problem in highly urbanised areas and where high volume traffic routes intersect koala habitats. In certain circumstances, the carriageway becomes an ecological barrier, dividing and isolating animal population.

<u>Consequences</u>

Where the mortality is ongoing, the viability of the resident koala population may be compromised, and local populations can decline towards extinction. This has been most clearly documented in southeast Queensland (Dique *et al*. 2003, Rhodes *et al*. 2015), and is suspected in the case of the former koala population around the Capricorn Highway just west of Duaringa, central Queensland (Melzer pers. obs.).

Where the infrastructure provides a barrier to movement, or the high traffic flow prevents successful crossing of the carriageway, there is a block to gene flow. The resulting genetic isolation can result in genetic differentiation among the population isolates. Again, this has been demonstrated in southeast Queensland (Lee *et al*. 2009).

<u>Threats to the Clarke-Connors Range Study Area</u>

While koala road-kills or vehicle-associated injuries occur throughout the region wherever road and rail intersect koala population, there are two areas where road-kills occur at a relatively high frequency. These are (1) the Bruce Highway, near St Lawrence, and (2) the Peak Downs Highway between Nebo and Eton. The Peak Downs Highway road-kill area is particularly obvious in Figure 10 above. An increase in public reporting of koala road-kills reflects heightened public interest associated with recent highway upgrades around Eton. The issues around the St Lawrence Bruce Highway road-kill area were discussed by Melzer and Tucker (2011, Attachment 1). The road-kill threats on the Peak Downs Highway are the subject of current research.

<u>General wildlife road-kills</u>

Melzer *et al*. (2018 Attachment 5) undertook short surveys to assess the entire spectrum of vertebrate wildlife being killed by vehicles on the Nebo to Eton stretch of the Peak Downs Highway. In the 12-day survey, they identified and mapped 96 vertebrate carcasses (Table 3). Of these over 50 percent were kangaroos and wallabies, with birds and brushtail possums accounting for 16.7 and 9.4 percent respectively. Koalas accounted for just over three percent of records.

Koala road-kills

The coordinates of dead koalas, and injured koalas taken into care, between 2014 and 2018 were entered into a GIS (Melzer and Santamaria unpublished). The distribution of these koala-vehicle incidents was unevenly distributed along the highway. Melzer and Black (2018 attached) were able to identify 10 clusters (three or more records) of road-kills (Figure 17) and to associate those with land form elements and vegetation types. The region of the Eton Range Realignment Project was not included in this analysis. The clusters Melzer and Black (2018, Attachment 4) identified largely coincided with the black spots identified by Schlagloth (2018, Attachment 3) (Figure 18).

Table 3. Summary of the road-kill located on the Peak Downs Highway between Eton and Nebo over 12 days of survey in 2017.

(Extracted from Melzer *et al*. 2018).

Faunal group	Elements	Sample number	Relative frequency (%)
Reptiles		3	3.1
Birds	Raptors (n=4) & others	16	16.7
Gliders	greater & squirrel gliders	3	3.1
Possum	brushtail possum	9	9.4
Koala		3	3.1
Kangaroos & wallabies	eastern grey kangaroo, whiptail wallaby, agile wallaby, indeterminate	50	52.2
Other mammals	bandicoot, bettong, rabbit, pig, dingo/dog, indeterminate	12	12.4
	Total	**96**	**100**

Schlagloth (2018, Attachment 3) identified 19 clusters of road-kills (including within the Eton Range Realignment Project), finally defining nine road-kill blackspots. Schlagloth's (2018, Attachment 3) modelling suggested that koala road-kill hotspots would be associated with increasing areas of high quality habitat. Importantly, the model suggested that the high quality habitat areas linked to road-kills:

(1) occurred as a mosaic within habitat of lesser quality rather than a solid block; and (2) where the boundary to area ration of the high quality habitat was high.

Koalas were less likely to be killed as the area of very poor quality habitat increased.

On the Eton to Nebo stretch of the Peak Downs Highway that translated into black spots, which occurred where there was relatively large areas of plant communities supporting the locally important food species *E. tereticornis* and *E. drepanophylla* as well as *E. platyphylla*; but where that habitat occurred as a mosaic rather than a solid block.

