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Investigation of the Impact of Roads on Koalas

Prepared by Australian Museum Business Services for the NSW Roads and Traffic Authority

Final Report

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1 Introduction

1.1 Introduction

This report summarises the results of the project *Impact of Roads on Koalas*. The project was funded by the NSW Roads and Traffic Authority (RTA) and implemented by Australian Museum Business Services (AMBS).

This project commenced in 1999 and extended until 2010. It included two study areas on and near the Pacific Highway in north-east New South Wales. One study area was associated with the construction of the Yelgun to Chinderah Bypass, while the other was associated with the upgrade of the Pacific Highway at Bonville. Included in this report are the results of a related study on how fauna (including Koalas) used a highway underpass at Raleigh, at the southern end of the Bonville study area.

1.2 Background

Roads can have major effects on wildlife and their habitats by reducing habitat quality, encouraging the spread of invasive species, and providing greater human access to undeveloped areas. Roads can impact on populations of vertebrate wildlife by, for example: removing, altering or and/or fragmenting habitat; causing mortalities by vehicle collisions (road-kill); imposing barriers or filters to wildlife movements; and causing animals to modify their behaviour (Taylor and Goldingay 2010; Trombulak *et al.* 2000). The types, severity and duration of these impacts can differ between the 'construction' and 'operation' phases of the roads.

The NSW Roads and Traffic Authority (RTA) is the NSW State Government authority that builds major roads, promotes road safety, manages traffic, regulates vehicles and licenses drivers. The RTA's responsibilities in 2011 include the management of 17,984 km of State roads, 4,316 km of national highways and nearly 2,878 km of regional roads and local roads (RTA 2011). In addition, the RTA and NSW local governments are jointly responsible for maintaining the roadside environment for most of the roads in NSW and the RTA provides support to local councils to manage regional roads and local access roads (RTA 2011). As such, the policies applied and actions taken by the RTA and its contractors have the potential to have a major influence on the environmental outcomes and management of ecological impacts of most major roads and highways and many of the smaller roads in NSW.

One of the RTA's major projects is the Pacific Highway upgrade. The Pacific Highway is one of Australia's busiest and most important interstate routes. It is the main connection between Australia's largest and third largest cities (Sydney and Brisbane, respectively), and also links the numerous towns and communities of the NSW North Coast. It is thus a fundamental piece of the State's infrastructure and vital to the NSW and National economies. The highway upgrade project is intended to improve safety, reduce travel times and accommodate growing traffic volumes. It includes the construction of a number of new sections and widening or safety improvements to other sections between Hexham and Tweed Heads. Much work on the highway has been undertaken in the past 15 years and the work is continuing.

The Pacific Highway passes through areas of habitat for the Koala, *Phascolarctos cinereus*, in numerous locations. The Koala has a fractured distribution and, in NSW, it occurs mainly on the central and north coasts (Reed and Lunney 1990), as does the route of the Pacific Highway. The Koala is an arboreal, marsupial mammal, dependant on the eucalypt forests of Australia's east coast, and is an Australian wildlife icon. The Koala is listed as a Vulnerable species in NSW under the *Threatened Species Conservation Act 1995*.

Roads are considered to pose significant threats to Koala populations because of their contribution to habitat loss, fragmentation and degradation, and because of the high vulnerability of Koalas to death and injury from collisions with motor vehicles (DECC 2008). Koalas also seem vulnerable to low genetic diversity as a result of genetic bottlenecking (DECC 2008), and it is possible that roads may exacerbate this by acting as barriers to gene flow.

The RTA has been implementing measures to try and reduce the impact of the Pacific Highway on Koalas since the early 1990s and has had some success (DECC 2008). One such measure has been the use of various designs of exclusion fencing to keep Koalas off roads and away from potential collisions. However, exclusion fencing, by its nature, hinders dispersive movements and therefore may exacerbate the barrier effect of roads and the fragmentation of habitats. To counter this there has been considerable development of fauna crossing structures (as complimentary mitigation measures to exclusion fencing), to provide safe passage across roads for Koalas and other wildlife. Other measures have included signage, imposition of speed limits, lighting and education programs to reduce the speed and increase the awareness of drivers and reduce the likelihood of road users colliding with Koalas (DECC 2008). These other measures are likely to be more applicable and successful on local and minor roads than on national routes such as the Pacific Highway.

The environmental impact assessment processes for two sections of Pacific Highway upgrades in known Koala areas (the Yelgun to Chinderah Bypass and the Bonville Upgrade; see Figure 1) in the late 1990s placed considerable focus on the potential impacts on Koalas and highlighted the conflict between the need to upgrade the highway and the need to conserve Koalas and other wildlife. The findings of ecological assessments, concerns raised by public input and commentary, and project approval conditions imposed by consent authorities implementing NSW environmental legislation and policy culminated in the recognition that greater understanding was needed about the impacts of roads on Koalas and the effectiveness of standard mitigation measures being proposed. In 1999 the RTA commissioned this study, *The Impact of Roads on Koalas* (hereafter referred to as "the study"), to examine the effects of road construction and operation on Koalas.

1.3 Aims and Objectives

The two key aims of this study were to examine the:

1) impacts of road construction and operation on koala populations;
2) measures to ameliorate negative impacts of roads on Koalas.

Specific objectives of the study were to:

- review relevant information regarding Koala biology, impacts of roads and amelioration measures;
- determine, in consultation with RTA, State Forests and NPWS staff, sites for research and monitoring for the study;
- examine the movement patterns and home ranges of Koalas and monitor changes in movement behaviour;
- examine the levels of road injury/mortality;
- examine the relative effectiveness of selected amelioration measures.

The main techniques used for this project included:

- literature review;
- capture, tagging and health checks of Koalas;
- radio-tracking of individual Koalas;
- scat transects;
- preliminary analysis of DNA recovered from tissue samples and scats;
- veterinary autopsies of dead Koalas and health assessment of sick Koalas;
- collection of road mortality statistics;
- Koala clearance surveys and monitoring prior to and during vegetation clearing;
- remote camera surveillance or sand tray monitoring of fauna movement structures.

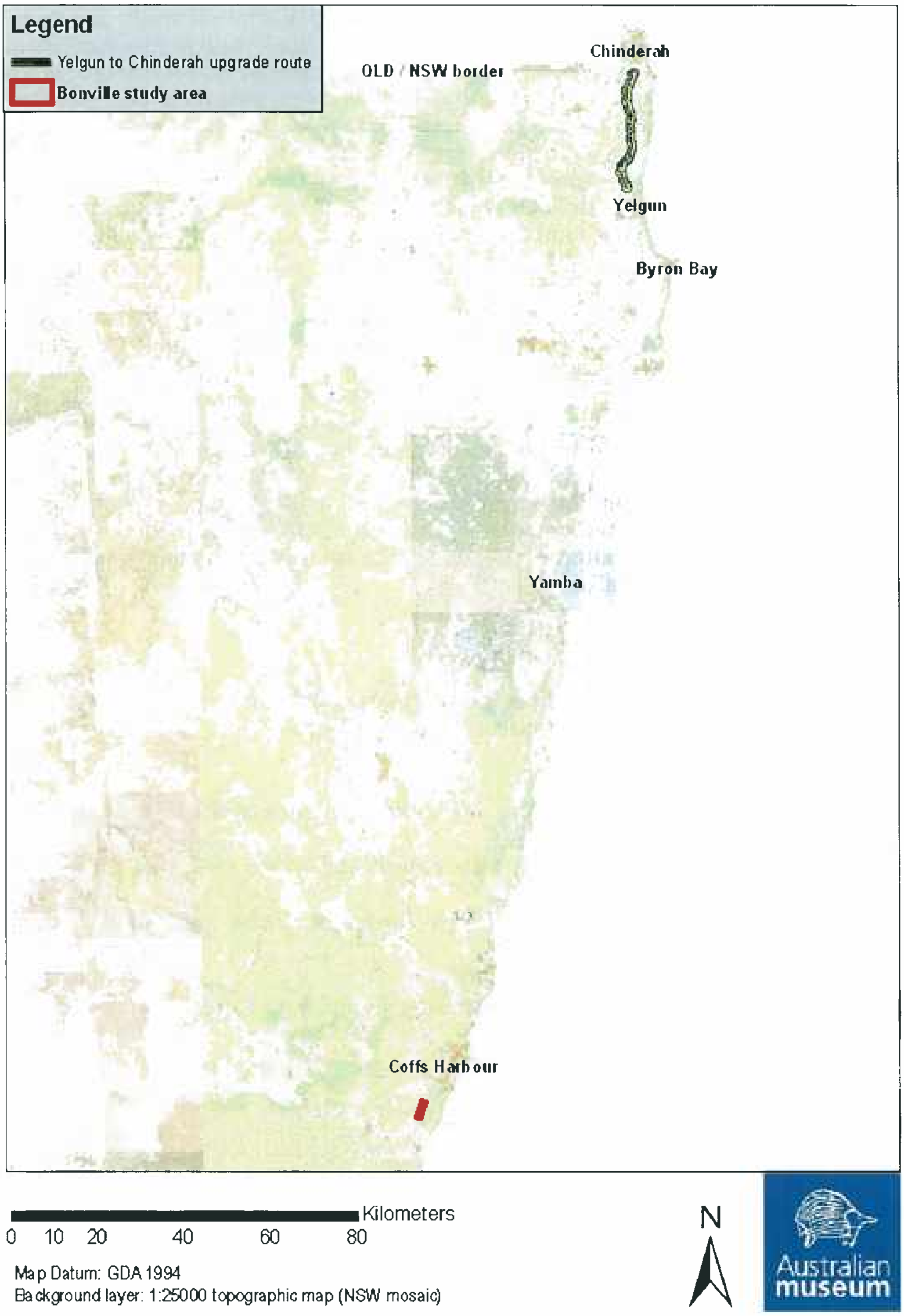


Figure 1: Locations of the Bonville and Yelgun to Chinderah study areas

2 Methods

2.1 Study Design

This study comprises a number of different survey and assessment techniques for monitoring Koalas that were implemented between 1999 and 2011. The field component of the study was conducted in two separate study areas, both along the Pacific Highway in north-eastern New South Wales (Figure 1). One study area (and sub-project) was located between Yelgun and Chinderah and the other was at Bonville. In each study area this project aimed to assess the impact on resident Koala populations from the upgrade of the existing two-lane highway to a four-lane, dual carriageway highway with limited access.

Monitoring programs at both the Bonville and Yelgun to Chinderah study areas were undertaken over three experimental stages: before, during, and after construction (Table 1). A range of direct and indirect methods were used (Table 1) and while these methods were often similar for both study areas, there were differences, as described in various sections of the report below. The project schedules at each site were dictated to a large extent by the highway construction schedules.

2.2 Bonville Study: Design and Constraints

2.2.1 Bonville Study Area

The Bonville study area is located approximately 18 km south of Coffs Harbour (Figure 1, Figure 2, Figure 3) where the highway passes through Bongil Bongil National Park. The National Park includes much of the former Pine Creek State Forest, an area (5,890 ha) of mixed hardwood native forest (3,925 ha) and plantation timber (1,965 ha). The forests are dominated by tall Tallowwood (*Eucalyptus microcorys*), Grey Gum (*E. propinqua*), Flooded Gum (*E. grandis*) and Blackbutt (*E. pilularis*) but also contain a mix of other Eucalypts and some rainforest elements. The proposed highway realignment through Pine Creek State Forest was selected in 1997 and aimed to minimise environmental impacts such as habitat severance and fragmentation, and edge effects, by following the existing highway corridor as closely as possible.

The study area comprised forest habitats up to 500 m either side of a 3 km section of highway between Perry's property, Raleigh in the south and Pine Creek in the north. This mainly comprised the area between the highway and the powerline easement to the west, the area between the highway and Balls Ridge Road to the northeast and accessible parts of the area between Overhead Bridge Road and Perry's property boundary to the southeast.

NSW State Forests undertook selective logging operations east of the highway in 2005, leaving approximately 40% of stems (M. Smith, pers. comm.).

2.2.2 Bonville Upgrade Construction Schedule

The design and impact assessment stages for the Bonville Upgrade were completed by 1999, prior to the commencement of this study. Major works for the new highway alignment commenced in late 2006. These included the clearing of vegetation, earthworks and road construction activities along the new highway alignment and in associated work areas (including service roads, compounds, lay down areas, etc.). This 'construction site' formed a north-south disturbance corridor through the study area. Vegetation clearing within the construction site mainly occurred from 8 December 2006 to 15 February 2007. Major construction works continued to late 2008. Traffic movement through the study area during 2007-2008 was maintained along the existing highway and on constructed service roads.

Fauna impact mitigation measures were constructed sequentially between June 2007 and June 2008, including:

- temporary fauna exclusion ('floppy-top') fences along the perimeter of the construction site;
- partial completion of permanent fauna exclusion fences along the new highway alignment;
- installation of permanent and temporary signage to enhance driver awareness;
- construction of a fauna underpass in the form of a 3 x 3 m box culvert approximately 100 m long at Raleigh (replacing the shorter box culvert / fauna underpass under the old highway);
- partial completion of a fauna underpass in the form of a 30 m wide bridge (known as Infra 2), located over a gully between Mailmans Track and Overhead Bridge Road; and
- partial completion of a fauna overpass (known as Infra 3) to the north of Overhead Bridge Road.

The new highway alignment was opened to traffic on 16 September 2008. Much of the temporary fauna fencing south of Overhead Bridge Road was removed in September 2008, opening the Raleigh underpass to possible fauna movement. Most of the major and ancillary works were completed by the end of December 2008. However, some construction continued after the switch, including construction of a truck stop at the former Sid Burke rest area, the on and off-ramps at Mailman's Track and works on the service roads. Temporary fauna fences were kept in place to the north of Overhead Bridge Road until late November 2008, while work on the permanent fauna fence and the Infra 3 land bridge continued.

All fauna movement structures and permanent fauna fences were completed and all temporary fauna fences removed by March 2009. Site management from early 2009 mainly involved maintenance of fauna fences and land bridge vegetation.

During December 2009, additional fauna exclusion fencing was installed at two locations in the study area an attempt to reduce Koala road mortalities that had recently occurred. This was installed at:

- the south eastern boundary between Perry's property and Bongil Bongil National Park, perpendicular to the highway; and
- an extension from south of Infra 2 towards Mailmans Track overbridge.

2.2.3 Bonville Study Schedule

The original schedule for the Bonville study involved three phases of 2 years duration each (pre-construction, during construction and post-construction), implemented consecutively over the 6-year period from 2000 to 2006. Changes to the construction timetable meant the study was largely suspended from late 2002 to late 2006. The final schedule was 2000 to 2002 and 2006 to 2010 (Table 1).

The move from Phase 1 to Phase 2 was marked by the 4-year suspension of the study. The move from Phase 2 to Phase 3 began in September 2008 with the opening on the new highway, but was effectively gradual due to ongoing roadworks, construction of permanent mitigation measures and removal of temporary mitigation measures. Monitoring of fauna movement structures largely commenced during December 2008 and January 2009.

A monitoring study of the original Raleigh underpass, at the southern end of the (then) Pine Creek State Forest, was undertaken from August 1999 to December 2000 (AMBS 2000a, 2001c) prior to the main study at Bonville. Monitoring fauna using this underpass was conducted in two phases: monitoring using sand plots was carried out for a period of 7 months from August 1999 to March 2000; and from April 2000, a remote camera system with flash unit and infra red trip beam was installed in the tunnel. Sand plot monitoring was continued alongside the remote camera.