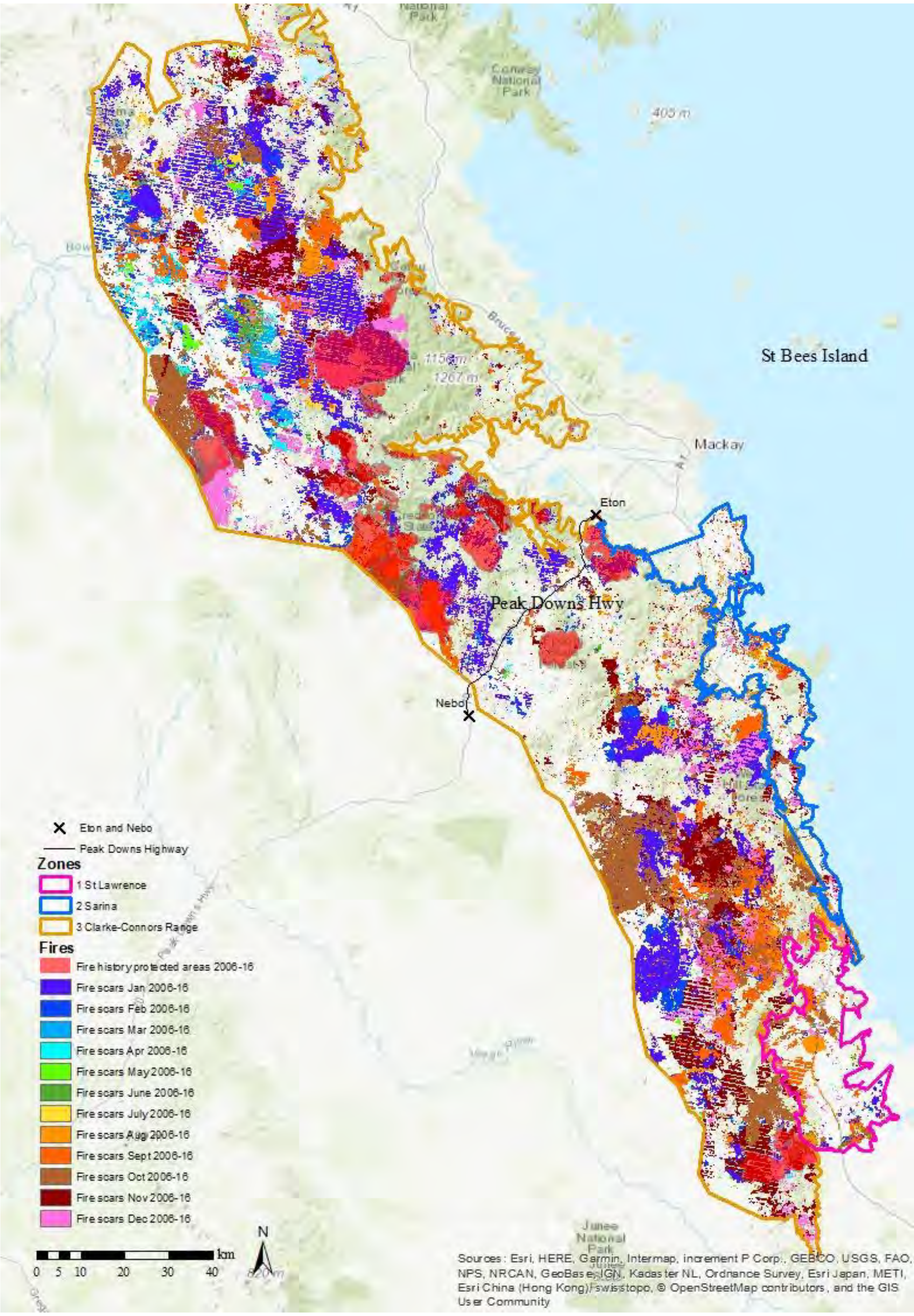

Figure 16. Fire scars by month over the decade from 2006 to 2016. Of note are the large areas of dry adapted vegetation, mainly south of the Peak Downs Highway, which remained unburned for a decade by 2016. (Department of Natural Resources Mines and Energy 2018)

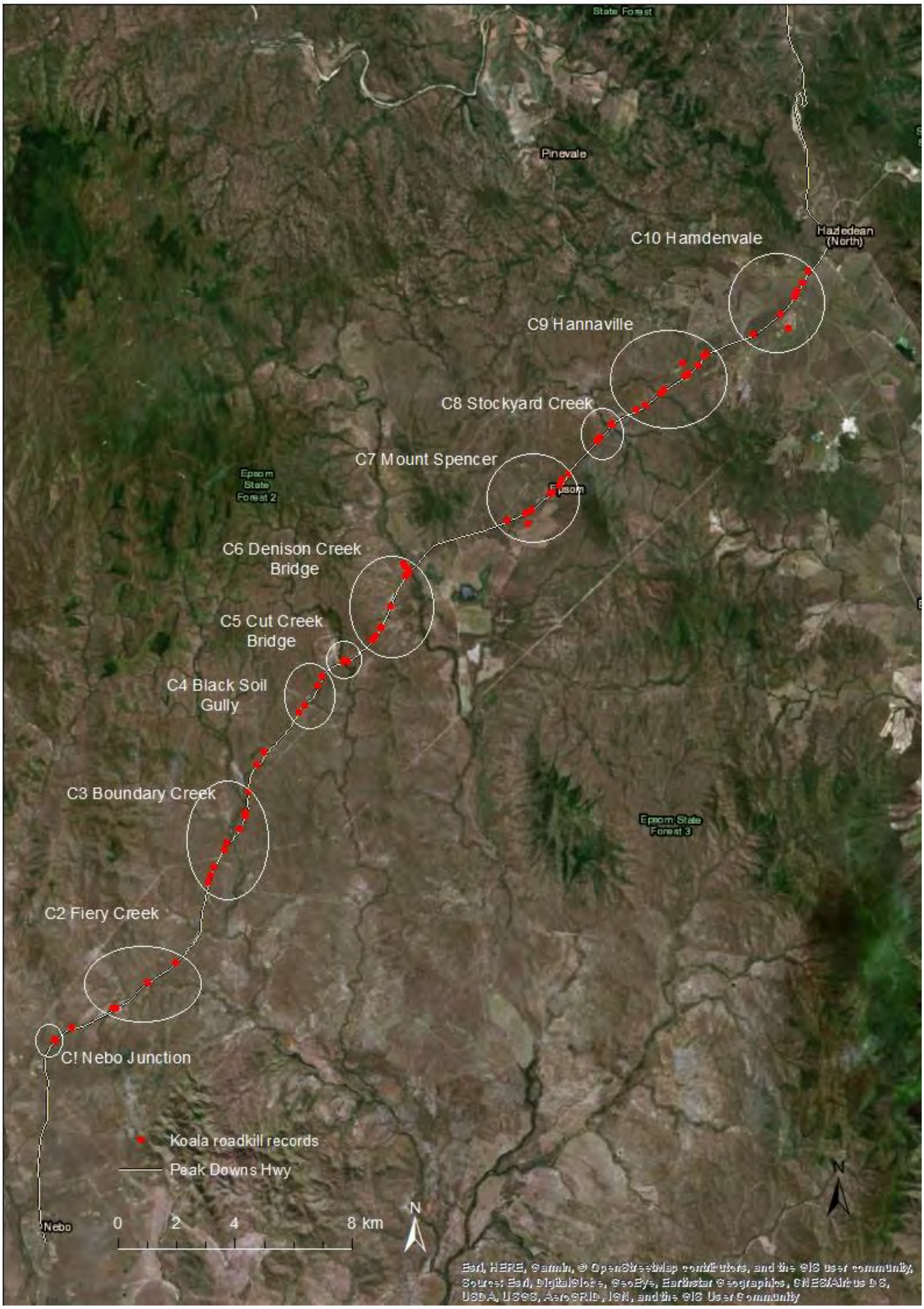

Figure 17. Distribution of koala sightings and road-kills (September 2014 – August 2017) between Nebo Junction and Hazledean on the Peak Downs Highway, Central Queensland. The koala records are shown as red points. The records were unevenly distributed and grouped into 10 clusters of three or more records (white ovals). (Extracted from Melzer and Black 2018)

Figure 18. Association between road-kill clusters -ovals (Melzer and Black 2018) and blackspots (Schlagloth 2018)

Melzer and Black's (2018, Attachment 4) analysis indicated that the kill clusters were associated with stream fringing vegetation, alluvial and clay flats, and minor drainage lines where *E. tereticornis* and or *E. platyphylla* were prominent elements of the overstorey, and associated ridges dominated by *E. drepanophylla*. This focus on drainage lines, and associated alluvia and valley floors as well as adjacent lower ridge slopes results in a reticulated landscape-scale habitat picture; the areas with the reticulation being associated with very low or no road-kills. This is consistent with Schlagloth's (2018, Attachment 4) model that the high quality habitat would have a high edge to area ratio. Schlagloth (2018) also predicted that koalas in a fragmented habitat, with a high edge to area ratio, would have to increase movement to exploit the resources. Ellis *et al.* (2018, Attachment 2) radio-tracked a number of koalas in the vicinity of the black-spots. They found long distance movements were common. So, in koala habitat around the Peak Downs Highway, the eventual consequence of such a habitat utilisation strategy is increased crossings of the carriageway and increased likelihood of a koala being hit by a vehicle.

Mitigation

In the Clarke-Connors Ranges Study Area mitigation options for koala road-kills are limited. Avoidance is not possible. It is not feasible to move roads, highways or railways away from koala habitat given: (a) the terrain, there are only limited opportunities to reroute road or rail corridors; and (b) the costs of moving major infrastructure are impossibly high. The remaining options are (a) modify driver behaviour so that collisions do not occur, (b) prevent koalas from entering a road or railway, and/or (c) provide a means for koalas to pass a road or railway without encountering a vehicle.

Modifying driver behaviour

Modifying driver behaviour is attempted through public education, warning signs and speed limit restrictions. The Department of Transport and Main Roads has installed warning signs on the Peak Downs Highway in Zone 3, and along the St Lawrence stretch of the Bruce Highway in Zone 1. Reduced speed limits have not been imposed, and given that these highways are major arterial routes, it is unlikely that speed reductions would be applied. Irrespective of that, signage and limits on speed have not been effective in southeast Queensland at least (Dique *et al*. 2003). In certain circumstances, changing traffic schedules may be effective. Ellis *et al.* (2016) modelled a shift in peak traffic flows due to daylight saving against known koala behaviour around Brisbane roads. They predicted an 8 to 11 percent decrease in koala-vehicle collisions with the one hour shift in peak traffic flows in early mornings and evenings. There is an opportunity to adjust traffic flows on the Peak Downs Highway, at least, by adjusting industrial work schedules so that traffic associated with shift changes does not induce peaks in traffic ahead of and soon after shift changes. More research is required to ascertain the feasibility and the likely magnitude of any effect on crepuscular wildlife such as the koala.

Preventing koala access

Barrier fences are commonly installed to prevent wildlife accessing carriageways, and, in Queensland, the Department of Transport and Main Roads has a manual for the design of fauna sensitive roads, as well as standard designs for the construction of koala proof fences (https://www.tmr.qld.gov.au/Community-and-environment/Environmental-management/Land/Fauna-management). These have been installed around the Eton Range Realignment Project (Figure 19).

Figure 19. Koala barrier fencing erected in association with the upgraded Eton Range upgrade of the Peak Downs Highway.

Melzer and Black (2018, Attachment 4; Table 5) reviewed the remainder of the highway between the Eton Range Realignment Project and Nebo. They identified 10 clusters that corresponded with the modelled blackspots (Schlagloth 2018, Attachment 3) providing target areas for investment in barrier fences. On the Bruce Highway, Melzer and Tucker (2011, Attachment 1) recommended the installation of barrier fences on the St Lawrence stretch to limit road strikes, as well as to direct fauna to underpasses where available.

Koala over or underpasses

The installation of underpasses to prevent wildlife from accessing carriageways is common, and, in Queensland, TMR has a manual for the design of fauna sensitive roads, as well as standard designs for the construction of wildlife underpasses (https://www.tmr.qld.gov.au/Community-and-environment/Environmental-management/Land/Fauna-management). These have been installed at the Eton Range Realignment Project on the Peak Downs Highway. On the highway, the road-kill clusters were associated with streams, alluvial flats, minor drainage lines and ridge lower slopes. Association was also made with bridges, culverts and drains necessary for the carriageway to traverse drainage lines. On the remainder of the highway between the Eton Range upgrade and Nebo, recent bridge reconstructions have spanned the lower stream terrace, or incorporated a dry bench allowing fauna to travel during normal stream flow condition. Melzer and Black (2018, Attachment 4) considered the bridges at Fiery Creek, Boundary Creek, Cut Creek, Denison Creek and Stockyard Creek provided suitable passageways for koalas without further works beyond periodic maintenance. However, in all cases barrier fences will be required to direct koala and other fauna to the passageways. Elsewhere existing culverts with a diameter over 1.5m had the potential to act as faunal underpasses (TMR 2002). All that is required is the installation of barrier fences to guide fauna to the culvert inlet. The usefulness of these as koala underpasses has not been demonstrated, and was potentially limited by the length of the passage, and the restricted view of habitat through the culvert. Given the age of the road, the majority of culverts were constructed of corrugated steel pipe. This form of construction produces a curved cross-sectional area rather than the square profile provided by contemporary concrete box culverts. In a number of cases, Melzer and Black (2018, Attachment 4) recommended planning for eventual upgrading of these to wildlife-underpass compliant box culverts (*e.g.* Hannaville, Mt Spencer, Black Soil Gully clusters, Figure 15).

On the Bruce Highway, near St Lawrence (Melzer and Tucker 2011, Attachment 1) recommended investigating the utilisation of existing bridges, in conjunction with barrier fences, to provide safe passage for koalas.

3.6 Predation

Koalas are subject to predation by native fauna (wedge-tailed eagles, powerful owls, dingos, large pythons) and by feral animals (wild dogs, foxes) and domestic dogs. Rarely, they are trampled by cattle. However, predation is not a management or conservation issue where the density of these predators is low, and/or where there is appropriate habitat structure to provide refuge or shelter. Fauna Rescue Whitsunday have received six cases of koalas attacked by domestic dog over the last two years (up to November 2018 Ian Gottke pers. com.). In all cases the koalas had entered urban centres. Whilst this would certainly be an underestimate as dog or dingo attaches in bushland would mostly go unrecorded, the impact is clearly not significant when compared with the rates of attack in southeast Queensland (see for example http://www.abc.net.au/news/2015-03-18/koalas-more-vulnerable-to-wild-dog-attacks-than-thought/6330014).

Predation is not a significant threatening process in this study region. However, predation may become significant in Zone 2 as settlement density increases.

3.7 Climate change

The problem

Contractions in the Queensland koala's range are expected to continue as the predicted increases in climate variability, and increased frequency and intensity of extreme weather events impact koalas (Adam-Hoskings *et al*. 2011), and their habitat (Adam-Hoskings *et al*. 2012). These predicted climatic changes, have been associated with human-induced increases in greenhouse gases – especially carbon dioxide, methane and nitrous oxide (IPCC 2013). There are expectations of an increase in maximum and minimum temperatures, increased frequency and duration of heat waves, as well as an increased severity and duration of droughts (Hughes and Steffen 2013, IPCC 2013). Consequently, there are widespread concerns about the survival of the koala.

Consequences

The impacts of climate change for Queensland's koalas, including those of the Clarke-Connors Ranges Study Area, arise from the increasing intensity of droughts, heatwaves and extended consecutive days without rainfall, combined with a gradual increase in both nocturnal and diurnal temperatures. These factors result in acute impacts including:

(a) short term seasonal and episodic declines in the water content of the foliage of primary food species, resulting in koalas not being able to get sufficient metabolic water;

(b) dieback of some tree species or collapse of local ecosystems through moisture stress or emergence of insect pests or microbial diseases,

(c) acute periods of heat stress with consequent impacts on immediate koala survival as well as consequent stress-induced disease emergence, and

(d) catastrophic impacts of forest fires during these periods.