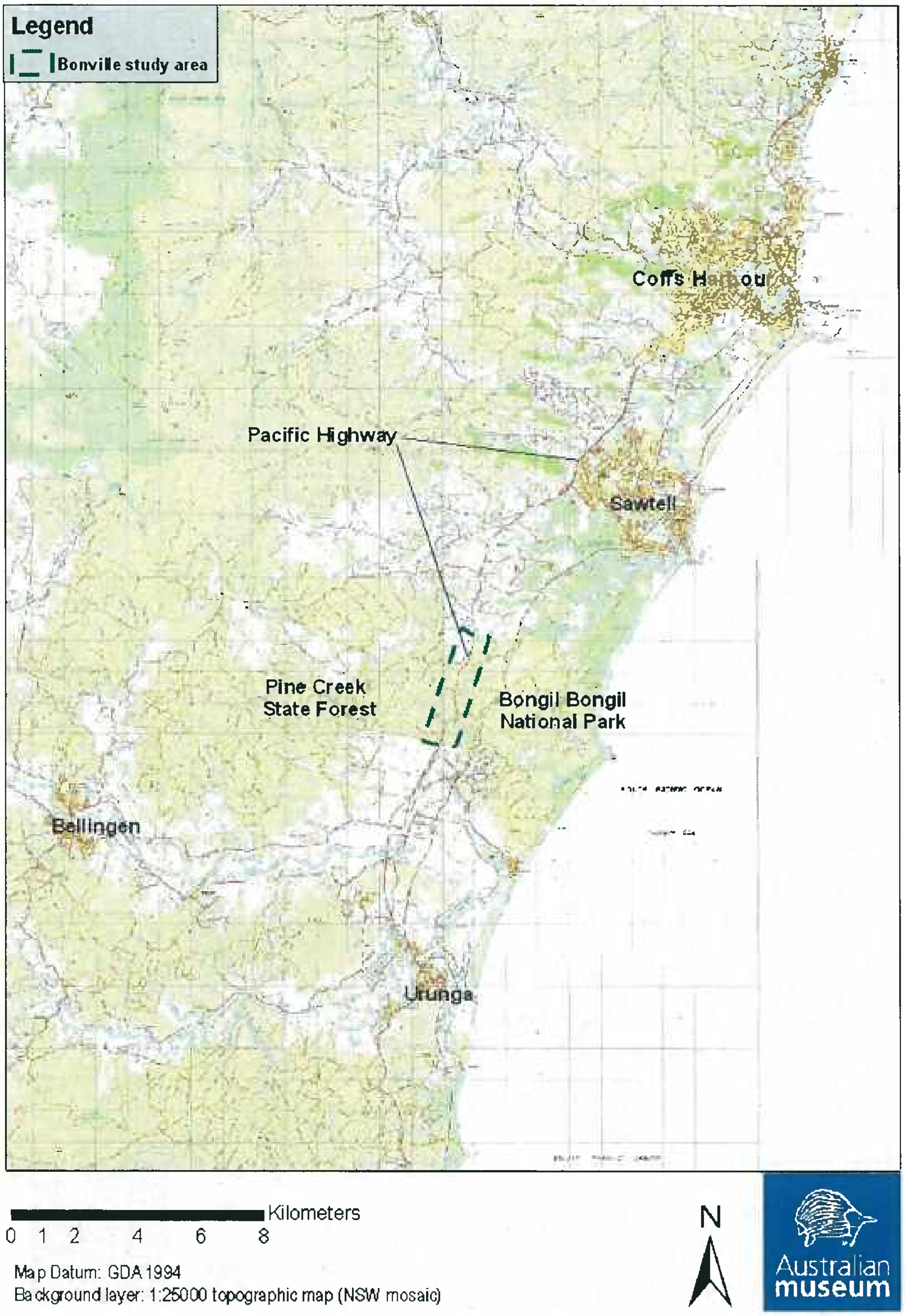


Figure 2: Location of the Bonville study area

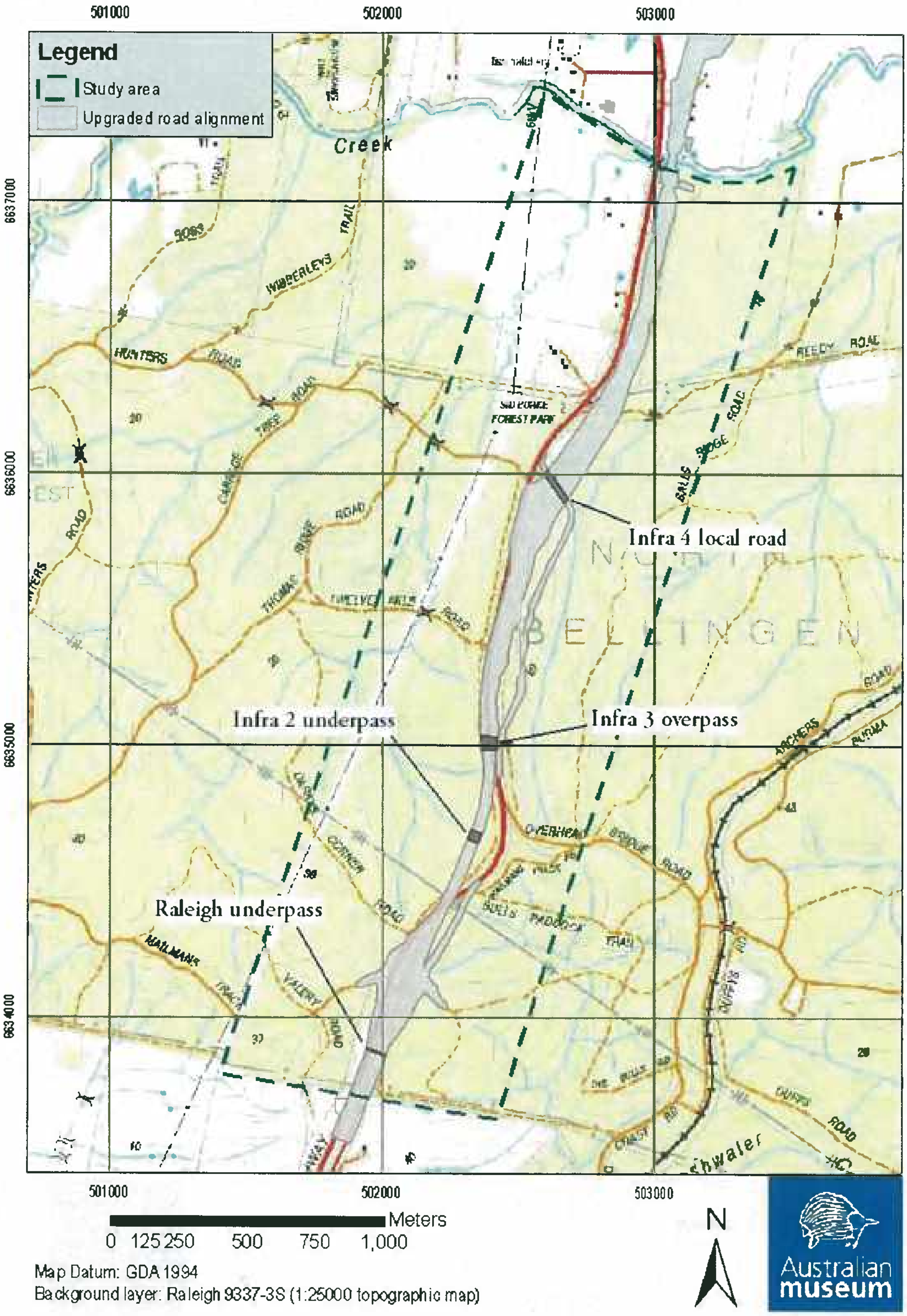


Figure 3: Layout of the Bonville study area

Table 1: Study schedules and methods for investigating the impacts of roads on Koalas at the Bonville and Yelgun to Chinderah study areas

Method / Phase	Bonville	Yelgun to Chinderah
Phase 1 – pre-construction	September 2000– September 2002	October 1999 – May 2000
Phase 2 – during construction	September 2006– September 2008	May 2000 – August 2002
Phase 3 – post-construction	September 2008– September 2010	August 2002 – August 2004
Koala capture surveys	✓	✓
Radio-tracking	✓	✓
Home-range estimation	✓	✓
Road mortalities	✓	–
Scat transects	✓	–
Scat quadrats		✓
Monitoring fauna movement structures (cameras)	✓	–
Monitoring fauna movement structures (Plot monitoring)	✓	✓
DNA studies	✓	✓

2.1 Yelgun to Chinderah Study: Design and Constraints

2.1.1 Yelgun to Chinderah Study Area

The Yelgun to Chinderah study area was a 30 km x 500 m strip along the Pacific Highway between near the towns of Yelgun in the Byron Shire (in the south), and Chinderah in the Tweed Shire, just south of the NSW-Queensland border (Figure 1, Figure 4). Compared with the Bonville study area, this is a much larger, diverse and more fragmented site. The natural habitats of the study area range from the relatively heavily-wooded Burringbar Range on the western boundary, to the broad, flat, coastal plain stretching to the Pacific Ocean in the east. However, much of the study area has been cleared for agriculture.

In the Tweed Shire, historical development impacts have reduced former heavily-forested areas to patches of native forest interspersed with urban development within an agricultural landscape (e.g., banana and sugar cane plantations). Koala populations here appear to be fragmented and under pressure from ongoing, clearing and development. Koala habitat occurs close to the highway in only a few locations, involving small areas. However, substantial Koala populations were present at locations several kilometres from the highway on both eastern and western sides along the length of the bypass.

2.1.2 Yelgun to Chinderah Bypass Construction Schedule

The design and impact assessment stages for the Yelgun to Chinderah Bypass were completed by 1999, prior to the commencement of this study. Major works for the new highway alignment commenced with vegetation clearing along the selected route from May 2000. Clearing started at the Eviron Road site on 23 May 2000 and at 'The Hill' (cut 36) on 26 June 2000. Highway and infrastructure construction continued for slightly over 2 years, and the upgraded road was opened in August 2002.

2.1.3 Yelgun to Chinderah Study Schedule

A little over 7 months was available to complete Phase 1 one of the Yelgun to Chinderah study. Phase 2 extended from May 2000 to August 2002, after which the study entered the Phase 3 post construction monitoring (Table 1). The project included the construction of two fauna overpasses and three fauna underpasses. Koala movements on three of these structures were monitored by undertaking scat surveys in fixed quadrats on a quarterly basis in Phase 3 (see Section 2.2.6).

Figure 4: Layout of the Yelgun to Chinderah study area showing Koala capture sites

2.2 Field Survey Methods

2.2.1 Pilot Surveys

In the Yelgun to Chinderah study area, initial scat surveys and discussions with local landholders were conducted to determine the location of Koala populations. Local breeding populations were found within several hundred metres of the existing highway, in most areas where there was suitable habitat. Six locations were targeted to capture and radio-collar Koalas (Figure 4). Despite the evidence of Koala presence along most ridge-lines, evidence suggested that the densities of Koalas in these areas were not high. Local residents were encouraged to report Koala sightings, so additional animals could be captured, tagged and radio-collared throughout the course of the project.

At the Bonville site, prior studies and local knowledge by members of the study team negated the need for pilot studies.

2.2.2 Capturing Koalas

Koala capture surveys were undertaken during each phase of the project, with the aim of capturing and radio-collaring a sample of the Koalas occupying the study area (Figure 3). Dates of each capture survey are shown in Table 2 and the methods used during each survey are described below.

Table 2: Koala capture survey dates at Bonville study area

Survey Dates	Project Phase
2000, 11-23 September	Phase 1, first capture survey
2001, 6-10 September	Phase 1, replacement of radio-collars from 2000 capture survey
2002, 30 September - 3 October	Phase 1, removal of radio-collars
2002-2006	Radio-tracking suspended
2006, 5-10 June	Phase 2, first capture survey
2006, 13-19 September	Phase 2, second capture survey
2007, 22-30 September	Phase 2, third capture survey
2008, 15-24 September	Phase 3, first capture survey
2009, 21-30 September	Phase 3, second capture survey
2010, 6-10 September	Phase 3, removal of radio-collars

Searches within the study area were carried out during daylight hours in capture survey periods. During the searches, trees were visually scanned for the presence of Koalas, with particular focus on potential feed trees. Searches were also made for other signs of Koala presence, including scats, skeletal material, fur and scratchings on tree trunks. In general, surveys were carried out along the network of tracks or along forest edges, in order to maximise the potential to locate Koalas within the available timeframe.

Two methods were used to capture Koalas. In 2000 the 'flagging' method was used. This typically involved four people (Figure 5) where Koalas were waved down by two climbers with flags attached to a long pole, with a third 'flagger' positioned on the ground to assist as the Koala descended. A fourth person would be positioned near the base of the tree to capture the Koala by hand and place it in a hessian sack. On rare occasions when a Koala was low enough in a tree, this capture technique could be used without the climbers.

From 2001, the 'fence and trap' method (Phillips 2011) was used more frequently due to the hazards in capturing Koalas in high trees (up to 40 m high). This method involved erecting a corr-flute fence to form an enclosure around the base of a tree (or trees) in which a Koala had been found and placing a metal cage-trap (60 x 30 x 30 cm) as a 'false' exit through the fence

(Figure 6). When the Koala descended from the tree it generally followed the fence until entering the cage-trap. Traps were set during the day and checked every 2-3 hours during the night until the Koala was caught or it escaped.

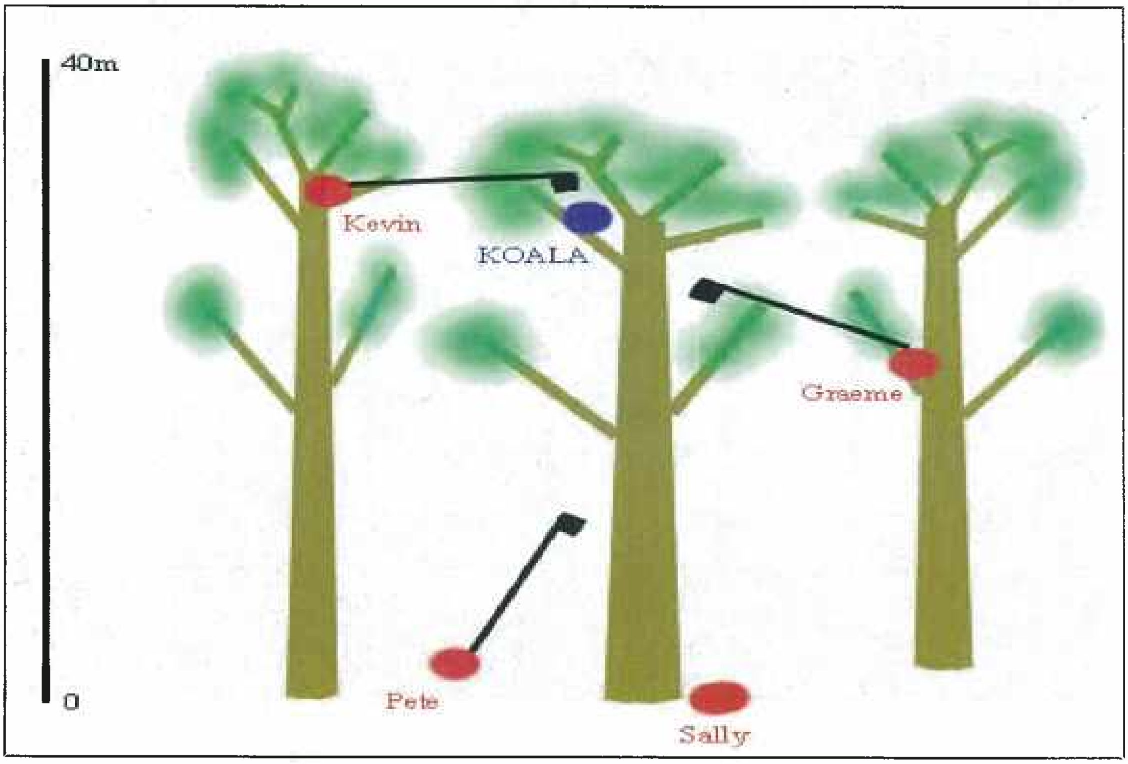


Figure 5: Sketch demonstrating the 'flagging' method for Koala capture

Figure 6: Design of ground trap for Koalas

Once captured, the Koala's health was assessed and details recorded of age, sex, weight, body measurements, and presence of pouch or back young (for females). All Koalas except sick animals or pouch young were ear tagged using coloured tags. The tags were engraved with unique numbers for identification of individual Koalas. One tag was placed in each ear, to reduce the likelihood of a Koalas identity being lost if a single tag fell off. Different coloured tags were used in unique combinations on the two ears so that Koalas could be recognised visually without being captured.

Overall health of the animals was a prime determinant in assessing their ability to carry a collar and therefore their long-term inclusion in the research. Visual assessment of the health of each animal (clinical signs of disease, body condition, age) was made at point of capture by Professor Rob Close, with advice on this matter sought from members of the WIRES if required. Koalas considered too unhealthy for release were transported to a Veterinary Hospital in for assessment by a vet experienced in the treatment of this species. In most cases a blood sample and a sample of ear tissue were taken for pathology and DNA analysis.

2.2.3 Radio-telemetry Studies

Koalas deemed fit for radio-telemetry studies were fitted with a collar carrying a transmitter and battery pack specifically designed for Koalas (manufactured by Titley Electronics). Collars were fitted around the animal's neck with sufficient room for it to slip over the head should it get caught on tree branches.

Collared Koalas were returned to the point of capture, released, and watched until they secured themselves in a sitting position in a tree. The animal's behaviour during capture and release was recorded. Pouch young were left in the pouch at all times unless they left the pouch of their own volition. All young were transported with their mothers in the same hessian bags. Hessian bags were washed and sterilised with bleach between uses.

All Koalas with radio-collars were monitored during the reporting period by tracking on foot with a hand-held receiver. Koalas were tracked once each day for the first 2 weeks after being collared (or re-collared) in order to assess their reaction to the capture and/or collar and check for signs of stress. After the first 2 weeks the Koalas were tracked every second day for another 1-2 weeks, then once a week or once a fortnight, depending on the range of movements and behaviour of the individual. This monitoring regime follows the recommendations of Bali and Delaney (1996). Koalas fitted with radio-collars were recaptured no more than 12 months after the initial fitting to remove or replace the collar.

During tracking events, the location of each Koala was determined as accurately as possible. Positioning with a hand-held GPS was the preferable method but this was rarely possible under the forest canopy. Position was normally plotted on topographic map by dead reckoning from a known landmark. Once the Koala was located, details recorded included the tree species, height of the Koala in tree, visibility, presence of pouched/back young, apparent health, and any noteworthy observations.

Home-ranges of individual Koalas were calculated using the kernel (KNL) algorithm within Arcview 3.2 spatial analysis package. Each home-range is based on (in most cases) over 25 location records from an individual. Recent evaluations point to the kernel (KNL) model being the most mathematically robust of all currently available estimation techniques (Harris *et al.* 1990; Seaman and Powell 1996; Kenward and Hodder 1996). However home-range estimates should be seen only as a general indication rather than exact measure of an animal's area of activity (Boulanger and White 1990).

2.2.4 Tree Use

In the Bonville study, the species of trees used by Koalas during the day were recorded when monitoring radio-tracked individuals. This monitoring occurred during all three phases of the highway upgrade with the tree species identified each time a Koala was located and recorded. Sometimes the species of tree could not be determined with confidence, generally due to the Koala not being visible and introducing uncertainty in relation to which tree it was in. Tree species identified with low confidence were omitted from the analyses.

The data were examined in terms of:

- the number of individual trees in which individual Koalas were observed;
- the number of species of trees in which individual Koalas were observed;
- a comparison of the number of trees and number of species of trees, with the length of time that Koalas were radio-racked;
- a comparison of tree use between the phases of the highway upgrade.

2.2.5 Road Mortality Monitoring

Road mortalities were recorded in the Bonville study area from the commencement of the project in late 1999 until the end of 2010. A variety of people inspected the Pacific Highway throughout the course of the project for injured or dead Koalas, including local sub-contractors, and personnel from NPWS, RTA, AbiGroup, WIRES and Bilfinger Berger Services Pty Ltd. During Phase 2 (construction), AbiGroup reported observations of any Koalas to the RTA and to AMBS. During Phase 3 (post-construction) Bilfinger Berger Services Pty Ltd were contracted by the RTA to undertake routine monitoring of the Pacific Highway for injured or dead Koalas.

The exact location and date were recorded. Carcasses were assessed in the field to determine the sex, whenever possible. Skulls of road-killed Koalas were collected and labelled for laboratory study. These were used by Dr R. Close to classify road-killed animals into three age-classes, based on the degree of tooth-wear, as follows:

- Juvenile: >1 yr old;
- Subadult: 1-2 yrs old;
- Adult: > 3 yrs old.

In the Yelgun to Chinderah study area, local people were encouraged to report sightings of road-killed Koalas. Local sub-contractors and personnel from the RTA were also required to report any recordings of injured or dead Koalas.

Tissue samples were collected from road-kill carcasses, whenever possible, to contribute to genetic studies.

2.2.6 Scat Surveys

Standardised Scat Transects

Standardised scat transects were conducted in the Bonville study area during 2000, 2006, 2008 and 2009 to encompass all phases of the highway project (Figure 7). Transects were 500 m in length where possible and scats were searched for near the base of trees within an area of 5 m either side of the centre of the transect. The presence of scats at the base of a tree was recorded and the age of the scats was estimated as being old, intermediate or fresh. Other data recorded for each scat record were tree species, diameter of the tree at breast height and the distance of the tree from the centre of the transect. A total of 19 transects were conducted in 2000, and 16 transects each in 2006, 2008 and 2009. (The decrease in number of transects was due to parts of the study area being logged in 2006). The locations of the transects from 2006 to 2009 were not exactly the same as in 2000 because the highway construction removed some of the habitat that had been surveyed previously.

Scat transects served two purposes. They provided indices of relative abundance of Koalas in the study area over time to assess population trends. Also scats found during the transects undertaken in 2000 were collected to extract donor DNA for genetic studies (see Sections below on faecal DNA).

Fence Transects

In the Bonville study area, scat searches were conducted along the length of the permanent fauna exclusion fences to determine if Koalas were approaching the new fauna fencing. Searches were undertaken along transects by walking outside the length of the fauna fence and searching for scats within 5 m of the fence. In most areas the 5 m-wide transect extended to the edge of the vegetation, however in a few areas the area was extended to 10 m where the edge of the vegetation was further from the fence (e.g. near the Raleigh underpass). Transects of the entire fence line on both sides of the highway were conducted on the following dates:

- 22 January 2009;
- 4 March 2009;
- 2-3 September 2009;
- 18-19 July 2010.

Scat Quadrat Monitoring

In the Yelgun to Chinderah study area scat quadrats (also called plot monitoring) were monitored quarterly during Phase 3 at the following locations:

- the overpasses at Taggarts Hill;
- above the road tunnel in Chinderah;
- on the large fauna overpass at the Yelgun end of the upgrade.

At each site Steve Phillips examined set 10 x 10 metre quadrats searching for all evidence of Koala activity and the presence of known food trees.