There have been cases of all these impacts in eastern Australian koala habitat within the last decade. Longer term changes may occur with:

(a) permanent reduction in soil water availability and the decline in water tables;

(b) reduction in the extent and abundance of critical koala food species, and

(c) contraction in the range of the eco-physiological envelope within in which the koala can persist.

There is some indication that the last two changes at least, are already evident in Queensland.

Landscape resilience

Some parts of the landscape, and associated ecosystems, are somewhat resilient in the face of these pressures. The Clarke-Connors Ranges Study Area is one such landscape. Queensland's coastal ranges – centred on the Clarke-Connors Range, have been identified as significant pre-historic climate-change refugia (Smith 2013), and have been proposed as future koala climate-change (Adam-Hoskings *et al*., 2011), and, more broadly, as a biodiversity refugia (Low 2011, Reside *et al.* 2013).

Empirically, current Queensland localities that support koalas represent refugia from the environmental challenges of the last 25 years (Melzer *et al*. 2013). In broad terms these local refugia are associated with the mountains, hills and scarps associated with the coastal ranges (including Kroombit Tops, Clarke-Connors Range), the precipice sandstones of the Carnarvon and associated ranges (including Blackdown Tableland), and the hills and ranges of the Einasleigh Uplands (https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/framework).

The circumstances that create a climate refuge are probably a unique combination of geology, land form, hydrology and associated vegetation that combine to provide a koala population with a suitable micro-environmental envelope. Characteristics of such an envelope are:

- Year-round food, and associated water availability;
- Shelter from heat and predators;
- Sufficient space for the social interaction and reproduction of a viable population; and most importantly
- Protection from destructive human interference such as inappropriate fire, habitat destruction, gradual habitat degradation etc.

Threats to the Clarke-Connors Ranges Study Area

The geography and extent of the Clarke-Connors Ranges Study Area provide the basis for the area being an extensive climate refuge for the koala. However, there are pressures on this refuge from land management. These pressures are more acute in zones 1 and 2 than in Zone 3 because of the greater fragmentation of habitat in these two zones, and the greater density of human settlement and intensity of activity. Key pressures are:

- Inappropriate dry season burning, and high intensity burning;
- Ongoing reduction in the area of habitat fragments, and clearing of entire fragments,
- Frequent disturbance of resting koalas by people, vehicles or dogs during stressful environmental conditions. Koalas seek shelter and reduce activity to lower their metabolic rate, reduce water loss and avoid overheating in hot conditions. Often this shelter is close to or on the ground. Disturbance (especially by humans an dogs) forces the koalas to leave shelter and to become more active, increasing risks of heat exhaustion.

Within Zone 3 the proposed damming of the perennial Connors River has the potential to impact on the value of the southern part of the study area as a refuge. There would be the loss of extensive areas of stream fringing and adjacent alluvial habitat. These land form elements and associated vegetation have been identified as the principle koala habitat within the study area.

Mitigation

Strategic planning to avoid impacts on koalas and koala habitat is required, particularly in relation to Zones 1 and 2. Key matters would be the scheduling of burns, alternatives to fire to reduce fuel loads, and protocols to reduce disturbance to koalas during periods of stressful weather conditions.

In the light of the contemporary understanding of the conservation status of the koala, and the significance of the Clarke-Connors Ranges Study Area, proposals for activities that may significantly impact the local koala population (e.g. Connors River dam) should be assessed appropriately.

4.0 Conservation management

4.1 Context

The Clarke-Connors Ranges Study Area is a 15,640 km^2 area of largely remnant forests and woodlands stretching over some 340 km of the east coast ranges of central Queensland. This rugged landscape is dominated by igneous hills and ranges with small plateaus, and is incised by rivers and streams flowing into the Burdekin and Fitzroy basins as well as numerous smaller coastal basins.

Land use is dominated by rangeland grazing, with moderate areas of state lands managed for conservation and forestry purposes. Relatively rich soils on small basaltic plateaus and in the alluvial valley floors have largely been cleared for pasture and horticulture. Urban settlement is largely confined to the east, with extensive, but low density, urbanisation at Sarina and a number of smaller coastal towns and settlements (e.g. Koumala, Carmila, Clairview, St Lawrence). Major infrastructure corridors (road and rail) run north-south across the east of the study area, and northeast – southwest across the centre of the study area. Three large water storages cover some 5,000 ha. Patterns of clearing and the distribution of land use are not evenly distributed across the study area. Three zones have been defined based on these differences. Zone 1, around St Lawrence, is characterised by a relatively large area of cleared land for grazing, primarily. Zone 2, around Sarina, is characterised by the greatest relative proportion of cleared land and intensive agriculture, and of residential development. Zone 3 is characterised by the greatest proportion of uncleared land, little in the way of horticulture, and relatively little residential development (Figure 2, Figure 9).

4.2 The koalas

Koala habitat occurs throughout the study area. It is most extensive to the west of the eastern escarpment of the Clarke-Connors Ranges, at the drier end of the moisture gradient. The habitat is most fragmented in the east in Zones 1 and 2. Koalas occur across the extent of the study area – probably only absent from the rainforest communities. Little is known of the population density. However, animals are common in many areas, especially around St Lawrence, and the catchment of the Connors River. The koalas are typical of Queensland koalas in terms of size and colour. Their diet is based on two widespread eucalypt species (*E. tereticornis*, *E. crebra*/*drepanophylla*). The population appears healthy with good body condition, no obvious symptoms of disease, and a very low incidence of chlamydial infection. Initial studies of ranging behaviour suggest individuals in this population range extensively over rugged terrain, whilst others occupy very small ranges of a few hectares. Genetics suggests that there is a single population across the study site, although some local variation is evident.

4.3 Threats

There are five key threatening processes acting on this koala population and/or its habitat within the study area.

4.3.1 Land clearing and fragmented habitat

Whilst broad-acre clearing is less likely under current policy and regulation, incremental small losses of habitat are expected to continue. This is especially the case in the fragmented landscape of Zone 2. Pressures to expand urban settlement are expected to continue as the regional population grows over the next 20 years. Increased density of small hectare blocks and suburban expansion will increase habitat fragmentation, and remove some relic habitat patches. Elsewhere, routine property management in grazing lands, or upgrades to road and rail corridors will see small patches of habitat cleared from time to time. At the landscape level in Zone 3, this is unlikely to be a significant effect given the extent of remnant forest and koala habitat in this zone. However, in the fragmented landscapes of Zones 1 and 2, the effect may threaten the viability of habitat patches or local koala populations.