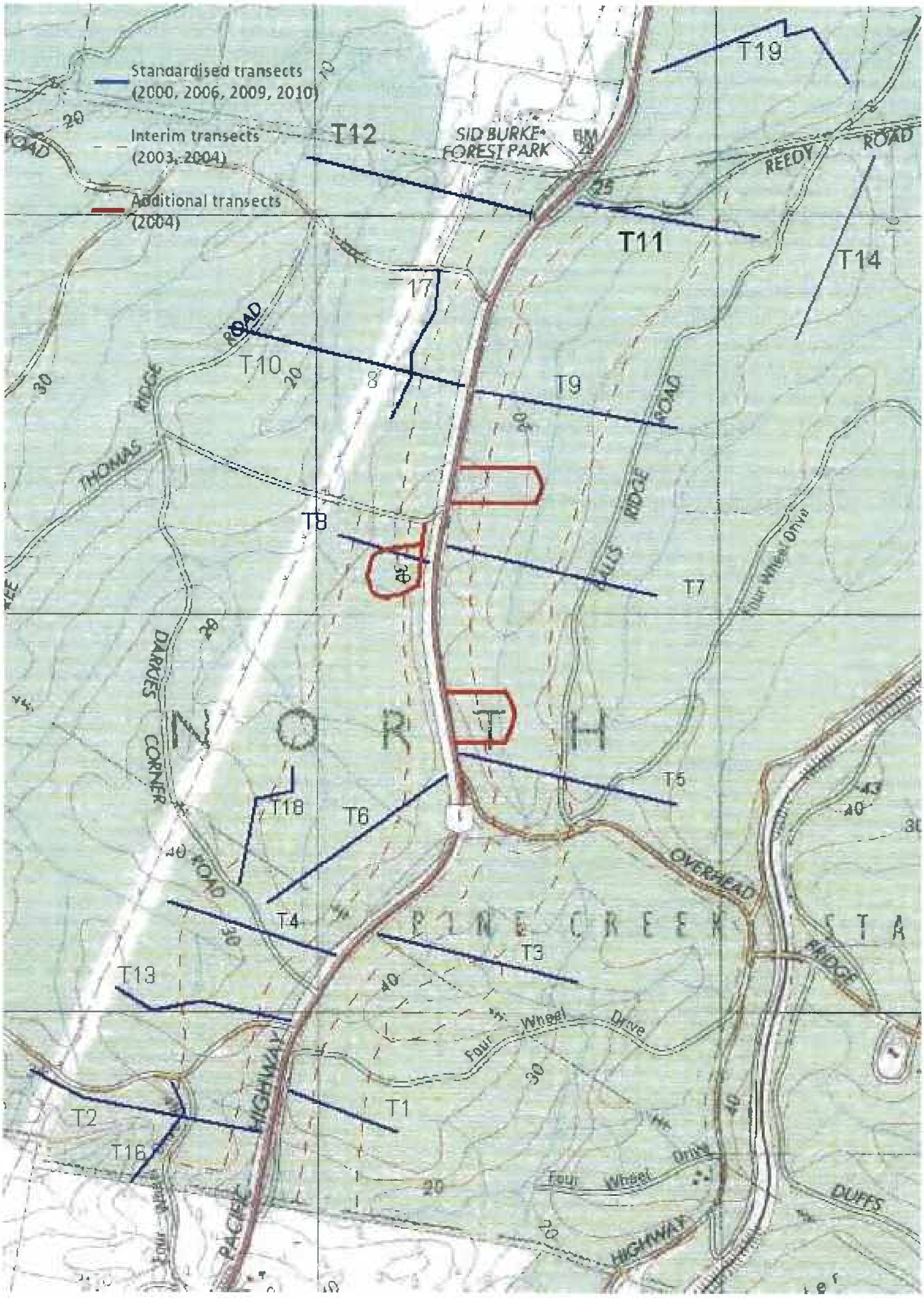


Figure 7: Scat transect locations in the Bonville study area

2.2.7 Koala Surveys and Monitoring Prior to and During Vegetation Clearing

"Clearance surveys" for Koalas were undertaken prior to and during vegetation-clearing (AMBS 2007a). The purposes were to:

- locate any Koalas potentially at risk from the vegetation-clearing works, so that protective measures could be taken if needed; and
- collect observational data on the impacts of clearing and response of Koalas to the works.

An AMBS representative, John Pile, was present throughout the vegetation clearing phase of the highway upgrade. Early in the morning (i.e. before clearing activities commenced for the day) visual searches were made of the trees scheduled for clearing that day. The searches were carried out after sunrise for approximately one and a half hours. Data were collected on the location, circumstances, habitat and behaviour of all Koalas sighted in and adjacent to scheduled work areas. All Koalas sighted were visually categorised as adult, sub-adult or juvenile, and individually identifiable characters were noted where possible.

Vegetation clearing works were suspended if Koalas were found inside the scheduled areas. Sighted Koalas were left for up to 2 nights to move out of the construction area of their own accord, to minimise unnecessary stress. In the event that a Koala remained in the area to be cleared for more than 2 nights, it would be captured and moved to safety, but not more than 100 m away. If Koalas were sighted while Pile was not present then contractors would contact him and work would cease until he arrived.

2.2.8 Monitoring Fauna Movement Structures

Plot Monitoring at Raleigh Underpass in 1999-2000

The original Raleigh underpass was located near the southern end of what was then Pine Creek State Forest, approximately 25 km south of Coffs Harbour) It was a reinforced concrete box culvert 20 m long and 3 m x 3 m in cross section aligned in an east-west direction under the Pacific Highway. It was a designated fauna underpass, constructed in about 1995 and decommissioned in 2007. It contained a number of treated pine horizontal and vertical logs ('furniture') to act as refuge points for fauna, particularly Koalas. Fauna exclusion fencing extended along both sides of the highway for approximately 150 m north and south of the underpass entrances.

Sand plots were operated to monitor Koalas and other fauna species using the Raleigh underpass between August 1999 and December 2000. The sand plots were 3 m wide, 1 m long and 5 cm deep trays filled with sand. One was installed at each end of the underpass, approximately 1.5 m inside the entrance. Each tray covered the entire width of the underpass. The sand was checked approximately twice per week for signs of footprints and then brushed smooth.

Camera Monitoring at Raleigh Underpass in 20000

A remote camera was installed in the underpass from 28 March 2000 December 2000 to photograph animals passing through the structure. The analogue camera was triggered by an infrared beam and used flash lighting to capture images in the dark. For security and protection, an aluminium housing box was used to protect the camera, infrared beam projector and 12 volt battery. The apparatus was mounted in a number of locations within the underpass, at a height that would record the presence of most fauna. When analysing the results, an animal was considered to have made a complete passage if it was photographed at each end of the tunnel.

The sand plot monitoring technique was continued alongside the camera monitoring until December 2000. This enabled better identification of fauna species and an opportunity to compare the costs and effectiveness of the two methods.

Camera Monitoring at Bonville Study Area 2008-2011

Three fauna movement structures within the Bonville study area (Figure 8) were monitored to determine their use by Koalas after the opening of the highway upgrade. These were:

- the rebuilt Raleigh underpass, a box culvert approximately 100 m in length with a height and width of 3 m by 3 m, located approximately 240 m south of Mailmans Track;
- the Infra 2 underpass, a gully under the highway 30 m in length, 35 m wide and approximately 4.5 m in height, located approximately 600 m north of Mailmans Track; and
- the Infra 3 land bridge, a fauna overpass 80 m in length and 44 m wide, located approximately 350 m north of Overhead Bridge Road.

The remote surveillance monitoring systems were installed at the Raleigh and Infra 2 underpasses from 2 to 6 December 2008, and at the Infra 3 land bridge from 9-12 January 2009 at which time the systems were connected to solar panels. The systems were designed to monitor the movements of Koalas at the structures, but were also capable of detecting other fauna species. A total of eight infra-red cameras were installed. These were located as follows:

- Raleigh underpass: two cameras, one at each end ('Raleigh East' and 'Raleigh West') with passive infra-red sensors monitoring the tunnel and treadle sensors on the furniture (climbing structures such as poles and logs).
- Infra 2 underpass: two cameras, set in approximately the centre of the underpass, one on the north side receiving images from the north side to the middle and one in the middle receiving images of the south side ('Infra 2 North' and 'Infra 2 South') with passive infrared sensors monitoring the base and furniture.
- Infra 3 land bridge: four cameras with active infra-red sensors on two poles in the centre of the land bridge ('Overpass 5', 'Overpass 6', 'Overpass 7' and 'Overpass 8'). Drift fences were also installed to prevent individuals passing through areas that could not be photographed due the view of the camera and positioning of the sensors.

The design of the systems considered various issues that could influence the results, particularly the species detected and the quality of the images. Variations to settings included the positioning of the cameras, illuminators and sensors, the 'sensitivity' of the sensors, the number of photos per trigger, and the resolution of the images. It was recognised that the initial settings were unlikely to be perfect and accordingly, adjustments were made during the course of the monitoring period, particularly in order to minimise any lag time between the trigger and photograph, and adjust the sensitivity to account for environmental conditions.

The positioning of the cameras within each fauna movement structure was important in designing the systems. The placement of a camera at each end at the Raleigh underpass was considered necessary as the structure was long compared to Infra 2 and Infra 3. The design increased the likelihood of recording an individual making a complete passage from one side to the other. The much greater widths of Infra 2 and Infra 3 made the installation of cameras at both ends prohibitive. Instead, cameras were set in the centre, such that an animal making a crossing would trigger the camera when it reached the middle of the structure. Given the relatively short length of the Infra 2 underpass and the lack of habitat within it, it was an assumption of the study that animals reaching the centre of the structure were likely to those making a complete passage, although this could not be proven conclusively.

The Raleigh and Infra 2 underpass cameras operated on battery power from 6 December 2009, with photos downloaded weekly. The Infra 3 land bridge cameras were operational from 12 January 2009 with photos being downloaded weekly for the first two weeks, and then every two weeks after that. From 12 January 2009 all camera systems were connected to re-chargeable batteries charged by solar panels, allowing an almost continuous power supply, with battery charges being checked regularly. On 12 January 2009 two additional infra-red illuminators were installed on the furniture at Infra 2.

The Infra 2 north underpass camera was moved on 29 June 2009 from the concrete batter at the base of the bridge, to lower down at the base of the rocks. The move occurred due to the initial sub-optimal quality of images retrieved by the camera. Images were improved by positioning the camera closer to the ground and beside the illuminator. The Infra 2 cameras were also re-wired at this time so they would act independently of each other. This increased the time between downloads by reducing the number of images.

Plot Monitoring at Bonville Study Area

Some additional plot monitoring was undertaken at the Bonville study area. This involved using sand trays and soot-track plates to determine if underpasses were being used by Koalas and other fauna. The monitoring was undertaken at two sites during the Koala breeding season in 2010; Infra 4 (within the study area) and Infra 13 (located about 4.5 km north of the study area) (Figure 8).

At Infra 4 and Infra 13, plots were installed on 12 and 13 August 2010. Sand trays were installed in both underpasses, while soot-track plates were installed only at Infra 13. Sand trays were approximately 1 m wide and 2-3 cm thick, and varied in length from 1 to 10 m depending on the requirements. Yellow, brick-layers' sand was used in the trays. The soot-track plates were each 400 x 1200 mm, and 0.6-0.8 mm thick. The plots were monitored from 12 August to 17 November 2010.

Three sand trays were installed at Infra 4. Two of these were installed on the western side of the underpass beneath the north-bound lanes of the highway, with one on the south, and one on the north of the local road there. These two trays each extended from the base of the bridge batter to the edge of the local road, a distance of about 10 m in the south, but only 1 m in the north due to the restricted space. The other sand tray was installed on the eastern side of the underpass, under the south-bound lanes of the highway, and extended for about 10 m from the base of the bridge batter.

Four sand trays were installed at Infra 13. Two were placed under the north-bound lanes of the highway, with one either side of the concrete drainage culvert, and two under the south-bound lanes, either side of the culvert. In each case, the trays extended from the base of the rocky bridge batter to the edge of the concrete culvert, a distance of about 10 m. Two soot-track plates were installed beneath the north bound lane of the highway adjacent to each of the sand trays there. Plates were secured to the ground with tent pegs, and soot was applied as evenly as possible using an acetylene blow torch.

The sand trays and soot-track plates were checked twice weekly to record tracks and wipe them clean of old tracks. Tracks were identified as accurately as possible using the diagrams and descriptions in Triggs (2004) and Menkhorst and Knight (2004). Each identification was classified as a definite, probable or possible identification. Photographs were taken of most tracks using a small digital camera, allowing for validation of identifications.

Plot Monitoring at Yelgun to Chinderah Study Area

Monitoring of 13 fauna crossings using sand traps was undertaken by Mark Fitzgerald from 10 February to 31 March 2003 (Fitzgerald 2003). Twelve of these crossings were associated with the Yelgun to Chinderah Upgrade. Sand trap configuration varied according to the structural constraints of particular crossings. Each sand trap was checked 2-3 times per week, with data recorded including presence of any identifiable fauna tracks, scats, and roadkills or fauna in the vicinity.

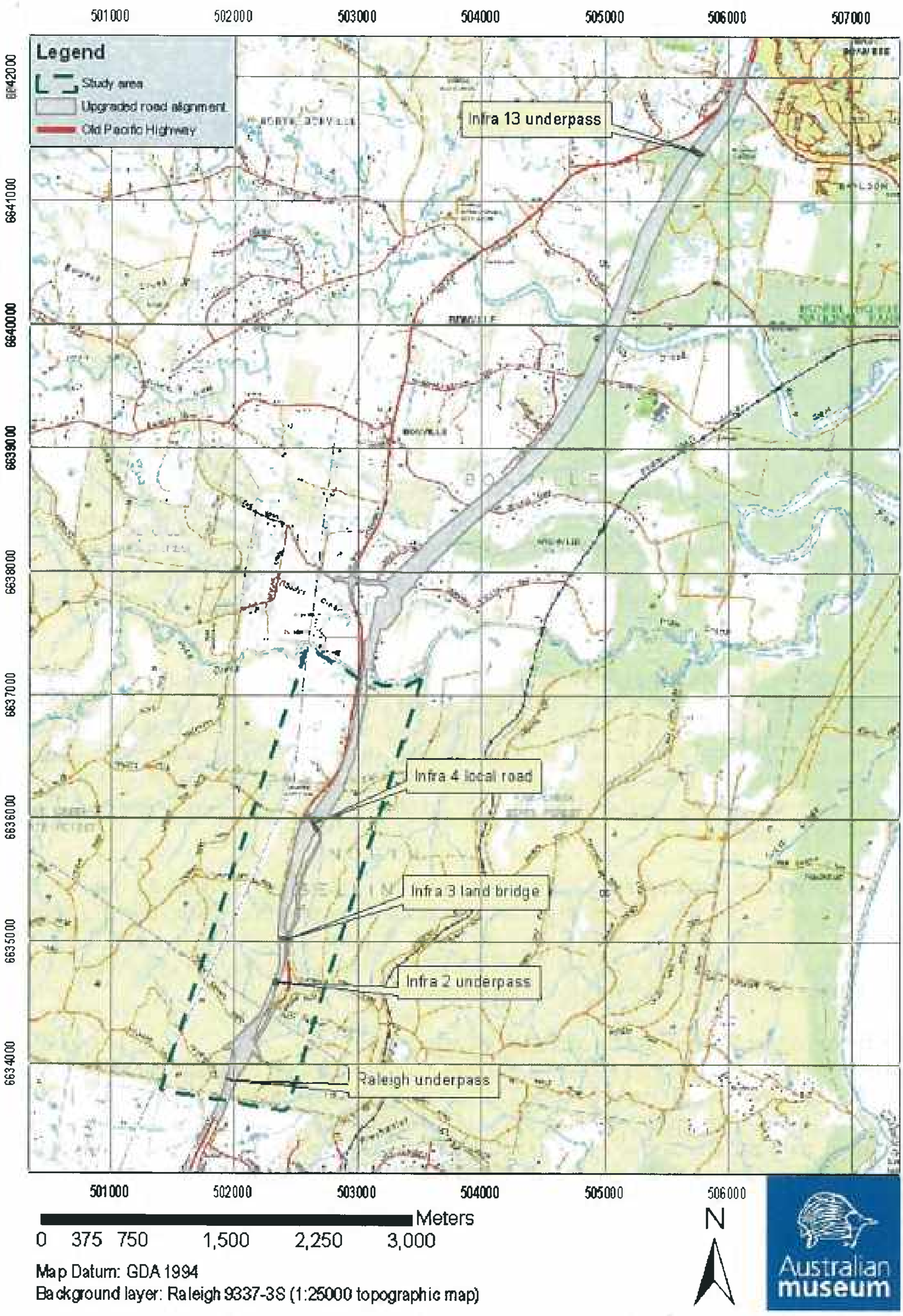


Figure 8: Location of monitored fauna movement structures

2.3 DNA Studies

A variety of DNA studies were used during the study to investigate what impacts roads might have on the genetic makeup and integrity of roadside Koala populations. To achieve this, the following aims were identified:

1) Determine the relationships of animals living close to the road. If daughters tend to occupy home-ranges close to those of their mothers, we would expect many females to be closely related. Similarly, if males arrive from more distant areas, they would be less closely related to those females except those that were their own daughters. If males survived long enough to produce two daughters (2-5 years post-maturity at 4 years), these matings might also be detected and would indicate that the animals had adjusted to the presence of the highway.
2) Discover whether road-killed younger animals might include offspring of resident parents or whether they were dispersing from points further away and are therefore less closely related.
3) Determine whether the genetic profiles were different on either side of the road due to pre-existing barrier effects. Differences would provide base-line data against which future studies could be compared.
4) Determine the genetic variation within the various areas sampled.

2.3.1 Tissue DNA

Tissue samples were collected from ear punches of all captured animals prior to ear-tagging, and from road-kills. Additional samples were collected by WIRES members and vets of local animals taken into care through illness or injury.

2.3.2 Faecal DNA

Extending the DNA study provided the chance to continue monitor the study population during the period that the main field surveys were suspended. The general method was to collect faecal pellet samples from across the known home-ranges of the radio-collared Koalas at Bonville, and compare the DNA from tissue samples with additional DNA obtained from the faecal pellets. DNA can be extracted from epithelial cells scraped from the bowel lining and collected in the mucus that coats each pellet as it moves down the bowel.

Koala faecal pellets were collected by C. Moon who walked four transects in 2003 (19/20//21/22/27/29 August) and 2004 (between 12 August and 3 September), parallel to the highway, with two transects on each side and within 500 m of the highway. He collected up to several pellets at each site, sprayed each with alcohol, as recommended by Hey (2003) and placed them in separate bags for each site. Each bag was numbered, the locality recorded and the freshness of the pellets estimated as fresh, intermediate or old with sub categories of each given the additional status of 'ish' (e.g. 'freshish'). The species of tree under which pellets were located was recorded as were any sightings of Koalas, tagged or untagged in the tree or nearby.

Pellets were assessed visually for likelihood of obtaining DNA (presence of a patina and state of the pellet surface) and DNA extractions were attempted on selected pellets. During 2004, it was ensured the pellet was dried before it was determined if it possessed a completed patina. Each pellet was then tested for the presence and quality of DNA by electrophoresis on agarose gels and comparing band intensity with an SPP-1/Eco RI marker run in parallel with the samples (Hey 2003). DNA was also extracted from the original tissues, where previous extractions were not available. Microsatellite DNA loci were then amplified using 8 primers (Hey 2003) for tissue samples and all faecal samples that contained sufficient DNA.

2.3.3 Additional Scat Transects for DNA Study

Due to the suspension of radio-tracking at Bonville from September 2002 to September 2006, scat surveys were undertaken in August 2003 and August 2004. The scats were then analysed for the presence of donor DNA and compared for relatedness to known animals studied in Phase 1. This was to test and examine the effectiveness of DNA collection as an alternative method to measure the local 'population'.

2.3.4 DNA Analysis and Interpretation

DNA analysis detects regions of nuclear DNA which have mutated in length of DNA sequence to produce a variety of genetic markers called microsatellites. The different lengths of DNA are detected via pairs of primers (short lengths of single stranded DNA), which attach to conservative reciprocal sequences at both ends of the microsatellite DNA. The microsatellite can then be amplified from tiny samples of tissue. Each primer pair defines a locus that operates like an individual gene which may have several alternative forms (called alleles). Each allele is a different length of DNA between the primer pair. These loci operate much like the well-known gene for ABO blood-typing. There are three blood-type alleles, A, B and O of the same gene (locus). Each individual will have two blood-type alleles (either AA, AB, AO, BB, BO, AO, or OO). Similarly with microsatellite loci, each Koala will have a combination of two of the alleles found for each locus. In this study six loci were examined and each locus had eight to 14 alleles. Each daughter or son would inherit one allele from the mother and one from the father for each locus. Because there are so many alleles for each locus, the chance of two unrelated individuals sharing the same alleles for all 6 loci is remotely small (unless the population being studied is inbred or certain alleles are much more frequent than others). In an inbred population, there would be few alleles for each locus. An adjacent, isolated, inbred population, however, might share a different set of alleles for the six loci. Thus the DNA data can reveal both the extent of inbreeding or genetic diversity, and the relatedness of individuals in the population.

The faecal DNA were used to examine whether the original study animals (known from their tissue samples) still survived and whether additional animals were residing in the study area. Any new animals detected may have been new arrivals or may have been missed capture studies. However, if faecal DNA in a fixed area was consistently no match to the DNA of the original resident, then the most likely explanation would be that territory had changed possession.

The faecal DNA study, therefore, was expected to add to the original study by determining whether more animals lived in the study area than had been estimated from actual sightings of animals. It would examine whether the original animals survived in the area and whether their home-ranges had changed. It would also test a DNA method of surveying Koalas that had never been tested in the field. This method has the potential to reduce costs of surveys and sample more animals than would be possible using conventional methods. The method is particularly appropriate for Bongil Bongil National Park where the height of the trees, the thickness of the vegetation and the terrain make the sighting and capture of Koalas extremely difficult and costly.

3 Results

3.1 Koala Captures

3.1.1 Bonville Study Area

At the Bonville study area from 2000 to 2010 there were 81 successful captures and recaptures of 47 individual Koalas, not including joeys captured with their mothers. Slightly more females (28) were captured than males (21). Of 37 individuals that were aged, 25 were classed as adults (3 years of age or greater), 11 were classed as sub-adults (2-3 years) and one was classed as a juvenile (less than 1 year old). In 2000, three mothers had a joey (back-young) when captured. In 2006 one mother was caught with a joey and in 2008 the same mother was caught with another joey. No mothers with joeys were caught in 2007 or 2009.

In September 2000, 33 Koalas were sighted and 23 of those were captured. In September 2001, three new Koalas were sighted and captured, while eight of the 2000 Koalas were re-captured. In June 2006, one Koala was sighted but could not be captured. During a second 2006 survey (September) six new Koalas were sighted and four of them were captured. In September 2007 nine new Koalas were sighted and four of them were captured, while two Koalas from 2006 were recaptured. In the first capture survey of Phase 3 (September 2008) eight new Koalas were sighted and six of them were captured, while three Koalas from 2007 were recaptured. During September 2009 nine new Koalas were sighted and seven of them were captured, while three Koalas from 2008 were recaptured. In September 2010, searches were not made for new Koalas. Five Koalas still carrying collars were recaptured and their collars were removed. Table 5 provides further details of captures.

Table 3: Details of captured Koalas at the Bonville study area

(F=female, M=male, J=juvenile, SA=sub-adult, A=adult)

Phase	Koala	Capture date	Sex	Age (Class; years)	Status
Phase 1	Dawn	11/09/2000	F	SA/A	Radio-collared, dead 16/03/2001
	-	11/09/2000	F	SA, 1.5	Not collared
	Thorpe	11/09/2000	M	A, 4	Radio-collar removed 21/08/2002
	Gaze	12/09/2000	M	SA, 1-2	Radio-collar removed 08/09/2001, moved out of study area
	-	13/09/2000	M	A, 5	Not collared, released
	Debbie & Joey	13/09/2000	F	A, 7	Radio-collared, dead 09/01/2002
	-	14/09/2000	F	A, 3-4	Not collared, released
	-	15/09/2000	M	A, >8	Not collared, released
	Betty & Joey	16/09/2000	F	A, 9	Radio-collared, dead 26/05/2001
	Matt	17/09/2000	M	A, 2	Radio-collar removed 30/09/2002, killed on road 3 weeks later
	Shane	18/09/2000	F	A, 5-6	Radio-collar removed 30/09/2002
	Nikki	18/09/2000	F	SA	Radio-collar found shortly after release
	Kieran	19/09/2000	M	A, 6	Radio-collar removed 02/10/2002
	Shirley & joey	19/09/2000	F	A, 5-7	Radio-collar found with teeth marks 07/01/2001
	Klim	20/09/2000	M	A, 3	Radio-collared, dead 07/07/2001
	-	20/09/2000	F	A, >3	Not collared, released
	Susie	21/09/2000	F	A, 5-7	Radio-collar removed 01/10/2002
	-	21/09/2000	F	J, >0.5	Not collared, released
	Alison	22/09/2000	F	A, 7	Radio-collar removed 03/10/2002
	Aussie Joe	23/09/2000	M	A, 6-7	Radio-collared, dead 16/03/2001

Phase	Koala	Capture date	Sex	Age (Class; years)	Status
-	-	23/09/2000	F	A, 4	Not collared, released
	Wilbur	08/09/2001	M	A, 6	Radio-collar removed 01/10/2002
	Jelena	20/10/2001	F	A, 3-4	Radio-collared, dead 23/10/2001
	-	??/09/2001	F	A, 4-5	Not collared, euthanased 14/11/2001
Phase 2	Scapula	15/09/2006	M	A, 6-8	Radio-collared, monitoring continued to Phase 3
	Tibia & joey I	15/09/2006	F	A, 3	Radio-collared, monitoring continued to Phase 3
	Iris	15/09/2006	F	A, 10	Radio-collar failed 22/04/2007, Sighted during Phase 3
	Venus	16/09/2006	F	SA, 2	Radio-collar removed 12/11/2006, moved out of study area
	Kenny	23/09/2007	M	A, 4-5	Radio-collared, dead 01/10/2007
	Leonard	25/09/2007	M	SA, 2-3	Radio-collared, dead 30/03/2008
	-	26/09/2007	M	SA, 1.5	Not collared, released
	Ruby	27/09/2007	F	SA, 1-2	Radio-collared, dead 18/10/2007
	Malcolm	28/09/2007	M	A, 3	Radio-collared, dead 12/01/2008
Phase 3	Matilda	16/09/2008	F	SA, 2	Radio-collar removed 4/10/2008, moved out of study area
	Hackett	16/09/2008	M	A, 6	Radio-collar removed 6/09/2010
	Sally	17/09/2008	F	SA, 2-3	Radio-collared, dead 29/06/2009
	Scapula	18/09/2008	M	A, >10	Radio-collar replaced, dead 29/05/2010
	Samantha	20/09/2008	F	SA, 2	Radio-collared, dead 21/02/2009
	-	21/09/2008	F	A, old	Not collared, taken to WIRES, euthanased 23/09/2008
	Tibia & joey II	21/09/2008	F	A,>5	Radio-collar replaced, radio-collar removed 7/09/2010
-	-	23/09/2008	F	A, >10	Not collared, released
Iris	Iris	24/09/2008	F	A, >10	Radio-collar replaced, dead 04/10/2008
Bob	Bob	22/09/2009	M	SA, 2	Radio-collared removed 16/10/2009, moved out of study area
Charlie	Charlie	25/09/2009	M	A, 8	Radio-collar removed 7/09/2010
Sheryl	Sheryl	25/09/2009	F		Not collared, euthanased 09/10/2009
Paul	Paul	27/09/2009	M	A, 6	Radio-collar removed 8/09/2010
Brown	Brown	27/09/2009	M	A, 5-6	Radio-collar failed 8/10/2009
Anna	Anna	28/09/2009	F	A, 3	Radio-collar removed 7/09/2010
Ian	Ian	28/09/2009	M	A, 6	Radio-collar found 21/02/2010

3.1.2 Yelgun to Chinderah Study Area

Over the three phases, 15 Koalas were captured and fitted with radio-collars. These Koalas were captured at various locations along the entire length of the Yelgun to Chinderah route (Table 4), with 12 captured in 1999, two in 2000, and one in 2001. The locations of captures ranged in distance from approximately 10 m up to 1 km from the existing road. Four of the Koalas were captured at locations that were directly in the path of the new road.

Table 4: Captured and radio-collared Koalas in the Yelgun to Chinderah study area

(M=male; F=female)

Capture location	Name	Sex	Age estimate (years)	Date of 1st capture
Cudgen / Cut 36	Doom	F	5-6	5/06/2000
	Conan	M	5-6	13/06/2000

Durranbah Quarry	Able	M	3-4	12/09/1999
	Eve	F	7-8	8/09/1999
	Kane	M	3	9/09/1999
	Cosmos	M	5-6	15/11/1999
	Astra	F	4-5	15/12/1999
	Patsy	F	2-3	26/06/2001
Tanglewood	Jane	F	7	3/09/1999
	Mongrel	M	7	11/09/1999
	Janice	F	4	11/09/1999
	Beaver	M	2-3	22/09/1999
Taggart's Hill	Dave	M	5	31/08/1999
Dunloe Park	Sibyl	F	8+	19/07/1999
Jones Road	Mrs Jones	F	7-8	30/08/1999

3.2 Radio-tracking

3.2.1 Bonville Study Area

A total of 34 individual Koalas were fitted with radio-collars, and 14 refittings were made. These Koalas were radio tracked for a cumulative total of 12,452 days. The shortest tracking period for an individual was 3 days and the longest was 1,453 days. The mean tracking period was 366 days per Koala (sd = 367.9 days).

During the first capture survey in 2000 14 Koalas were fitted with radio-collars. During September 2001, two new Koalas were fitted with radio-collars, while radio-collars were replaced on eight of the 2000 Koalas. All Radio-collars were removed at the end of Phase 1 in September 2002.

The radio-tracking study recommenced in September 2006 when four Koalas were fitted with radio-collars. During September 2007, four new Koalas were fitted with radio-collars, while radio-collars were replaced on two of the 2006 Koalas.

In September 2008 four new Koalas were radio-collared and the radio-collars were replaced on three Koalas from 2007. In September 2009 six new Koalas were radio-collared were recaptured and the radio-collars were replaced on three Koalas from 2008. In September 2010, five Koalas still carrying collars were recaptured and their collars were removed.

Over the course of the study 12 Koalas were captured but not fitted with radio–collars. Nine of these were assessed as not fit enough to carry a collar and were released at the point of capture. Three were assessed as being unfit for release and were taken into care or euthanased. Two collars ceased operating and three collars were found detached from their Koala. Collars were removed from 16 Koalas. Four Koalas left the Bonville study area (one each during Phases 1 and 2, and two in Phase 3) so their collars were removed. At the end of Phase 1 collars were removed from seven animals and at the end of Phase 3 (the end of the experiment) collars were removed from five animals. Fourteen Koalas died during the study while carrying radio-collars (see Section 4.2.1 for a discussion).

Table 3 and Table 5 provide further details of captures and radio-tracking.

Table 5: Number of Koalas sighted, captured and radio-collared during each capture survey at Bonville

(N = new; R = replaced)

Survey Dates	Project Phase: monitoring activity	New Koalas	Koalas	Koalas radio-

		sighted	captured	collared
2000, 11-23 September	Phase 1, first capture survey	33	23	14N
2001, 6-10 September	Phase 1, second capture	3	11	10 (8R, 2N)
2002, 30 September - 3 October	Phase 1, removal of radio-collars	-	6	0
2006, 5-10 June	Phase 2, first capture survey	1	0	0
2006, 13-19 September	Phase 2, second capture survey	6	4	4N
2007, 22-30 September	Phase 2, third capture survey	9	11	6 (2R, 4N)
2008, 15-24 September	Phase 3, first capture survey	8	9	7 (3R, 4N)
2009, 21-30 September	Phase 3, second capture survey	9	10	9 (3R, 6N)
2010, 6-10 September	Phase 3, removal of radio-collars	-	5	0

Phase 1 (2000-2002)

During Phase 1, Koalas were radio-tracked for up to 743 days. Of the 14 Koalas radio-collared in September 2000, four were tracked crossing the highway during Phase 1, and often on multiple occasions. One young animal (Gaze) used the Raleigh underpass to move from west to east, and then remained well outside the designated research area, and so was removed from the monitoring project in September 2001. Other Koalas remained within home-ranges and did not cross the highway, although by September 2001, two had dropped their collars, and four had died (Shirley, Dawn, Betty, Klim and Aussie Joe), apparently from natural causes.

Three radio-collared Koalas died between September 2001 and September 2002, as follows:

- Jelena was road-killed 3 days after fitting the collar;
- Debbie died apparently from natural causes; and
- Shane was run over crossing the highway.

By September 2002, at the end of the Phase 1 monitoring, seven Koalas remained with radio-collars, which were then removed. One of these Koalas (Matt) was killed on the highway 3 weeks after its collar was removed.

Phase 2 (2006-2008)

Phase 2 radio-tracking commenced in September 2006, after 4 years of suspension. Four Koalas were fitted with radio-collars and radio-tracked for up to 737 days. Two of these (Scapula and Tibia) were monitored continuously until September 2008. One (Venus) left the study area, crossing the powerline easement and moving 3.5 km south west. The collar of the fourth one (Iris) failed during April 2007 and the animal could not be relocated. In September 2007 the collars were replaced on Scapula and Tibia. Four other Koalas (Kenny, Leonard, Ruby and Malcolm) were fitted with radio-collars in September 2007, and all of them died before September 2008.

Tibia maintained a relatively regular home-range between the southern extent of the National Park, Mailmans Track and Bulls Paddock Trail. Slight irregular movements were recorded when the vegetation clearing activities were nearby. She carried pouched young (Fibula I and II) on the both occasions she was captured.

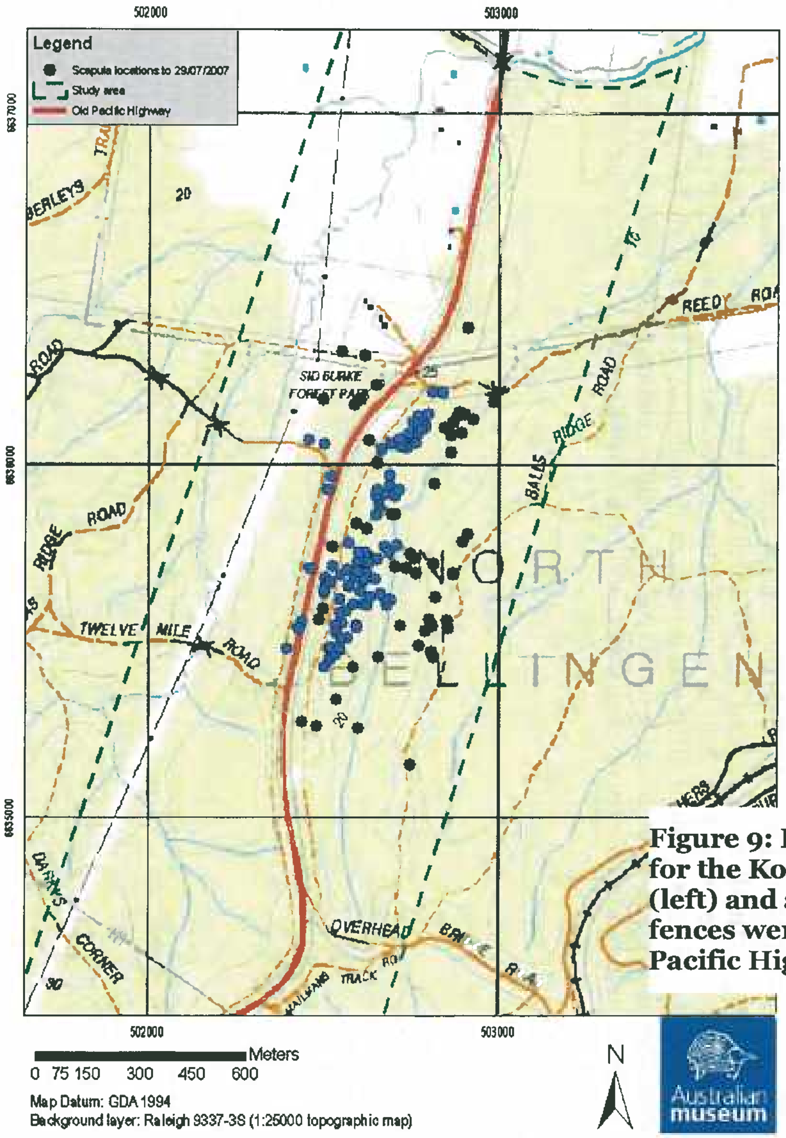
During radio-tracking in Phase 2, Scapula was located mostly to the east of the highway, although he crossed several times (Figure 9), with the last recorded move to the western side on 30 July 2007. After then, he stayed in a small strip of remnant vegetation between the highway and the Powerline Track, north of Hunters Road. When he was recaptured in September 2007 he showed signs of extensive fighting, including having had his ear tag ripped out. After this, he was recorded mostly south of Hunters Road, and on three occasions was found south of Twelve Mile Road.

Leonard showed unusual ranging behaviour upon release after collaring. He patrolled the temporary fauna fence along the western side of the highway and appeared to be trying to find a way to the eastern side. On 15 October 2007 he was recorded on the eastern side of the highway in the forest south of Overhead Bridge Road, and appeared to have become settled in the area near Overhead Bridge Road and Mailmans Track Road, despite three other Koalas being sighted nearby (one of which was Tibia). He was found dead on 30 March 2008.

Ruby was found sliced in two inside a highway construction area. The autopsy report indicated the injury was consistent with that of a collision with heavy machinery. Heavy construction equipment had been operating in the area. While not conclusive, the evidence suggests that Ruby was killed in a collision with construction equipment during Phase 2. This was the only evidence of a direct, mortal impact from the construction of the roads identified during this study.

Phase 3 (2008-2010)
During Phase 3, Koalas were radio-tracked for up to 720 days. Six Koalas were radio-collared in September 2008, including two re-captured animals (Scapula and Tibia) from Phase 2, which had their radio-collars replaced. During this Phase, Scapula occupied a different home-range (Figure 9) compared to Phase 2, mostly in a small vegetation strip adjacent to the recently-completed fauna exclusion fencing. He was found dead on 29 May 2010, apparently of old age. Tibia maintained a regular home-range in the southern area of the National Park, but was not observed to breed again. A large male (Hackett), captured on the eastern side of the highway, was recorded within a regular home-range until the removal of its radio-collar in September 2010. The three other Koalas collared in September 2008 were all females. Sally was located on the eastern side of the highway, close to Hackett on several occasions before being found dead on 29 June 2009. Samantha was on the western side of the highway and stayed within a very small home-range until she was found dead on 21 February 2009. Matilda moved 5.4 km in a south-easterly direction after capture release, thereby leaving the study area so her radio-collar was removed on 4 October 2008.

Six new Koalas were fitted with radio-collars in September 2009. Three males (Charlie, Ian and Paul) were recorded within regular home-ranges until the removal of their radio-collars in September 2010. Another male (Bob) moved north outside the study area after release and its radio-collar was then removed. Another male (Brown) moved erratically after release but its radio-collar failed on 8 October 2010 and it was not relocated. A young female (Anna) captured with a pouched young, maintained a home-range which overlapped with Tibia. Anna and Tibia were often found relatively close to each other, and Anna may have been an offspring of Tibia.