4.3.2 Fire

Fire is a critical threatening process acting across all but the wettest landscapes in the study area. The risks to koalas, and to koala habitat, are high if burning occurs under inappropriate conditions, e.g. where canopy fires or scorching occurs. In the fragmented landscapes of Zones 1 and 2, inappropriate fire risks local koala extinctions and/or habitat degradation. In Zone 3, severe fire weather combined with inappropriate land management practices (e.g. long periods of fuel accumulation) will result in high intensity fires with an associated loss of the canopy and death of koalas. Associated scorching of the canopy results in the loss of food and water for koalas and consequent local declines in koala numbers.

4.3.3 Drought

Whilst the Clarke-Connors Ranges are considered biodiversity refugia under climate change scenarios, parts of the study area are likely to be affected by severe droughts. This includes Zones 1 and 2, the northern and southern parts of the study area, as well as the lower altitude fringes. It is also expected that some landscape elements, such as ridge crests, would be subject to water deficits. The study area is considered a drought refuge for koalas. However, this refuge is vulnerable to burning during any drought. In the fragmented parts of the study area, drought affected habitat patches may lose resident koalas. There may be limited opportunity for these patches to be recolonised such that local extinction occurs.

4.3.4 Collision with vehicles

Koala death and injury due to collisions with road and rail vehicles occur across the study area. These are highly visible events especially along the Peak Downs Highway in Zone 3, and the Bruce Highway in Zone 1. Along the Peak Downs Highway, long term, unrelenting road mortality presents a threat to koalas that reside near the highway. There will be, however, little impact on the population as a whole given the extent of habitat and the distribution of koalas to the north and south of the highway. There may be impacts on local population viability and to individual animal welfare. In the fragmented landscape in Zone 1, the road mortality has the potential to reduce the viability of populations living in habitat isolates, risking local extinctions. Further, if the rate of mortality is such that there is no effective movement across the Bruce Highway, gene exchange among patches will be hindered and will result in genetic changes in small isolated populations.

4.3.5 Pest plants and feral animals

Pest plants and feral animals threaten koalas and their habitat both in the short term and through more gradual changes.

Feral dogs are known predators of koalas, and especially when hunting in packs they can decimate local populations in certain circumstances. Generally, this occurs close to urban residential, or small hectare bush settlements, but there is no indication that it is occurring in the study area. However, the koalas in the more fragmented parts of the study area (e.g. Zone 2), close to urbanisation are considered most vulnerable to feral dogs.

Pest plants degrade koala habitat directly, by smothering the overstorey of stream fringing koala food trees (*Cryptostegia grandiflora*, rubber vine; *Macfadyena unguis-cati,* cat's claw creeper). Dense stands of feral shrubs or grasses will deter koala movement, and preclude the establishment of regenerative seedlings. Examples are *Lantana camara* (lantana), and *Megathyrsus maximus* (Guinea grass).

Pest grasses (especially *Megathyrsus maximus* and related forms) directly threaten koalas and koala habitat by increasing flame height and intensity. Such fires kill koalas, and also kill the normally fire-adapted eucalypt species. The threat from these plants is greatest in Zones 1 and 2 where individual habitat patches can be more readily invaded by the pest species, and more readily burned in entirety.

An emerging long term threat to koala habitat in the study area arises from the three species of feral deer inhabiting the region. These browsers eat tree seedlings and ringbark saplings. As numbers and distribution increases, the impacts are expected to become more apparent.

4.3.6 Domestic stock

In certain circumstances, cattle directly threaten koalas, and also inhibit regeneration of koala food tree species.

Cattle mob koalas when they are travelling overland, causing significant injury and death (Melzer, pers. obs., Hill *et al.* 2019). However, this is usually in circumstances where there are no trees for refuge in the vicinity (Melzer pers. obs.).

In heavily grazed landscapes or under particular environmental or stocking conditions, seedlings and saplings of koala food species (e.g. *E. tereticornis*) are browsed. This can result in the loss of a regenerating food tree species cohort in the koala habitat.

4.4 Landscape resilience

Threats to the koalas and their habitat apply across the entire study area. However, the potential impacts vary among the three zones because of historical and current land-use practices (Table 4) with consequent changes to landscape resilience (Thrush *et al*. 2008, SOE 2016). The landscape mosaic in Zones 1 and 2 is vulnerable to incremental loss of habitat patches, particularly with ongoing urbanisation of Zone 2. The dispersal of koalas through this mosaic is also likely to be impeded with increased fragmentation and loss of habitat patches. In Zone 2, the gradual increase in settlement and associated intensification of infrastructure will inevitably increase the magnitude of the threats. The experience from southeast Queensland indicates that without concerted management intervention, it is likely that the Zone 2 koala population will be lost.

Table 4. Risk ranking of general threats to koala populations and habitat as well as overall resilience in Zone 1, Zone 2 and Zone 3 of the Clarke-Connors Ranges Study Area.

Threat	Habitat			Natural disaster		Disease	Vehicle collisions	Feral biota		Climate change	Resilience
	Loss	Fragment	Degrade	Drought	Fire			Dogs	Plants		
Zone											
1	High	High	High	Medium	High	Medium	High	Low medium	High	Medium high	Medium
2	Medium	Medium	High	Medium	High	Low	High	Low medium	High	Medium high	Low
3	Medium	Low	Low	Low	Medium	Low	Low	Low	Low	Low	High

4.5 Management

Rangeland grazing

The majority of the remnant vegetation, and associated koala habitat, is subject to rangeland grazing. It is self-evident that the management practices employed by these land managers have been compatible with the maintenance of a healthy koala population. The perpetuation of this approach is to be encouraged. It would be useful to understand better their approach to apply suitable practices elsewhere. For example, some landowners within the study area and adjacent to the Peak Downs Highway reported using grazing to reduce fire fuel loads. This practice may be reflected in the fire history (see Section 3.3 Fire, and Figure 15). There is a large area of the central study area, encompassing the highway, where large fires have been absent for over a decade. Such an outcome removes the threat to koalas from wildfire, and in some circumstances will allow the establishment of more koala food trees. The likelihood that rangeland grazing practices may enhance koala populations is worthy of further investigation.

Peak Downs Highway

Without intervention, the ongoing koala mortality associated with the Peak Downs Highway will impact local population viability, and individual animal welfare. The road reserve has the potential to act as a population sink, with the surrounding forests providing the source koalas to feed the sink (Lunney *et al*. 2016). There is the potential for the highway to act as a barrier to movement across the highway (ecological barrier) as traffic loads increase and/or as the highway is incrementally upgraded. This could restrict gene flow between the north and south of the study area. However, given the extent, and open nature of koala habitat north and south of the highway, and the wide distribution of koalas across the region, the highway is unlikely to affect the genotype of these populations or the viability of the regional population.

There is also a societal impact. The road-kills are highly visible and there is a high traffic low. So public awareness of the welfare issues to this iconic species is high.