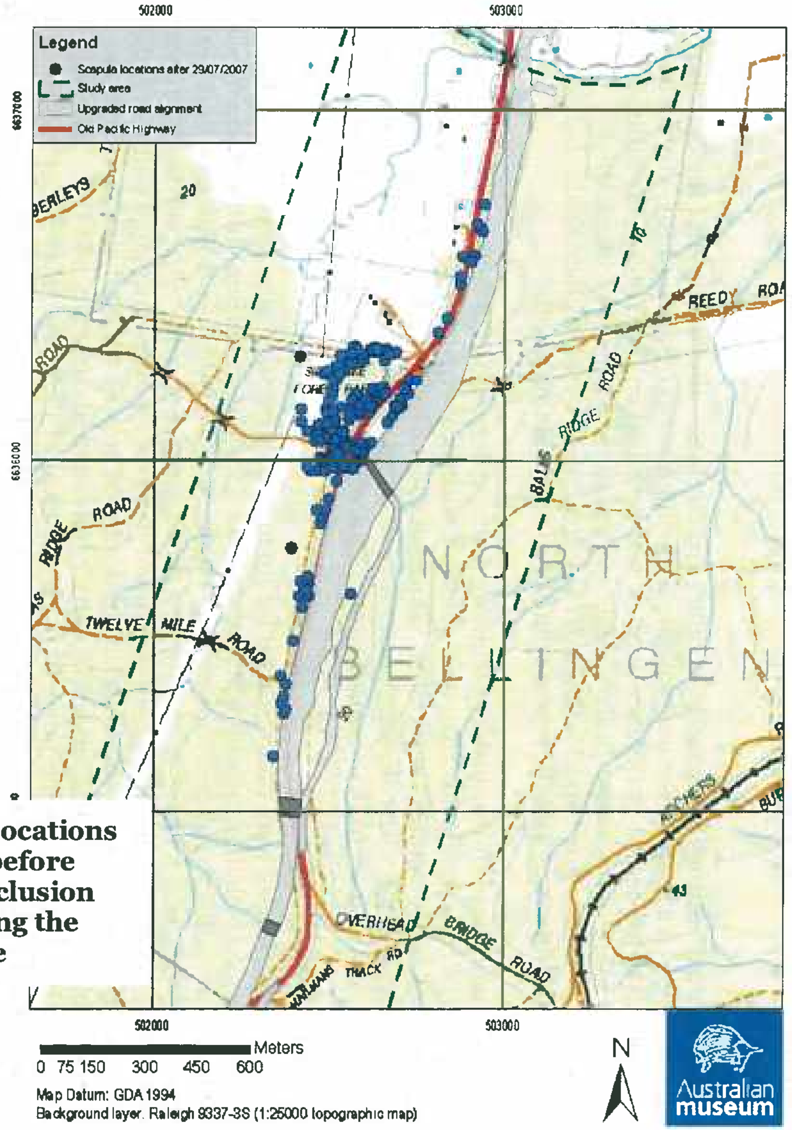


Figure 9: Radio-tracked locations for the Koala "Scapula" before (left) and after (right) exclusion fences were installed along the Pacific Highway, Bonville

3.2.2 Home-range Estimates

Bonville Study Area

Home-range sizes for Koalas across all years of the study were a mean of 30.6 ha for males and a mean of 15.7 for females (Table 6). Mean home-range sizes were largest during Phase 2 for both males and females, attributable to two individual large home-range sizes during that time of 53.2 and 69.7 ha (for Scapula and Leonard respectively). The home-ranges of each Koala that were tracked in the study area from 2000 to 2010 were mapped (see Appendix).

Table 6: Home-range sizes of males and females from each Phase

	Females (all phases)	Females P1	Females P2	Females P3	Males (all phases)	Males P1	Males P2	Males P3
Mean (ha)	15.7	14.2	24.2	14.1	30.6	22.4	46.8	30.7
SD	8.5	7.9	8.4	9.1	16.1	8.4	8.8	9.6
N	13	7	2	4	14	2	6	5

SD = Standard Deviation, N = number of Koalas tracked, P=Phase.

The home-range sizes of two Koalas (Scapula and Leonard) appear to have been affected by the construction activities. These two Koalas were the only ones monitored during Phase 2 that had home-ranges overlapping both sides of the highway. Clearing of vegetation impacted sections of their home-ranges and it appeared that the construction activities disturbed the animals resulting in them extending their home-ranges as they attempted to become settled. Both Koalas crossed the highway at least once during the monitoring period, but following installation of the temporary fauna fencing, Scapula was mainly restricted to the western side of the highway. At first, Scapula roamed along the length of the fauna fence, moving further south than previously. It appeared that Scapula was attempting to find a way back to the eastern side of the highway. Eventually he settled near the Sid Burke Rest Area, a place at which he was recorded prior to the erection of the temporary fence, and that was probably part of his original home-range. Following installation of the fauna exclusion fence, Scapula's home-range was much smaller.

The home-range of one Koala (Tibia) was relatively consistent for the duration of Phase 2. It was recorded in the southeast section of the study area, south of Overhead Bridge Road. Its home-range size during Phase 2 was approximately 30 ha in the first year (2006-07) and 20 ha in the second year (2007-08). The larger home-range size during the first year of monitoring corresponded with the time when most of the vegetation was cleared and the new service road was constructed. Tibia made her furthest move north and east, shortly after the new service road was opened to traffic during the first year of Phase 2. These movements coincided with construction of the new road, but she appeared to cope with the disturbance reasonably well and raised two offspring during Phase 2. Similarly, another Koala (Iris) was re-discovered during the September 2008 surveys in the same area previously identified as her home-range (before her collar failed) on 22 April 2007, indicating that her home range was largely unaffected by the disturbances of the road upgrade.

The Koala Malcolm was slightly further from the construction activities than other Koalas, and had a smaller home-range size (17.6 ha) compared to the average for males in the study area (30.6 ha). His home-range was very close to that of Scapula's when he became isolated on the western side of the highway after the installation of the fauna fencing. At this time, Malcolm appeared unsettled and crossed the powerline easement on several occasions. He died shortly after these observations.

Yelgun to Chinderah Study Area

The 15 Koalas that were radio-collared (see Table 4Table 4) were tracked for various lengths of time up until August 2004. The Koalas generally maintained a home-range in the vicinity of their capture point. This was the case at Duranbah Quarry where two female Koalas (Astra and Patsy) had large home-ranges of 42.2 ha and 22.5 ha respectively. Astra undertook a number of large movements across Eviron Road and to the east before moving back to the original site, which accounts for her large home-range compared with Patsy. The home-ranges of these two Koalas overlapped with some trees being shared although at different times. These trees were in the area that was cleared for highway construction. Large moves in both animals were observed, apparently in response to road construction activities. No adverse health effects were observed in either animal although neither was recorded with young after their initial collaring.

The four Koalas captured in the path of the new road died before construction activities began. Most other Koalas affected by construction activities, particularly vegetation clearing, appeared to either move away, or modify their home-ranges by extending their remnant ranges into nearby areas. One Koala (Eve) did not modify its home-range. After approximately 40% of its 6 ha home-range was removed during construction, this Koala remained in just one or two trees then appeared to starve to death. Another Koala (Conan) appeared to have been affected by blasting activities and not vegetation clearance during construction, and although sickly for some time, it survived and recovered its health.

3.2.3 Tree Use

In the Bonville study area the number of trees in which individual Koalas were recorded using during the three phases of the study ranged from 28 to 157 (Table 7). The number of trees used increased significantly with the length of time of observations (Pearson's correlation: r=0.693, n=27; p=0.0001) (Figure 10) The mean number of trees used by individual Koalas was highest in Phase 2, although this was not statistically significant (Figure 11).

A total of 1,986 observations were made of Koalas using various tree species. Over all three phases of the study, radio-collared Koalas were recorded in a total of 39 species of trees (Table 8), while individual Koalas used between seven and 17 tree species each. The mean number of tree species which Koalas were observed in was similar in each phase of the highway upgrade (Figure 11). The species in which Koalas were recorded most often were Tallowwood, Flooded Gum and Grey Gum (Table 9, Figure 12). There was a significant correlation between observation days and the number of tree species a koala was recorded in (Pearson's correlation: r=0.490, n=27; p=0.009) in Phase 1 but not in the other two phases, though the trend of increase was weaker than it was for total tree numbers. The diversity of tree species used by Koalas (H) was significantly lower in Phase 2 than in Phase 1 (Mann-Whitney U-test: U = 57, P = 0.014; AMBS 2007b). Similarly, evenness of the tree species used by Koalas (J) was significantly lower in Phase 2 than in Phase 1 (Mann-Whitney U-test: U = 55, P = 0.026; AMBS 2007b). During Phase 3, diversity and evenness were similar to Phase 1.

At least 50% of observations of Koalas were in just Tallowwood, Flooded Gum and Grey Gum during each of the three phases. During Phase 2, over 50% of observations were in just Flooded Gum and Tallowwood, and Grey Gum was used much less (Figure 12).

Table 7: The number of trees and number of species of trees which radio-collared Koalas were observed to use

(Highest and lowest figures are shaded; * does not include animals that were radio-collared but soon left the study area, died or dropped their collars)

Koala	No. days collared	No. trees in which observed	No. species of tree in which observed
Phase 1			
Alison	741	81	12
Aussie Joe	174	28	9
Betty + Joey	248	49	9
Dawn	173	31	10
Debbie + Joey	470	57	13
Keiran	741	92	11
Klim	290	38	8
Matt	743	77	12
Shane	742	76	12
Shirley + Joey	110	20	9
Susie + Joey	740	78	11
Thorpe	709	79	10
Wilbur	388	44	10
Phase 2			
Iris	221	65	8
Leonard	59	43	7
Malcolm	47	43	9
Scapula)	734	243	17
Tibia +Joeys	737	157	9
Phase 3			
Samantha	155	32	10
Sally	286	47	11
Scapula	604	118	12
Tibia	716	88	10
Hackett	720	104	14
Anna	345	53	11
Paul	346	39	7
Ian	146	31	14
Charlie	347	31	12

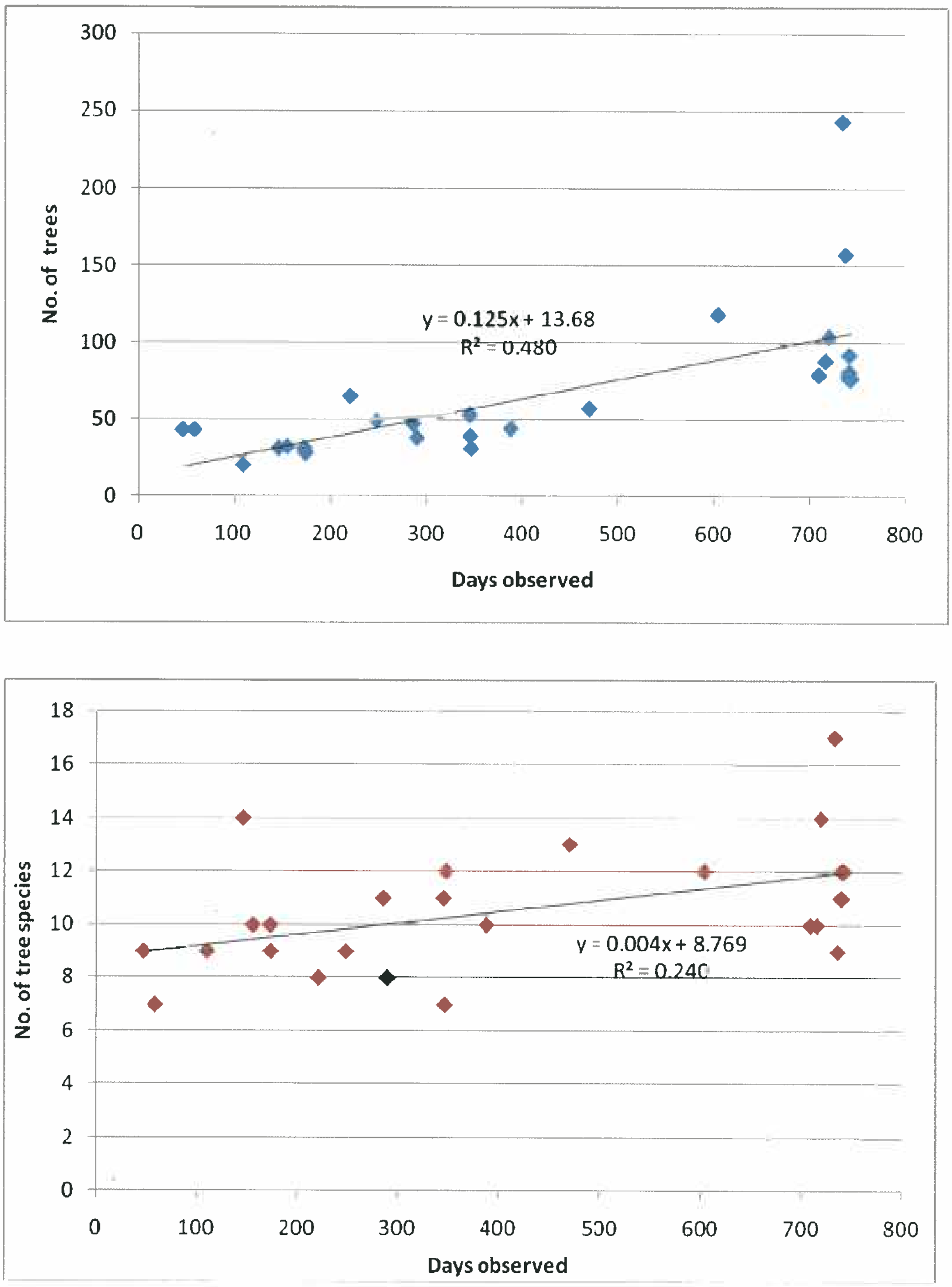


Figure 10: Number of trees (top) and number of tree species in which Koalas were observed versus the number of days each animal was radio-collared

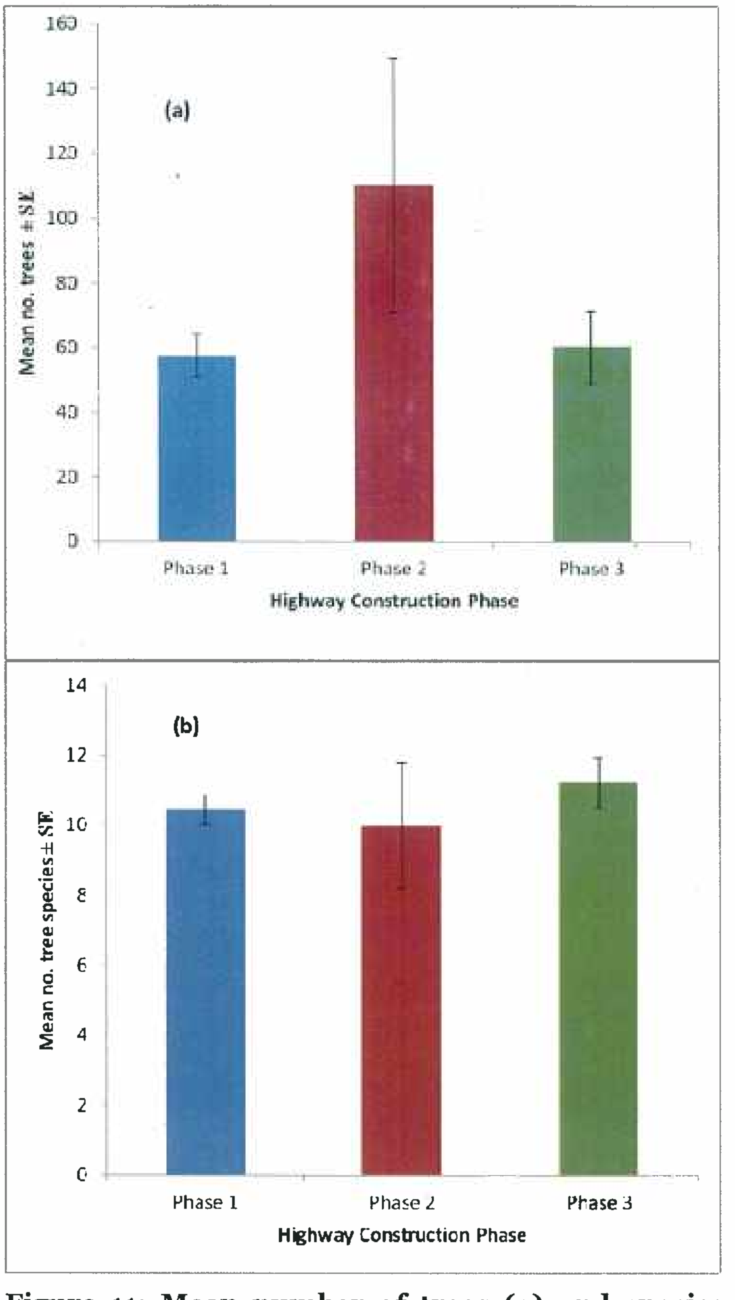


Figure 11: Mean number of trees (a) and species of trees (b) used by radio-collared Koalas at Bonville 2000-2010

(Phase 1, n=13 Koalas; Phase 2, n=5 Koalas; Phase 3, n=9 Koalas.)