The strategic installation of wildlife barrier fences is likely to reduce the road mortality and lower community concerns. Existing bridges and some culverts meet the specifications to act as koala underpasses. The installation of barrier fences to guide koalas towards the inlet of these structures should assist to maintain population connectivity across the highway. The success of such installations can only be ascertained by monitoring wildlife traffic along the barriers and through the underpasses, as well as monitoring the nature and frequency of road-kills. Their success will require the maintenance of the integrity of the infrastructure, and accessibility of the underpasses.

Strategic planning and management

The lesson from the review of the South East Queensland koala management program was the need for a strategic approach including multiple levels of government, community, NGO's and industry (Rhodes *et al*. 2017). Without the involvement of all the key stakeholders, the regional long-term persistence of the koala was unachievable. A first step is meaningful strategic planning to ascertain the stakeholders, and to define and prioritise the areas of interest (Melzer 2013).

In the Clarke-Connors Ranges Study Area three broad management units are suggested – Zones 1, 2, 3. Key stakeholders for each zone reflect the principal land-users, associated regulatory and planning bodies in State and Local government, as well as key non-government organisations (Melzer 2013).

Given the declining koala abundance and distribution, and degradation of koala habitat generally in Queensland, as well as increasing human population, associated industrial and infrastructural development, together with intensifying climate pressures (e.g. catastrophic fire conditions in spring 2018), a broad management framework for the study area is essential.

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Appendix 1 Geology of the Clarke-Connors Ranges Study Area

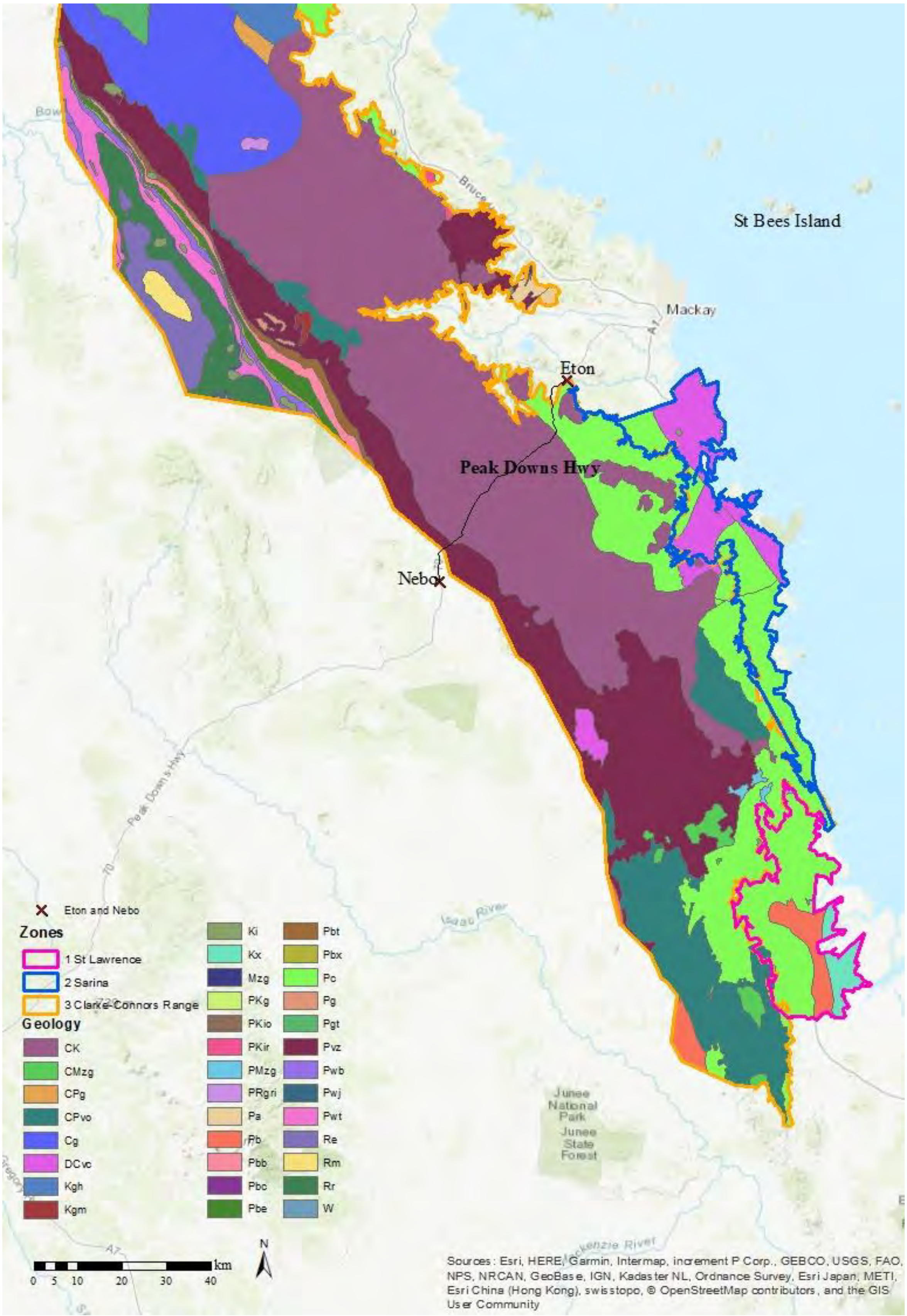

Figure A1.1. Geology of the Clarke-Connors Ranges Study Area. Legend code explained in Table A1.1 below.

Table A1.1. Geological units within the Clarke-Connors Range Study Area. (Extracted from Detailed Geology Release - March 2017. State of Queensland (Department of Natural Resources, Mines and Energy) 2018. Retrieved July 4, 2018 from http://qldspatial.information.qld.gov.au/catalogue/custom/search.page)

Code	Geological Units	Rock Types	Dominant Rock	Age
Pb	Back Creek Group	Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite	Sedimentary Rock	Early Permain - late Permain
Pbe	Blenheim Subgroup	Micaceous siltstone, pebbly in places, labile sandstone, quartzose lithic sandstone, coquinite, limestone	Sedimentary Rock	Late Permain
Pa	Calen Coal Measures	Sandstone, siltstone, carbonaceous mudstone, coal	Sedimentary Rock	Early Permain?
Pbc	Collinsville Coal Measures	Quartzose sandstone, conglomerate, siltstone, coal	Sedimentary Rock	Early Permain
Pbb	Gebbie Subgroup	Quartzose sandstone, lithic labile sandstone, sandy siltstone, siltstone, carbonaceous shale, calcareous sandstone, coquinite, fossiliferous	Sedimentary Rock	Early Permain - late Permain
Re	Clematis Group	Medium to coarse-grained quartzose to sublabile, micaceous sandstone, siltstone, mudstone and granule to pebble conglomerate	Sedimentary Rock	Middle Triassic
Pwj	Rangal Coal Measures, Bandanna Formation, Baralaba Coal Measures	Sandstone, siltstone, mudstone, coal, tuff, conglomerate	Sedimentary Rock	Permain
Pwt	Fair Hill Formation, Fort Cooper Coal Measures	Sandstone, conglomerate, mudstone, carbonaceous shale, coal, cherty tuff	Sedimentary Rock	Permain
Pbx	Exmoor Formation	Quartzose to sublabile sandstone, siltstone, mudstone, rare limestone	Arendite-mudrock	Late Permain
Rm	Moolayember Formation	Micaceous lithic sandstone, micaceous siltstone	Arendite-mudrock	Middle Triassic
Pwb	Moranbah Coal Measures	Labile sandstone, siltstone, mudstone, coal, conglomerate in the east	Arendite-mudrock	Late Permain
Kx	Styx Coal Measures	Quartzose sandstone, green lithic sandstone, mudstone, conglomerate, carbonaceous shale and coal	Arendite-mudrock	Early Cretaceous
Rr	Rewan Group	Lithic sandstone, pebbly lithic sandstone, green to reddish brown mudstone and minor volcanilithic pebble conglomerate (at base)	Arendite-mudrock	Early Triassic - Middle Triassic
Pbt	Tiverton Formation	Lithic sandstone, coquinite, calcareous sandstone and siltstone, conglomerate; fossiliferous	Mixed siliciclastic /carbonate rocks	Early Permain
DCvc	Campwyn Volcanics	Sandstone, siltstone, mudstone (locally with radiolarians), pebbly sandstone, breccia, mafic hyaloclastite, rhyolitic ignimbrite; minor conglomerate, lapilli tuff, limestone	Mixed mafites and felsites (mainly volcanics)	Late Devonian - early Carboniferous
Pc	Carmila beds	Siltstone and mudstone, volcanilithic sandstone and conglomerate and minor altered basalt; local rhyolitic to dacitic ignimbrite and rhyolitic to andesitic volcaniclastic rocks	Mixed volcanic and sedimentary rocks	Early Permain
Kgh	Hecate Granite	Biotite-hornblende granodiorite, biotite adamellite, aplitic microgranite, diorite	Granitoid	Early Cretaceous
Kgm	Mount Barker Granodiorite	Hornblende, biotite granodiorite, diorite	Granitoid	Early Cretaceous
PRgri	Ridgelands Granodiorite	Grey medium-grained biotite-hornblende to hornblende-biotite granodiorite, grey to cream medium-grained biotite-hornblende tonalite to quartz diorite, locally xenolith-bearing	Granitoid	Late Permain - early Triassic
Pgt	Thunderbolt Granite	Pale grey, pale pinkish grey, or pale greyish pink to pale pink, medium-grained, uneven-grained to moderately porphyritic hornblende-biotite monzogranite; with traces of titanite, clinopyroxene, allanite, and scattered mafic inclusions to 30cm (most <10cm)	Granitoid	Early Permain
CK	Urannah Igneous Complex	Hornblende-biotite adamellite and granodiorite, hornblende diorite, quartz diorite, biotite granite, hornblende gabbro, hornblende microdiorite	Granitoid	Carboniferous - Cretaceous

Ki	Ki-CQ	Gabbro, leuco-diorite, quartz hornblende diorite, biotite-hornblende granodiorite, microgranite, rhyolite, trachyte	Granitoid	Early Cretaceous
PMzg	PMzg-BBG	Granite, granodiorite, diorite, gabbro	Granitoid	Permain - Mesozoic
PKg	PKg-BBG	Quartz diorite, granite	Granitoid	Permain - early Cretaceous
Pg	Pg-BBG	Adamellite, granodiorite	Granitoid	Permain
CMzg	CMzg-BBG	Adamellite	Granitoid	Carboniferous - Mesozoic
CPg	CPg-BBG	Granodiorite, adamellite, granite, diorite, gabbro, dolerite, monzonite	Granitoid	Late Carboniferous - early Permian
Cg	Cg-BBG	Granodiorite, adamellite, granophyre, porphyry, tonalite, gabbro, monzonite	Granitoid	Carboniferous
Mzg	Mzg-BBG	Microdiorite, minor hornfelsed sediment	Dioritoid	Mesozoic
PKio	PKio-BBG	Altered porphyritic dolerite	Gabbroid	Permain - Cretaceous
PKir	PKir-BBG	Rhyolite	Felsites (lavas, clastics & high-level intrusives)	Permain - Cretaceous
Pvz	Lizzie Creek Volcanic Group	Basalt and andesite, and interbedded volcaniclastic rocks; generally subordinate dacite, rhyolite, trachyte; conglomerate, labile sandstone, siltstone, calcareous siltstone, shale, carbonaceous shale, locally containing fossil plant fragments; minor coal	Mafites (lavas, clastics & high-level intrusives)	Early Permain
CPvo	Connors Volcanic Group	Felsic to mafic volcanic rocks; rhyolitic to andesitic flows, high-level intrusives, and volcaniclastic rocks including ignimbrite	Mixed mafites and felsites (mainly volcanics)	Carboniferous - early Permian
W	Water body	Water body, unspecified	Water bodies	Water bodies