Table 8: Number of records of Koalas in various plant species at Bonville 2000-2010

Plant Name	Species	No. Records	Percentage
Tallowwood	*Eucalyptus microcorys*	463	23.31%
Flooded Gum	*Eucalyptus grandis*	413	20.80%
Grey Gum	*Eucalyptus propinqua*	223	11.23%
Turpentine	*Syncarpia glomulifera*	129	6.50%
Blackbutt	*Eucalyptus pilularis*	125	6.29%
Grey Ironbark	*Eucalyptus siderophloia*	123	6.19%
Forest Sheoak	*Allocasuarina torulosa*	99	4.98%
White Mahogany	*Eucalyptus acmenoides*	97	4.88%
Red Bloodwood	*Corymbia gummifera*	73	3.68%
Blue Gum	*Eucalyptus saligna*	60	3.02%
Rainforest spp.	-	50	2.52%
Brushbox	*Lophostemon confertus*	30	1.51%
Blackwood	*Acacia melanoxylon*	18	0.91%
Scentless Rosewood	*Synoum glandulosum*	16	0.81%
Silver-leaf Butterwood (Black Wattle)	*Callicoma serratifolia*	16	0.81%
Red Mahogany	*Eucalyptus resinifera*	6	0.30%
Sandberry (Axebreaker)	*Trochocarpa laurina*	6	0.30%
Jackwood	*Cryptocarya glaucesens*	5	0.25%
Swamp Mahogany	*Eucalyptus robusta*	4	0.20%
Willow Bottlebrush	*Callistemon salignus*	4	0.20%
Vine	-	3	0.15%
Red Ash	*Alphitonia excels*	3	0.15%
Broad-leaved Paperbark	*Melaleuca quinquenervia*	2	0.10%
Scrub Turpentine	*Rhodamnia rubescens*	2	0.10%
White Sally Wattle	*Acacia floribunda*	1	0.05%
Lilly Pilly	*Acmena smithii*	1	0.05%
Laceflower Tree	*Archidendron* sp.	1	0.05%
Bangalow Palm	*Archontophoenix*	1	0.05%
Pink Bloodwood	*Corymbia intermedia*	1	0.05%
Soft Corkwood	*Caldcluvia paniculosa*	1	0.05%
Green Native Cascarilla	*Croton verreauxii*	1	0.05%
Bitter Pea	*Daviesia* sp. (*arborea*?)	1	0.05%
Hard Corkwood	*Endiandra sieberi*	1	0.05%
Mahogany hybrid	*Eucalyptus* sp.	1	0.05%
Fig	*Ficus* sp.	1	0.05%
Rusty Plum (Plum Boxwood)	*Niemeyera whitei*	1	0.05%
Large Mock-olive (Large-leaved	*Notelaea longifolia*	1	0.05%
Native Olive	*Notelaea* sp.	1	0.05%
Crabapple (White Birch /	*Schizomeria ovata*	1	0.05%
Guilfoylia	*Guilfoylia monostylis*	1	0.05%
Total		**1,986**	**100%**

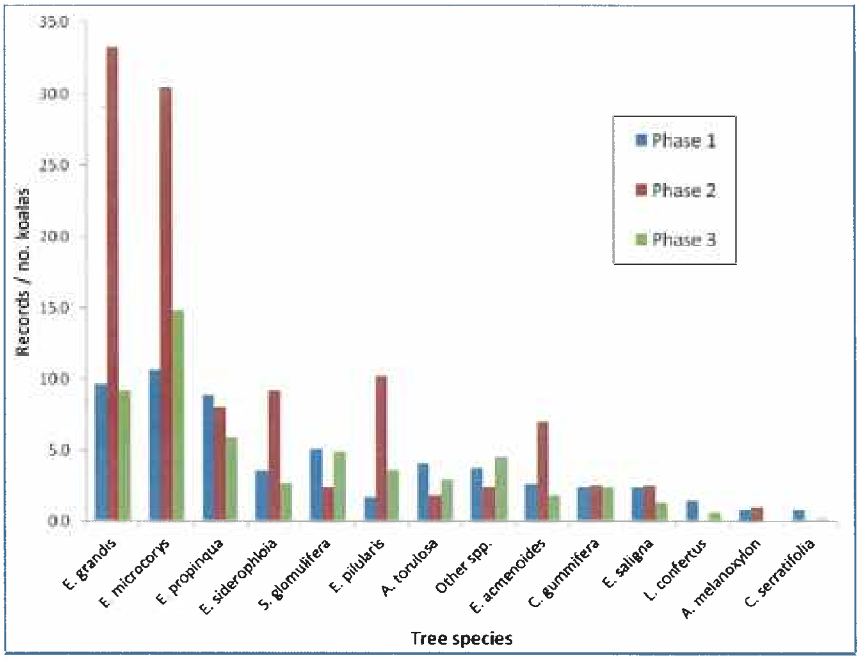


Figure 12: Frequency of radio-tracked Koalas (number of records of Koalas / number of Koalas) recorded in each tree species

(Phase 1, n=13 Koalas; Phase 2, n=5 Koalas; Phase 3, n=10 Koalas).

Table 9: Numbers of records of Koalas in main tree species during phases of highway upgrade

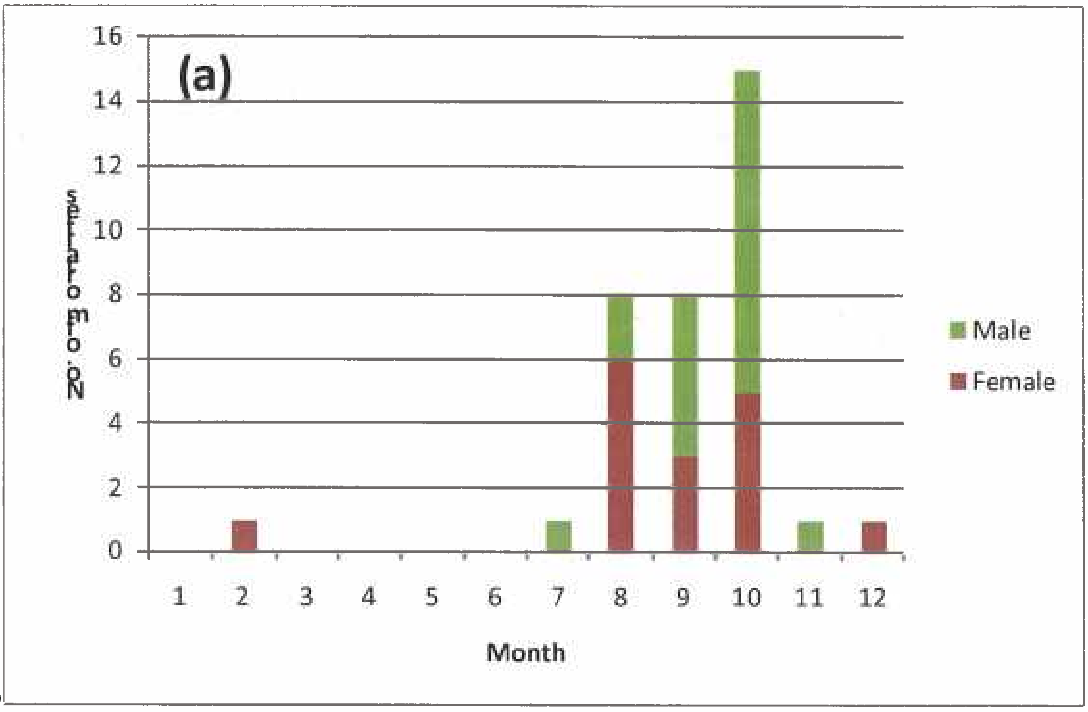
Tree	Species	No. records of Koalas (n = no. Koalas)		
		Phase 1 (n = 13)	Phase 2 (n = 5)	Phase 3 (n = 10)
Tallowwood	*Eucalyptus microcorys*	138	152	148
Flooded Gum	*Eucalyptus grandis*	125	166	92
Grey Gum	*Eucalyptus propinqua*	115	40	59
Turpentine	*Syncarpia glomulifera*	66	12	49
Forest Sheoak	*Allocasuarina torulosa*	53	9	30
Other spp.	*Other (multiple) spp.*	48	12	45
Grey Ironbark	*Euc. siderophloia*	46	46	27
White Mahogany	*Euc. acmenoides*	34	35	18
Red Bloodwood	*Corymbia gummifera*	31	13	24
Blue Gum	*Eucalyptus saligna*	31	13	13
Blackbutt	*Eucalyptus pilularis*	22	51	36
Brushbox	*Lophostemon confertus*	19	0	6
Blackwood	*Acacia melanoxylon*	11	5	0
Silver-leaf Butterwood (Black Wattle)	*Callicoma serratifolia*	11	1	3

3.2.4 Road Mortality

Road Mortality, Bonville Study Area

There were 65 Koala road mortalities recorded in the study area from 2000 to 2010 (details in Appendix). By years, the highest number of deaths (13) was recorded in 2000 and the lowest (0) in 2010 (Figure 13). Over these years, the numbers of deaths were highest in the months from August to November with the mean number of deaths highest in October (approximately 2.5). There were no deaths in January, April and June in any year (Figure 13). A high proportion, 56 (86%) were killed in the 4 months from August to November.

The remains of 35 of the road-killed Koalas were sufficiently intact to determine their sex: nineteen were males and 16 were females. Twenty-seven were aged by tooth wear: 15 adults (>3 years old), nine sub-adults (1-3 years old) and two juveniles (<1 year old) (Table



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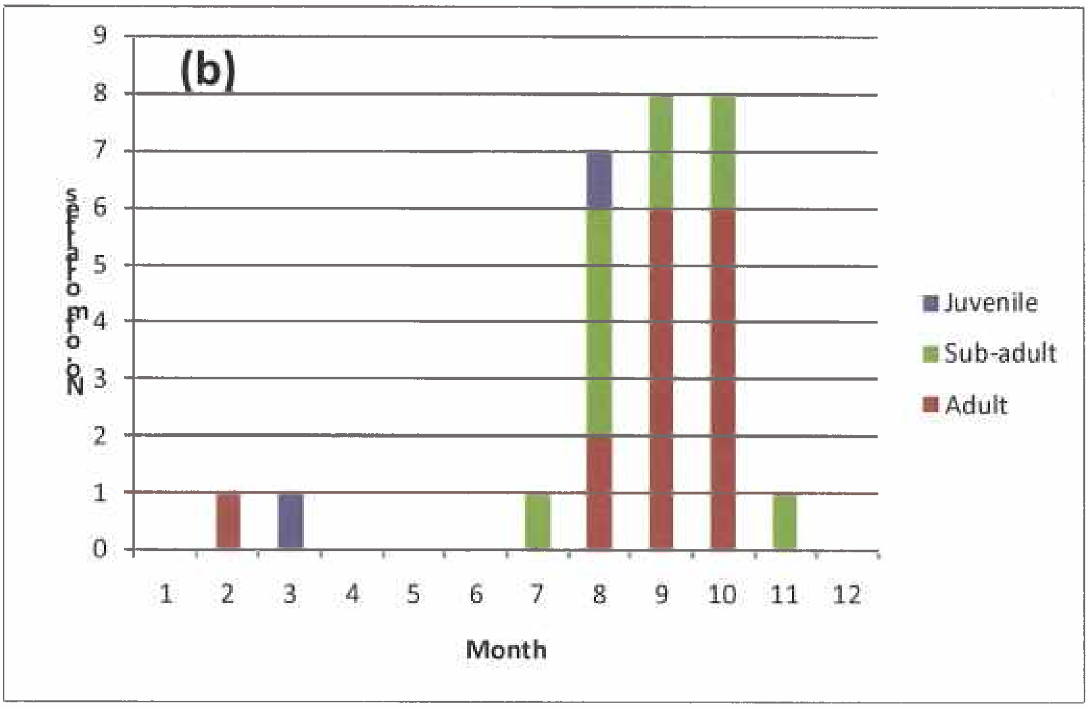

Figure 14: Seasonal Koala road mortalities at the Pacific Highway, Bonville, 2000-2010 by (a) sex classes and (b) age classes
(Animals not sexed or aged are omitted).

Table 10). Road mortality of the subsample of sexed animals indicates that males and females showed similar clustering of collisions in the August to October period (Figure 14). Likewise, road mortality of the subsample of aged Koalas indicates that adults and sub-adults showed similar patterns of seasonal impacts centred on the August to October period (Figure 14). Any slight differences amongst the sex and age groups might be accounted for artefacts of the small data set.

The locations of road mortalities in the study period showed some definite patterns (Lassau *et al.* 2008). Thirty-one (48%) of 65 locations were within 100 m of the four intersecting roads, Mailmans Track, Overhead Bridge Road, Hunters Road and Darkes Road. A further nine (14%) were at Sid Burke Rest Area. Several were also recorded at Pine Creek Bridge, though the precise number is uncertain. These localities are all some form of open corridor that leads onto the highway. Lassau (*et al.* 2008) interpreted this as indicating that Koalas disperse along tracks (to avoid obstacles) that lead them onto the highway.

During periods of Phase 2 and early Phase 3, when exclusion fencing was incomplete, mortalities were clustered close to breaks or gaps in the fencing (see Discussion).

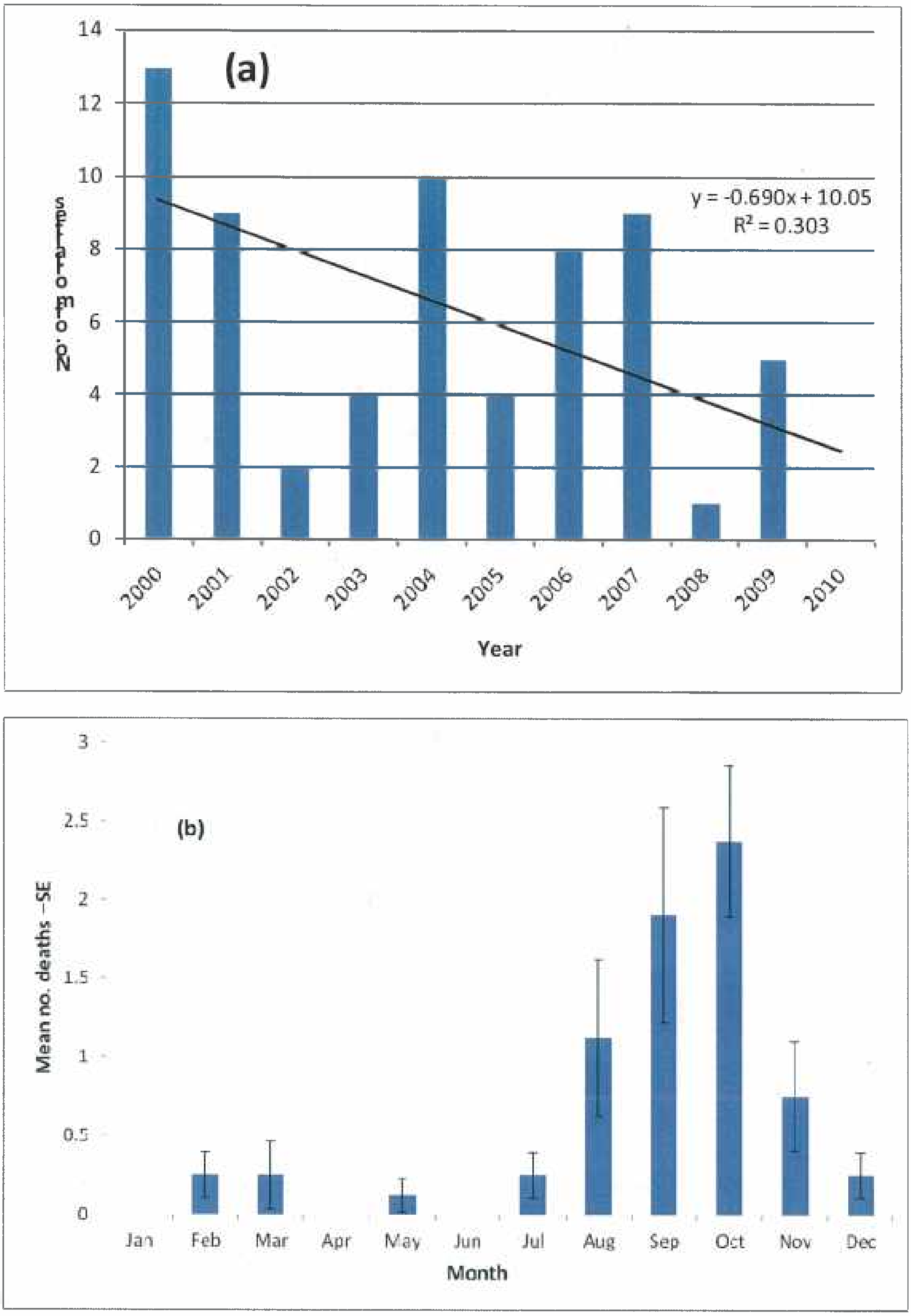

Figure 13: Koala road mortalities at the Pacific Highway, Bonville, 2000-2010 by (a) years and (b) months

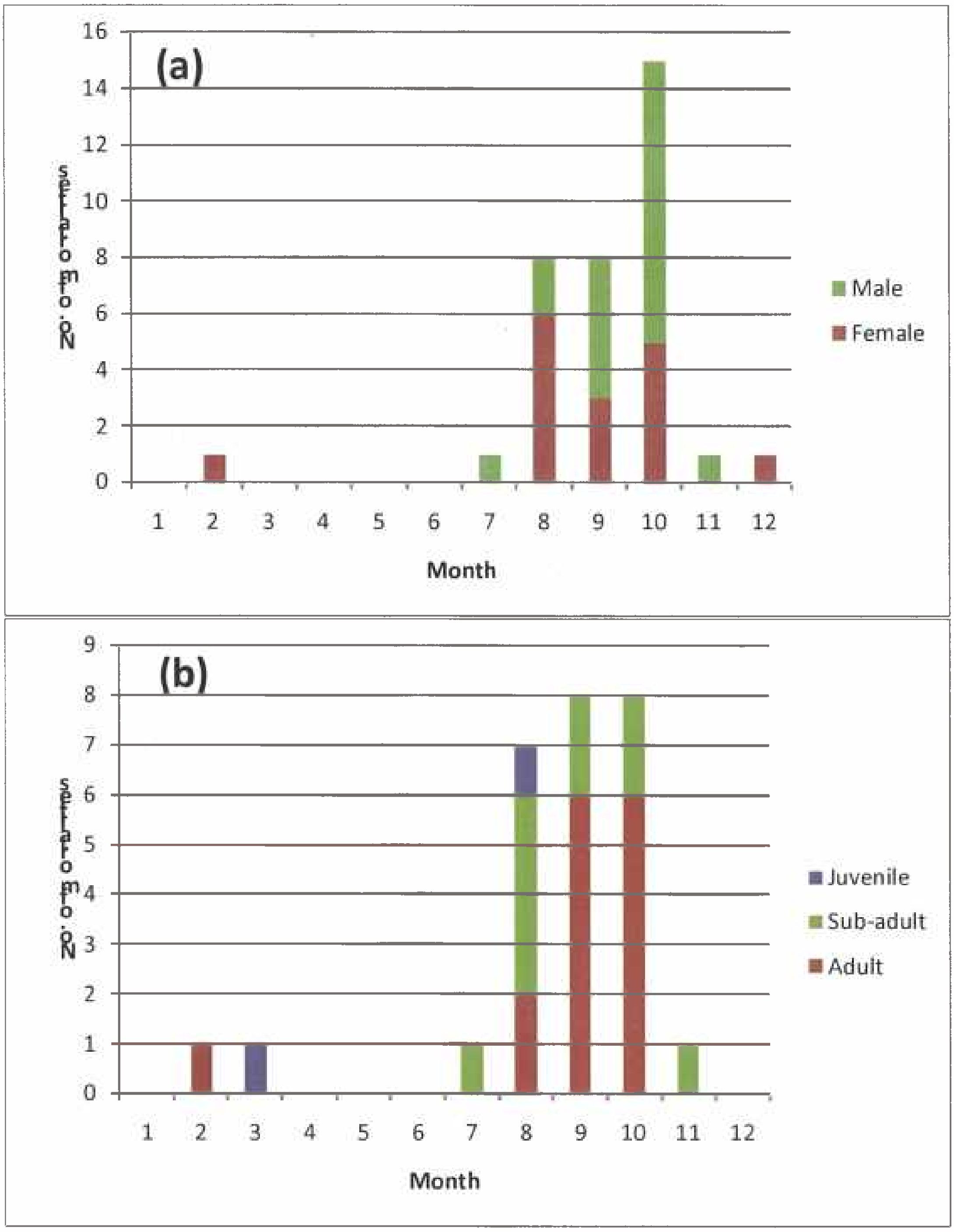

Figure 14: Seasonal Koala road mortalities at the Pacific Highway, Bonville, 2000-2010 by (a) sex classes and (b) age classes
(Animals not sexed or aged are omitted).