Appendix 2. Broad vegetation groups of the Clarke-Connors Ranges Study Area

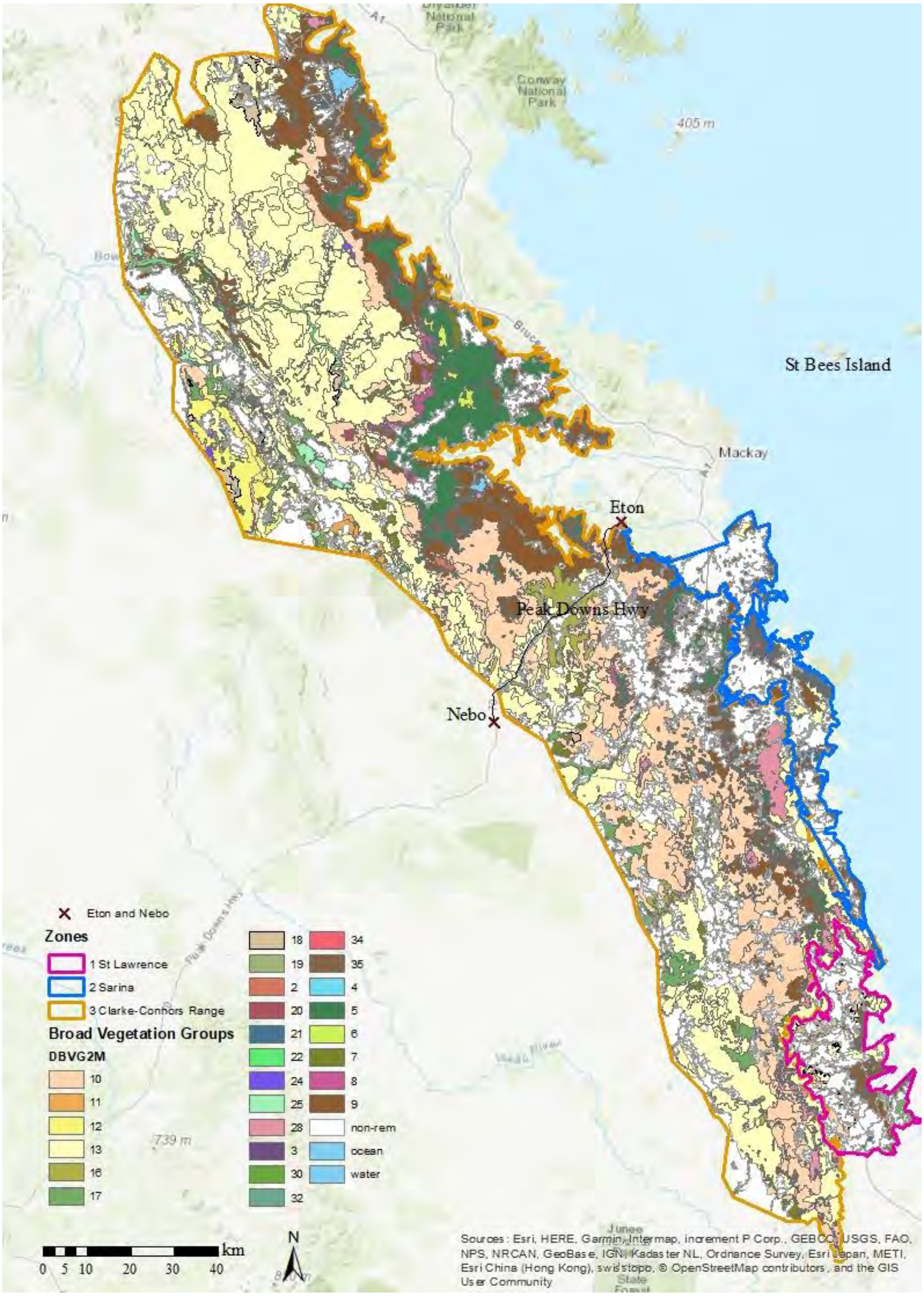

Figure A2.1. Broad Vegetation Groups of the Clarke-Connors Ranges Study Area. Map units are described in Table A2.1 below.

Table A2.1. Broad vegetation groups within the Clarke-Connors Range Study Area.

(Queensland Government Regional Ecosystem Descriptions, Broad Vegetation Groups, Accessed 5/10/2018 https://publications.qld.gov.au/dataset/redd/resource/1df33499-435c-42f7-bec2-ac311a2d521d)

Map Unit	Broad Vegetation Group
2	Complex to simple, semi-deciduous mesophyll to notophyll vine forest, sometimes with *Araucaria cunninghamii* (hoop pine).
3	Notophyll vine forest/ thicket (sometimes with sclerophyll and/or Araucarian emergents) on coastal dunes and sandmasses.
4	Notophyll and mesophyll vine forest with feather or fan palms on alluvia, along streamlines and in swamps on ranges or within coastal sand masses.
5	Notophyll to microphyll vine forests, frequently with *Araucaria* spp. or *Agathis* spp. (kauri pines)
6	Notophyll vine forest and microphyll fern forest to thicket on high peaks and plateaus.
7	Semi-evergreen to deciduous microphyll vine thicket.
8	Wet eucalypt tall open forest on uplands and alluvia.
9	Moist to dry eucalypt open forests to woodlands usually on coastal lowlands and ranges.
10	*Corymbia citriodora* (spotted gum) dominated open forests to woodlands on undulating to hilly terrain.
11	Moist to dry eucalypt open forests to woodlands mainly on basalt areas.
12	Dry eucalypt woodlands to open woodlands, mostly on shallow soils in hilly terrain.
13	Dry to moist eucalypt woodlands and open forests, mainly on undulating to hilly terrain of mainly metamorphic and acid igneous rocks.
16	*Eucalyptus* spp. dominated open forest and woodlands drainage lines and alluvial plains.
17	*Eucalyptus populnea* (poplar box) or *E. melanophloia* (silver-leaved ironbark) (or *E. whitei* (White's ironbark)) dry woodlands to open woodlands on sandplains or depositional plains.
18	Dry eucalypt woodlands to open woodlands primarily on sandplains or depositional plains.
19	*Eucalyptus* spp. (*E. leucophloia* (snappy gum), *E. leucophylla* (Cloncurry box), *E. persistens, E. normantonensis* (Normanton box)) low open woodlands often with *Triodia* spp. dominated ground layer.
20	Woodlands to open forests dominated by *Callitris glaucophylla* (white cypress pine) or *C. intratropica* (coast cypress pine)
21	*Melaleuca* spp. dry woodlands to open woodlands on sandplains *or* depositional plains.
22	*Melaleuca* spp. on seasonally inundated open forests and woodlands of lowland coastal swamps and fringing lines. (palustrine wetlands).
24	*Acacia* spp. on residuals. Species include *A. clivicola, A. sibirica, A. shirleyi* (lancewood), *A. microsperma* (bowyakka), *A. catenulata* (bendee), *Acacia rhodoxylon* (ringy rosewood).
25	*Acacia harpophylla* (brigalow) sometimes with *Casuarina cristata* (belah) open forests to woodlands on heavy clay soils.
28	Open forests to open woodlands in coastal locations. Dominant species such as *Casuarina* spp., *Corymbia* spp., *Allocasuarina* spp. (she-oak), *Acacia* spp., *Lophostemon suaveolens* (swamp box), *Asteromyrtus* spp., *Neofabricia myrtifolia.*
30	*Astrebla* spp. (mitchell grass), *Dichanthium* spp. (bluegrass) tussock grasslands.
32	Closed tussock grasslands in coastal locations.
34	Wetlands associated with permanent lakes and swamps, as well as ephemeral lakes, claypans and swamps. Includes fringing woodlands and shrublands.
35	Mangroves and tidal saltmarshes.

Attachment 1: Melzer, A. and Tucker, G. (2011) Koalas of the St Lawrence Region of Central Queensland.

Attachment 2: Ellis, W., FitzGibbon, S., Bath, B. *et al*. (2018) Koalas of the Clarke-Connors Range.

Attachment 3: Schlagloth, R. (2018) Managing Central Queensland's Clarke-Connors Range koala population: Predicting future koala road-kill hotspots.

Attachment 4: Melzer, A., and Black, L. (2018) Infrastructure investment opportunities on the Nebo to Eton stretch of the Peak Downs Highway, Central Queensland.

Attachment 5: Melzer, A., Black, L. and Gottke, A. (2018) Wildlife mortality on the Nebo to Eton stretch of the Peak Downs Highway