Table 10: Road mortalities of Koalas at Bonville 2000 to 2010

Date	Month	Year	Sex	Age Class	Date	Month	Year	Sex	Age Class
23/02/2000	2	2000	-		16/09/2004	9	2004	-	
12/05/2000	5	2000	-		21/09/2004	9	2004	-	
17/07/2000	7	2000	M	Sub-Adult	4/10/2004	10	2004	F	Adult
3/08/2000	8	2000	-		8/10/2004	10	2004	-	Adult
5/09/2000	9	2000	-		22/10/2004	10	2004	M	
5/09/2000	9	2000	-		29/07/2005	7	2005	-	
12/09/2000	9	2000	-		4/08/2005	8	2005	F	Sub-Adult
13/09/2000	9	2000	F		3/11/2005	11	2005	M	Sub-Adult
23/09/2000	9	2000	F	Adult	13/11/2005	11	2005	-	
5/10/2000	10	2000	M		5/09/2006	9	2006	M	
7/10/2000	10	2000	M		3/10/2006	10	2006	M	
11/10/2000	10	2000	M	Sub-Adult	9/10/2006	10	2006	M	Adult
12/10/2000	10	2000	-		28/10/2006	10	2006	-	
22/03/2001	3	2001	-	Juvenile	15/11/2006	11	2006	-	
24/03/2001	3	2001			22/11/2006	11	2006	-	
21/08/2001	8	2001	F	Juvenile	29/11/2006	11	2006	-	
21/09/2001	9	2001	M		20/12/2006	12	2006	-	
7/10/2001	10	2001	-		2/08/2007	8	2007	F	Adult
19/10/2001	10	2001	M	Adult	8/08/2007	8	2007	M	
20/10/2001	10	2001	M	Sub-adult	11/08/2007	8	2007	F	Sub-Adult
22/10/2001	10	2001	F		14/08/2007	8	2007	F	Adult
22/11/2001	11	2001	-		19/08/2007	8	2007	F	Sub-Adult
20/02/2002	2	2002	F	Adult	12/09/2007	9	2007	F	Sub-Adult
21/08/2002	8	2002	-		4/10/2007	10	2007	F	
1/09/2003	9	2003	M	Adult	5/10/2007	10	2007	F	
10/2003	10	2003	-		11/10/2007	10	2007	M	
16/10/2003	10	2003	M	Adult	22/09/2008	9	2008	-	
22/12/2003	12	2003	F		25/08/2009	8	2009	M	Sub-adult
1/09/2004	9	2004	M	Adult	11/09/2009	9	2009	-	
7/09/2004	9	2004	-	Adult	20/09/2009	9	2009	M	Sub-adult
8/09/2004	9	2004	-	Adult	9/10/2009	10	2009	-	
8/09/2004	9	2004	-	Adult	23/10/2009	10	2009	F	Adult
15/09/2004	9	2004	-						

Road Mortality, Yelgun to Chinderah Study Area

Six Koalas were reported in collisions with vehicles on the completed Yelgun to Chinderah Bypass in 2004, during Phase 3 (Table 11) and five of these died as a result.

Table 11: Details of Koalas hit by motor vehicles along Yelgun to Chinderah Freeway
(* collision was not fatal)

Koala / Date	Easting	Northing	Description
01/01/04	551235	6856443	Sleepy Hollow – 1 km north
23/07/04	551038	6862109	*Koala crossing the Freeway at Christies Creek, ushered off
25/07/04	551073	6855895	Northbound Sleepy Hollow rest area, southern entrance, male 6.95 kg
26/07/04	551057	6862099	Northbound Christies Creek about 50m north, male 5.15 kg
25/08/04	551584	6873850	Chinderah, 100 m north of the Murwillumbah exit, fractured skull, euthanized, female
24/09/04	551057	6862103	Northbound Christies Creek, north end of Koala fence, male

3.2.5 Scat Surveys, Bonville Study Area

Forest Scat Transects

The highest number of scats counted during the scat transect surveys was in 2000, and the lowest was in 2010 (Figure 15). In 2000 Intermediate-aged scats were more abundant and fresh scats were less so. In all other years (2006, 2009, 2010), fresh scats were more abundant than other age classes. From 2000 to 2010, scats were found at or near the bases of 13 species of trees. Overall, scats were recorded most often in association with Grey Gum Table 12). Scats were also recorded frequently near Tallowwood and Forest Sheoak (*Allocasuarina torulosa*) although for Tallowwood, no scats were recorded in 2009 and 2010.

Fence Scat Transects

Four scat transects along the outsides of the permanent fauna exclusion fences were completed in 2009 and 2010. The highest number of scats recorded was in September 2009 (Figure 16) when clusters of scats were recorded under three trees on the west side, and six trees on the east side of the highway. In January 2009 and July 2010, scats were found under one tree only, and in March 2009 no scats were found.

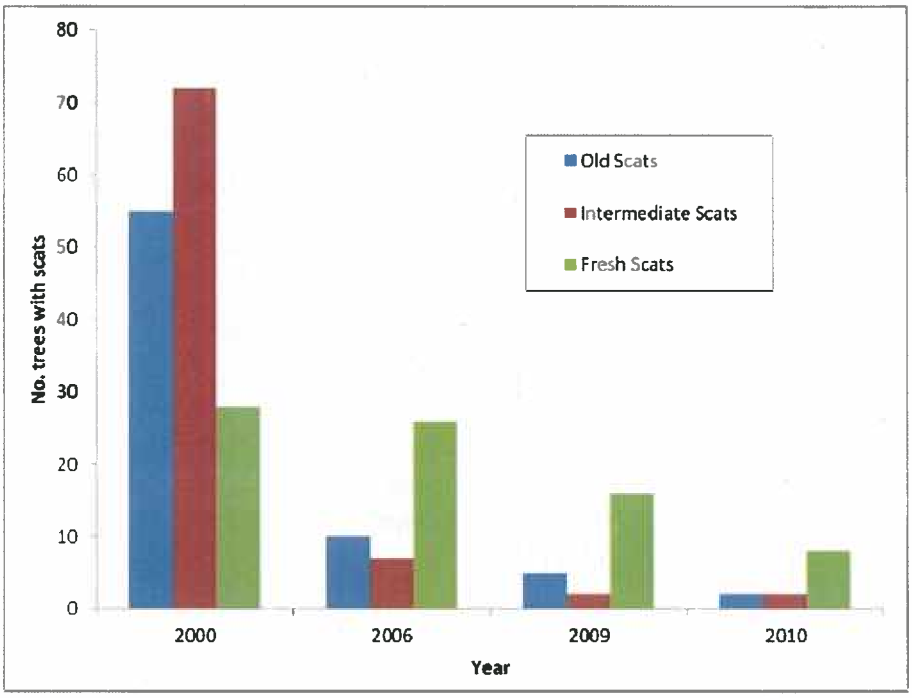

Figure 15: Number of trees with Koala scats (of different ages) under them, counted at Bonville during repeated transect searches 2000-10

Table 12: Species of tree with Koala scats recorded underneath in years 2000-10

Tree	Species	No. Trees with Scats			
		2000	2006	2009	2010
Grey Gum	*Eucalyptus propinqua*	42	16	8	3
Tallowwood	*Eucalyptus microcorys*	36	15	0	0
Forest Sheoak	*Allocasuarina torulosa*	22	6	8	5
Turpentine	*Syncarpia glomulifera*	8	0	3	2
Flooded Gum	*Eucalyptus grandis*	6	0	0	0
White Mahogany	*Eucalyptus acmenoides*	6	0	0	0
Blackbutt	*Eucalyptus pilularis*	3	0	0	0
Grey Ironbark	*Eucalyptus siderophloia*	2	0	2	1
Red Bloodwood	*Corymbia gummifera*	2	0	0	0
Brushbox	*Lophostemon confertus*	1	0	1	0
Guioa	*Guioa semiglauca*	1	0	0	0
Blue Gum	*Eucalyptus saligna*	1	0	0	1
a rainforest species		0	0	1	0

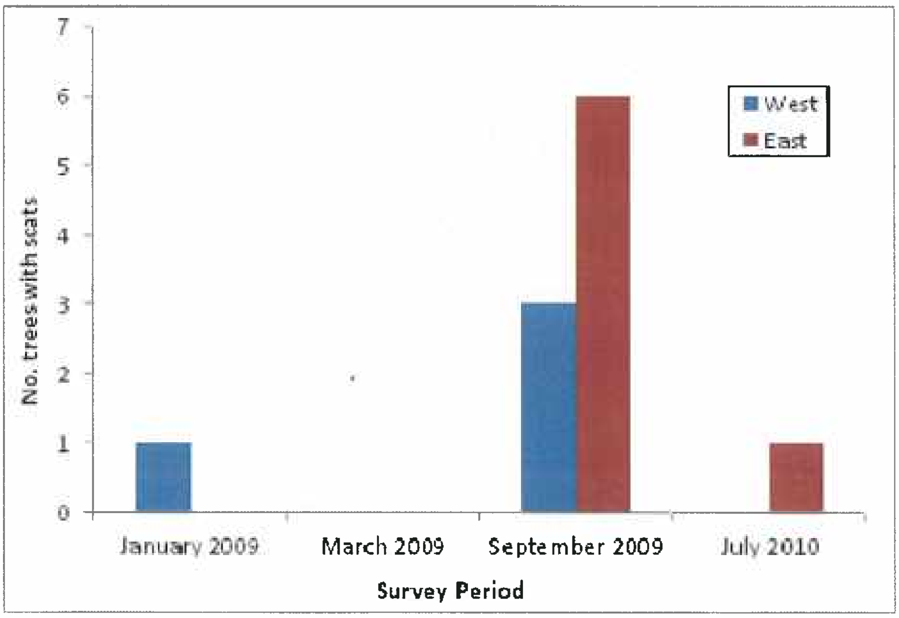

Figure 16: Number of trees with Koala scats recorded underneath them during monitoring of fence transects, east and west of the Pacific Highway, Bonville 2009-2010.

3.2.6 Koala Surveys and Monitoring Prior to and During Vegetation Clearing

The clearing works in the Bonville Study area extended from 8 December 2006 to 15 February 2007. Several Koalas were sighted in the area to be cleared. All moved of their own accord and none required capture and relocation. No Koalas were killed or injured during vegetation clearing.

Prior to vegetation-clearing, the home-range of a radio-collared Koala (Scapula) at Bonville included most of the highway and midway to Reedys Road. He was found on six occasions in or near vegetation clearing work zones. Several other Koalas were also found in the work zones. Vegetation-clearing contractors were informed of their locations and assisted to work around them.

The following diary notes document significant events during the vegetation-clearing phase.

- 8 December 2006 – A Koala was sighted 10 metres to the east of the eastern clearing line in a Flooded Gum. It had moved by the next morning.
- 11 December 2006 – Scapula (an adult male Koala collared in September 2006) was in a tree on the lower service road, close to the vegetation clearing works.
- 12 December 2006 – Scapula was 40 m east of the active log dump.
- 18 December 2006 – Scapula was directly in front of the vegetation-clearing works at 7:00 am, and his tree would have been felled had it not been for pre-clearing surveys.
- 2 January 2007 – Scapula was 20 m from the vegetation-clearing front, which was due to resume the following day.
- 3 January 2007 – A Koala was sighted in a Forest She-oak 50 m southeast of chainage 9580, and reported to RTA.
- 4 January 2007 – At 07:00 Scapula was in the top of a tree just in front of the vegetation-clearing works. At 17:00 he had moved to the nature strip 20 m wide and vegetation-clearing was occurring on both sides of him.
- 5 January 2007 –Scapula was in the construction site and close to the vegetation clearing works, but at a safe distance.
- 24 January 2007 – Iris (a radio-collared Koala) was located beside the highway, and was looking stressed. She was captured and moved to a tree within her known home-range.
- 24 January 2007 – A Koala was reported along the edge of construction was left in place and monitored.
- 3 February 2007 – Habitat-tree clearance supervisors located a Koala just outside the site in a resident's backyard.
- 15 February 2007 – Vegetation-clearing were completed.

3.2.7 Monitoring Fauna Movement Structures

Raleigh Underpass 1999
The remote camera at the Raleigh underpass in 1999 recorded at least three, and possibly four, movements of Koalas (AMBS 2001). Three of the traverses were made by two animals which were captured and tagged during the 2000 capture trip. Another unknown animal may have completed a crossing but this was not confirmed as only one set of tracks was observed in the sand tray on the western entry. Other mammals recorded using this structure included Brush-tailed Phascogale, wallaby, bandicoot, rat, cat, dog and fox.

Remote Surveillance Monitoring, Bonville Study Area 2008-2011
From 6 December 2008 to 14 April 2011, monitoring cameras at the monitored fauna movement structures in the Bonville study area obtained 2,521 records of 38 species of mammals, birds, reptiles and frogs using the structures. Koalas were recorded 26 times during the monitoring period (Table 13) and definitely or probably made complete passages on 10 occasions (e.g., see Plate 1). Koalas were not recorded on the overpass. Koalas were recorded using both the 'furniture' (Plate 1) and the floor of underpasses.

Table 13: Koala records from the remote camera surveillance monitoring at fauna movement structures at Bonville 2008-2011

Record number	Date	Fauna Movement Structure				Complete passage?
		Infra 2 south	Infra 2 north	Raleigh east	Raleigh west	
1	01/05/2009, 03:14	✓				**Yes**
2	21/09/2009, 03:14			✓		Unlikely
3	21/09/2009, 03:20			✓		Unlikely
4	21/09/2009, 03:23			✓		Unclear, but likely
5	22/09/2009, 23:57	✓				**Yes**
6	26/09/2009, 21:56			✓		Unlikely
7	27/09/2009, 02:37	✓				**Yes**
8	16/10/2009, 20:53/54				✓	No (returned)
9	16/10/2009, 21:33/36				✓	No (returned)
10	16/10/2009, 22:28/29				✓	No (returned)
11	17/10/2009, 03:21				✓	Unlikely
12	17/10/2009, 03:36				✓	Unclear, but likely
13	24/10/2009, 20:15		✓			**Yes**
14	10/09/2010, 00:49		✓			**Yes**
15	10/09/2010, 00:55	✓				**Yes**, same as record number 14
16	18/09/2010, 00:20				✓	See record number 17
17	18/09/2010, 00:26			✓		**Yes**, enter and exit on pole
18	18/09/2010, 00:31				✓	Unlikely, exit on pole
19	18/09/2010, 00:32				✓	Unlikely, enter on pole
20	18/09/2010, 00:40				✓	Unlikely, exit on pole
21	18/09/2010, 01:03				✓	See record number 22
22	18/09/2010, 01:06			✓		**Yes**, enter and exit on ground
23	18/09/2010, 04:17			✓		See record number 24
24	18/09/2010, 04:21				✓	**Yes**, enter and exit on ground
25	24/09/2010, 19:20				✓	See record number 26
26	24/09/2010, 19:24			✓		**Yes**, enter and exit on ground

Plate 1: Koala photographed on 18/09/2010 at Raleigh West

Fauna other than Koalas were also recorded using the movement structures (see Appendix). Those species or groups most often recorded included Swamp Wallaby (*Wallabia bicolor*; 206 records), Lace Monitor (*Varanus varius*; 293 records), Red Fox (*Vulpes vulpes*; 105 records) and small mammals (550 records). The small mammals appeared to be a combination of species from the genera *Antechinus*, *Rattus* and *Melomys*. Confirmed species within these genera included the Bush Rat (*Rattus fuscipes*) and the introduced Black Rat (*Rattus rattus*). Two species of bandicoot were recorded, the Long-nosed Bandicoot (*Perameles nasuta*) and the Northern Brown Bandicoot (*Isoodon macrourus*).

Plot Monitoring, Bonville Study Area 2008-2011
No Koalas were recorded during the plot monitoring at Infra 4 and Infra 13 in either sand trays or soot-track plates. However, a range of other species or faunal groups were recorded (see Appendix) including wallabies, bandicoots, possums, rodents, dogs, foxes, lizards, snakes and small birds.

Scat Quadrat Monitoring, Yelgun to Chinderah Study Area
No Koala scats were observed in quadrats during the quarterly monitoring of sites at overpasses at Taggarts Hill, Chinderah and Yelgun.

Plot Monitoring, Yelgun to Chinderah Study Area 2008-2011
Sand traps, monitored from 10 February to 31 March 2003 along the Yelgun to Chinderah route, had 1,248 'readable' tracks from 22 fauna groups or species, including eight non-native species. The species recorded most were Swamp Wallabies, dogs and bandicoots. No Koala tracks were recorded.

3.3 DNA Studies

3.3.1 Tissue DNA

A total of 66 alleles were found at the six examined loci amongst the 78 animals (live and road-killed) from the combined Bonville and Yelgun to Chinderah areas. Of these 66 alleles, 12 were found in the northern study area that were not found in the southern study area, while 19 were found in the south but not in the north. Nevertheless, it is still possible, though unlikely, for animals in the north and south to have the same allele profile. Of the 21 Koalas captured in the Bonville study area, there were 42 alleles for the 6 loci. Nine additional alleles were found in Koalas from adjacent areas in the Coffs Harbour area, while the Bonville animals had three alleles not found elsewhere. Studies of additional animals from the Coffs Harbour area may remove these local differences or, less probably, indicate that the Bonville animals represent a distinguishable population.

Heterozygosity was high in both the Yelgun to Chinderah and Bonville populations: Ho=0.78 and 0.72 respectively. This compares with considerably lower values found in the Campbelltown population near Sydney (HO = 0.49) (Lee *et al.* 2010). The allele profiles of individual animals can indicate relatedness. Any animals that share one of the two alleles at each locus could be first order relatives; i.e. siblings, parents or offspring. Where one parent is known, as in the case of a mother and pouch young, it is then possible to predict the other potential parent or parents. The Yelgun to Chinderah region contained four sub-regions which could be recognised by their genetic profiles. However, two of those sub regions had few samples. Kinship analysis showed that six of the Yelgun to Chinderah animals were probably related and four of these formed a geographic cluster; the remaining two were only 6 km and 15 km from the main cluster. Another group of three animals had profiles consistent with being first order relatives but were not closely related to the first group. Three of the nine individuals in the two groups were males. Of a further five animals in the clusters that were not closely related, four were males. This pattern is consistent with the hypothesis that males are more likely to disperse from the maternal home-range than females, which tend to set up populations structured along matrilines (Fowler *et al.* 2000)

The profiles of the initial 21 study animals at Bonville are such that all but two of the animals could have first order relatives amongst the 21. The exceptions are a young male ('Gaze') and a young female ('Dawn') who both crossed the road after capture. 'Gaze' crossed the road via a culvert and moved out of the study area before his collar was removed.

Despite the apparently close relationship of the 21 Bonville animals, only one of the three females in the study with young had a potential father ('Kieran') for her young amongst the known males. Two old males (Aussie Joe, Antonio), despite their age, could only be the fathers of three of the other 19 Koalas in the study. These two lines of evidence suggest that, untagged males are apparently in the area.

Of the 35 Koalas road-killed or collected by WIRES in the Coffs Harbour region, 23 had potential first order relatives amongst the 21 Bonville study animals. These 23 included two pairs of individuals, from Toormina and Bonville which had identical profiles. Of the six road-kills collected in Bongil Bongil National Park (i.e. in contiguous habitat with the study area) there were five alleles not found among the living animals captured in Bonville. This finding is consistent with the hypothesis that those animals killed are dispersing from more distant areas. However, the result could also be due to the small sample size.

3.3.2 Faecal DNA

Samples from Scat Transects 2003
During the 2003 scat transects at the Bonville study area, Chris Moon collected 41 bags containing a total of 204 pellets. After selection for a suitable patina, DNA extractions were attempted from 101 of these pellets and 40 pellets from 23 bags appeared to have sufficient DNA to attempt PCR amplification of microsatellites. Results were recorded from at least one locus for 35 pellets from 20 of the 23 bags. Eleven of these bags contained two or more pellets that produced results, and for seven of these, the DNA data were consistent with two pellets from each bag being from the same animal.

Ratings of pellet freshness could not always predict success of DNA typings. Of the 19 pellets for which three or more microsatellite loci could be scored, 14 had been labelled as 'fresh', one as 'intermediate' and four as 'old'. By comparison, five 'old', 11 'intermediate' and eight 'fresh' pellets had less than three scorable loci.

DNA typings were obtained for tissues from seven formerly radio-collared Koalas (Wilbur, Alison, Susie, Shane, Matt, Kieran, O'Neil). One of the eight primers failed to provide results for either tissues or faecal pellets and a further two produced results only for the tissues, while another locus produced results for only nine pellets. For the five primers that provided information, only one pellet provided typings from all five primers, 12 from four primers, seven from three primers, 10 from two primers and five from one primer only.

Of the five primers that produced results for both tissues and pellets, a total of 24 alleles was found for the tissues and 31 for the pellets, with 16 shared. The relatively larger number of alleles for pellets may be due to mistypings. The tissues, in general, produced sharper bands whereas the pellets were more difficult to score and bands that differed by only two base pairs were sometimes difficult to distinguish.

When results from tissues were compared with those from pellets, there were no direct matches. However, pellets with profiles similar to but not exactly the same as the tissue DNA of Shane, Alison, Susie, Matt, Klim and Kieran were found in their respective areas.

Twelve different profiles were discovered, including four on the western side of the highway, and eight on the eastern side. Those eight included six profiles described above and two different ones.

Samples from Scat Transects 2004
Of the 146 pellets collected (from 34 bags) 101 were suitable for DNA extraction. Mitochondrial DNA analysis of the 101 pellets indicated that 99 samples would have sufficient DNA to attempt amplification. Microsatellite results could be recorded for at least one locus for 76 pellets. Twenty-eight bags contained two or more pellets from which DNA could be

extracted and results indicate that the pellets came from the same animal in all except one instance where two distinct profiles were detected from the same bag of pellets.

Of the 99 pellets analysed, 36 had been classified as 'fresh', 45 as 'recent' and 18 as 'old'. However, only 46 samples could be scored at three or more loci. Twenty-one of these samples had been labelled as 'fresh', 23 as 'recent' and two as 'old'. By comparison, 15 'fresh', 22 'recent' and 16 'old' pellets had fewer than three scorable loci and therefore could not be included in the complete DNA analysis. This indicates that the ratings of pellet freshness could not always predict the success of DNA typing, except in cases where the pellets are classed as old.

One of the six loci (21.3) failed to provide results for the majority of the faecal samples (75/99 reactions) and two of the tissue samples. The other five loci successfully amplified 50-70% of all reactions. Overall, 23 samples failed to amplify any locus, 11 amplified at only one locus, 19 at two loci, three at three loci, two at four loci, 25 at five loci and 16 at all six loci.

The majority of the 41 samples that amplified at five or six loci possessed identical genotypes to at least one other sample. This usually occurred when pellets had been sampled from the same bag. Any samples displaying this trend were considered to be the same individual and as a result only one set of data was used for further analyses. This revealed that a total of 15 individuals had been detected in the Bonville study area during this sampling.

The genotypes of the 15 individuals were compared to the genotypic data for the 12 road-killed Koalas and to the genotypic data obtained from nine known residents of the Bonville study area. None of these nineteen tissue genotypes matched a single profile for the pellet DNA. However, both the tissue and pellet samples shared many alleles, indicating that a degree of gene flow is occurring somewhere in the population.

The results of the parentage analysis show that all 15 pellet samples match at least one candidate parent. 12 matches had a high confidence of being correct (>95%), one match had a relaxed confidence (80%) and two matches were without any confidence levels. Four of the matches had no mismatching alleles for five or six loci that had been compared. The remaining 11 matches did contain mismatching alleles for between one and three loci. The majority of the mismatches occurred when the allele sizes differed by two base pairs. Other mismatches occurred when the pellet sample was a homozygote and the parent heterozygote, indicating the presence of a null allele.

4 Discussion

4.1 Koala Ecology and Behaviour

4.1.1 Introduction

The Koala *Phascolarctos cinereus* (Family Phascolarctidae) is a marsupial mammal and one of the largest of Australia's arboreal mammals, with males weighing an average of 12 kg. It occurs in the forests and woodlands of eastern Australia. Koalas are solitary animals but occupy home-ranges that may overlap extensively with those of other Koalas. Koalas are herbivores that feed almost exclusively on the foliage of *Eucalyptus* species and their home-range areas are determined largely by the supply of preferred food trees.

4.1.2 Koala Habitat

Koalas inhabit eucalypt forests where they feed mostly on the foliage of eucalypt trees. The quality of their habitat depends on the suitability of a variety of resources such as food tree abundance and diversity, forest structure, soil type, topographic position and disturbance history (Smith and Andrews 1997). However, while it is true that some areas can sustain more animals than others (Phillips and Callaghan, 2010), it may not mean that such areas are inherently 'better' for the Koalas themselves. Koalas with established home-ranges in low density populations may live longer, suffer less from disease, produce more surviving offspring over their lifetimes, fight less and have slower rates of tooth wear than those in high density populations. However, it may be more difficult and dangerous for dispersing animals in low density populations to establish home-ranges and they may have to travel further to maintain their territory and access its resources, which might expose them to greater risks. They may also be more vulnerable to extreme weather conditions, fires and floods. There has been a tendency to recognise high quality habitat based on the features that support high density populations. However, it might be more appropriate to recognise lower quality habitat as that where extreme conditions lead more often to localised, temporary extinction of the population.

Most attempts to classify the quality of areas as Koala habitats are based on the type and frequency of tree species known to be used for food (Phillips and Callaghan 2000, Ellis *et al.* 2002, Moore and Foley 2005). Superior habitats are usually considered to be those that have more 'preferred' species. The latter are usually defined as those trees that are chosen by Koalas more frequently than expected from observed frequencies.

However, there are many variables that affect the palatability and use of the foliage and these variables make the assessment of habitat quality a difficult task. They include:

1) **Nutrient content**: Koalas obtain all their nutrients from the cellular contents of the leaves and in more fertile areas the supplies of nutrients are likely to be higher and more dependable. Nitrogen levels, which are generally low in eucalypts, are a major determinant of leaf choice (Moore and Foley 2005). Besides the fertility of a site, slope, aspect, and rainfall are also likely to affect nutrient content and consequently habitat selection. However, Martin and Handasyde (1999) reported thriving Koala populations on nutrient-poor soils in South Gippsland, Victoria.
2) **Secondary metabolites**: eucalypts combat herbivores by producing toxic secondary metabolites (phenolics and terpenes). Koalas must detoxify metabolites, which takes energy. In particular, formylated phloroglucinols have been found to negatively affect leaf choice. Levels of this compound vary from tree to tree and from species to species and would be a factor in determining habitat quality (Moore and Foley 2005).
3) **Water content**: in general, Koalas obtain moisture from the cytoplasm of dietary leaves, although they can sometimes supplement this with dew, rain and surface water. In the absence of the latter three sources, as in periods of drought, Koalas might adjust their water balance by eating more leaves or choosing more succulent leaves. However, there is a limit to the amount of food that can be held in the digestive

system. Consequently, a given site will be useful to Koalas if it has a water table that is reached by the tree roots and supports several species that will enable the resident Koalas to adjust their water balance and nutrient requirements. Clifton *et al.* (2007) considered that Koala distribution is limited by the ability of the animals to maintain water balance.

4) **Temperature control**: Koalas maintain their body temperature by respiratory evaporation. Consequently, maintaining water balance becomes particularly important in hot, dry conditions. Moreover, the higher the relative humidity, the less effective is respiratory cooling. Koalas also reduce their body temperature by behaviour whereby they sprawl to expose the greatest body area and the maximum amount of white belly fur to reflect heat. Many also choose trees with heavy foliage to obtain maximum shade for daytime resting. Such shade trees are often not used for food (Sluiter *et al.* 2002, Ellis *et al.* 2010) and therefore it requires additional energy to find and climb them. Less energy would be required if such shade trees were distributed evenly throughout the home-range.
5) **Disease**: Koalas are vulnerable to Chlamydia and infertility and death can be outcomes. They can also suffer from a number of other diseases.
6) **Ectoparasites**: Ticks and leaches can cause significant blood loss in wetter habitats, and the paralysis tick is potentially lethal to Koalas (Martin and Handasyde 1999).
7) **Tree size**: Moore and Foley (2005) found that Koalas tend to choose larger trees for feeding even if they contain more toxins.
8) **Fire**: Koalas are vulnerable to fire, and their habitats, dominated as they are by eucalypts, promote fire to greater or lesser extents. Fires can result in direct deaths as well as short-term losses of food, water and shade. Both fire frequency and fire intensity affect habitat quality. The presence of shelter in the form of caves, cliffs or fire resilient vegetation (e.g. rainforest gullies) may allow additional opportunities to survive.
9) **Direct threats**: Rhodes *et al.* (2006) found that the abundance of roads and dogs (along with habitat area) affected Koala distribution at Port Stephens, NSW.

McAlpine *et al.* (2006) used modelling analysis to determine the importance of several variables to account for Koala occurrence. They discovered that Koala occurrence increased with the overall area of all forest habitats, Koala habitat patch size, and the proportion of preferred food species. They found that Koala occurrence decreased with increases in the distance between Koala habitat patches (i.e. habitat isolation), decreases in the density of forest patches (patches/100 ha) and increases in the density of sealed roads (metres/hectare). They found that habitats supporting lower quality food species were more important than they had expected and concluded that such habitats could support some breeding and low density Koala populations. Connected areas of even marginal habitat are therefore likely to be important for Koala movement and dispersal.

In a Queensland population Thompson (2006) found that differences in tree choice occurred between individuals, although taller and larger trees were generally preferred. Thompson considered that assessing the quality of habitat by the presence of a small number of preferred tree species is too simplistic. He recognised that block size, habitat fragmentation, connectivity and disturbance levels in nearby areas contribute to the quality of Koala habitat.

4.1.3 Koala Population Biology

Despite the iconic status of the Koala and the number of researchers studying its biology, there are a surprisingly large number of gaps in the collective knowledge. For example, there is still considerable disagreement about the overall number of Koalas and also the optimal density of Koalas required to maintain sustainable numbers in different locations. In general, declines in Koala numbers at sites with high population densities are considered to be matters of some concern. However, there are also sites where population densities are recognised as being too high. These are mostly the results of translocations of Koalas to islands off the coast of Victoria and South Australia and to certain mainland sites where forests are being defoliated (Martin and Handasyde 1999).

There are several observations that are consistent with the hypothesis that the normal status for most Koala populations is low density:

1) Koalas were not discovered for 10 years after European settlement of Australia, suggesting that they must have been quite rare in central NSW at least (Lunney *et al.* 2010a). John Gould reported that during his collecting trips between Sydney and Brisbane in 1838 to 1840, the only Koalas he saw were those pointed out to him by aboriginal guides and that the species was scarce and difficult to collect (Martin and Handasyde 1999).
2) After the decline of the Dingo (*Canus lupus dingo*) and aboriginal hunting in the 19th century, population numbers of Koalas increased rapidly. This was followed in turn by disease outbreaks and predation by fur hunters (Gordon and Hrdina 2005). Rapid increase of population numbers followed by overpopulation also apparently occurred in the 20th century in parts of mainland Australia and on islands off Victoria and South Australia after translocations were made (Martin and Handasyde 1999).
3) Koala populations have the potential to recover well, due to female Koalas' longevity in established home-ranges (up to 15 years), low age of first breeding (2 years), annually breeding, and high success in raising offspring to the weaning stage (Martin and Handasyde 1999).
4) Koalas can locate each other even at very low population densities (R. Close, unpubl. data). Melzer and Lamb (1994) considered that extremely low density populations in central Queensland appeared to be breeding well.
5) Both male and female Koalas can disperse many kilometres across country that is sparsely inhabited, if at all, by other Koalas (Ward and Close 1998, Lunney *et al.* 2010b).

4.1.4 Dispersal and Home-ranges

The dispersal of Koalas, and the extent, overlap and permanency of their home-ranges are crucial behaviours driving the impacts of roads and road construction on the species.

Generally, the Koala breeding season is in spring and summer (Martin and Handasyde 1999). In the vicinity of Bongil Bongil National Park (previously Pine Creek State Forest), breeding begins in August corresponding with a dispersal of males from July to September (R. Close, this study). Most births occur between November and March and young gain independence at around 12 to 18 months of age. Animals reach sexual maturity at an age of 2 years, and while mature young males disperse, mature young females often remain in a home-range adjacent to their mother's. Young, sexually-mature males (2 to 3 years of age) can find it difficult to compete with larger, older males in their immediate area. They tend to leave their mother's home-range to establish in a new area not occupied by an older male and seek an available female to mate with (Martin and Handasyde 1999).

The factors that govern Koala dispersal and home-ranging include the social relationships between individuals, the size, density, and reproductive health of the population, and the proximity and connection to neighbouring populations. In turn these factors depend on the tree species available locally, the tree size, the amount of plant secondary metabolites (Moore and Foley 2005), the terrain, the soil, and the many components of successful water balancing. Consequently, the factors vary from region to region and from individual to individual, thereby resulting in different patterns of dispersal and home-range features in different areas.

Dique *et al.* (2003a, b) conducted a detailed radio-telemetry study of dispersal patterns of 195 Koalas at three sites in south-east Queensland. Successful weaning rates were 53/64 for males and 55/62 for female joeys. Most young Koalas dispersed in their second or third year, while no males older than 3 years and only three females older than 3 years dispersed. Of 32 young males, 23 dispersed while five remained and survived. Of 40 young females, only 14 dispersed while 15 remained and survived. All dispersals began between June and December, but males moved earlier than females: more than 50% of males moved in July to August, while more than 50% of females moved in September to November. Mean distances moved were similar for both sexes (3.5 km for males, range 1.1-9.7 km; versus 3.4 km for females, range 0.3 – 10.6 km). Four young males and six females died before establishing home-ranges: five were killed by vehicles, three by dogs and two by drowning. The probability of survival was higher for males dispersing in their third year rather than in their second. All males that left when aged between 20 and 24 months were born between October and January, while those dispersing when aged 28-32 months were born between January to April. The female pattern resembled that of the younger male group.

Dique *et al.* (2003 b) also summarised information on dispersal from seven previous studies undertaken in four states and quite different in population density, climate and tree species. The proportion of young males dispersing ranged from 72-100% while for females it was 35-100%. A distinctly higher rate of dispersal in males than females was observed in three of the studies. Age at dispersal ranged from 1 to 4 years while time of dispersal was October to March in South Australia and Victoria, August to November for northern NSW, and June to December for southern Queensland. Dispersal distances ranged from 0.3-11.7 km. Survival of dispersing males was 83% (pooled values for 3 studies, n = 42), compared to 73% for females, (n =26).

Thompson (2006) studied 210 Koalas in southern Queensland and found home-ranges of 5 to 17 ha that overlapped and were continually changing. There was some competition between males for space. Movement was affected by local conditions. Non-resident males sired 20-60% of young, but some local males contributed more than others. Variation was found in breeding patterns between geographically close sites. Higher proportions of older animals were found in secure sites. Rates of dispersal and immigration were high, and the existence of a large pool of nomads was suggested to explain this. Modelling indicated that secure areas are functioning at close to a stable level rather than as providers of dispersers. Thompson considered that net migration into a breeding area is critical.

Ellis *et al.* (2009) considered that non-food tree selection has a big effect on home-range use. They radio-tracked 59 Koalas on a Queensland island (3,000 ha) where there was a total population of 200-300 animals. Their work covered two seasons and revealed that:

1) Male bellowing (indicating the mating season) occurred from September to February.
2) Forty of 66 births (61%) occurred between October and December.
3) Koalas moved averages of 54 m between dawn and dusk and 63 m between dusk and dawn, with no differences between males and females.
4) Home-ranges varied from 0.6 to 40 ha.
5) No male/female differences in home-range size were found (averages of 8.6 ha ± 9.4 for males and 7.9 ha ± 8.7 for females).
6) Home-ranges did not change significantly from season to season.
7) No relationship was found between body mass and home-range size.
8) Koala home-ranges shifted over time: on average 55% of the breeding season home-range was used during the second season but only 11% of the non-breeding season home-range was used in year 2.
9) All home-ranges overlapped with at least seven others and on average shared 25% of their area with other home-ranges. The extent of overlap was from low to complete and did not depend on gender.
10) Sharing trees was not frequent: 60% of Koalas did not share trees even once; only 51 of 5,950 trees were ever shared; 61% of the time Koalas used trees in their home-range that no other Koala ever used, but only 22% of trees were used more than once.

Koalas at Campbelltown (south-west of Sydney) have been studied for over 20 years (Lunney *et al.* 2010; Lee *et al.* 2010; Phillips and Callaghan 2000; Close and Ward 2004; Close unpubl. data). Koalas in that peri-urban population have long-term home-ranges (up to 12 years). They can maintain high reproductive levels and show remarkable longevity. Most females have established permanent home-ranges that change little from year to year. A few others change marginally over time. Some females establish home-ranges near to mothers while others disperse up to several kilometres away. Some males and females move long distances but males are found more often as road-kills. The density of Koalas at Campbelltown is low (0.1/ha) and home-ranges tend to be greater than 20 ha. Mortality rates are low compared with other populations that have been studied. Among seven radio-collared females that died, one was 8 years old, another 10 and the remainder 12-14. Cumulatively, there were 66 years of tracking data collected from those seven animals. This population is Chlamydia-free.

Studies of translocated Koalas can provide insights on movements and establishment of home-ranges after a disturbance; in this case of being moved into new environments. Four groups of 12 to 17 Koalas were released in different sites and radio-tracked for 2 years. Lee *et al.* (1990) found that:

1) Survival and reproduction were not affected by translocation into areas containing the same feed trees as the source area.
2) Koalas dispersed following release in November but this did not affect reproduction.
3) Familiarity between individuals in a group did not reduce the tendency to disperse.
4) Some Koalas chose areas with unfamiliar food trees.
5) All 12 young were weaned.
6) Most adults maintained or increased their weight.
7) Only 11 of 22 females continued to breed, due mostly to Chlamydia infection.
8) Males tended to disperse further in the first few weeks.
9) Most had settled in 3 months (three took 5-6 months).
10) Only old animals appeared to be impaired by the translocation or change of diet.
11) Dispersal patterns varied with release location: one area had a strong male bias; all males dispersed from all localities: at one site most females remained within 200 m of the release site while the four males moved 0.5-4 km.

Prevett (1991) released and tracked four Koalas (two adult and one sub adult females and one adult male) from sites 2.5-10 km from their capture points, into unfamiliar areas in Victoria that already contained resident animals. He also followed a further four that were released at the point of capture. He found that:

1) The translocated animals moved extensively and often directionally from their release site in comparison with three of the non-translocated animals.
2) Translocated animals continued to move for several months until movements lost directionality and the activity became localised.
3) Translocated animals moved 7, 10, 10 and 12 km.
4) Koalas were able to cross large tracts of open and alienated land.
5) Forested areas occupied by established Koalas were avoided.
6) Animals used local and non-local eucalypts and gardens.

Santamaria (2002) studied 30 translocations from French Island to mainland Victoria (half adults, half sub-adults; two-thirds female and one-third male). Seven died, eight were lost, and one was injured. Only 14 were still in the study after 26 months. Six females bred after the first breeding season. As many as 64% of the survivors increased in weight and 28% maintained their weights. Three release sites were used and distances dispersed within the sites were the same for all three sites after 126 days or 19 months. No significant differences in distances travelled were observed between sexes or age groups except at one site where adults moved farther than sub-adults. The source site was Chlamydia-free: but at the end of the study most study animals tested positive for Chlamydia.

Close *et al.* (unpubl. data) translocated one young male and three young females 100 km south from Campbelltown to Tarlo River National Park. Koalas had not been recorded at the release site since the 1970's. One female moved 500 m south from the release site before its transmitter failed. A second female moved 500 m west, established a home-range and raised two young. She left the site for a 1 km foray of short duration in November 2009, possibly a mating action. The male moved 4 km north in the first year, and was captured and returned to the release site the following year. He then found a site a few km to the east. In the following spring he moved 12 km north and was brought back to his first sedentary site and released with the third female. He moved 6 km north again in spring 2009 and his collar was removed. He displayed a consistent pattern of making long distance, northwards movements in spring, followed by exploratory movements, which became shorter and shorter leading to a sedentary period in June in an area that resembled a home-range. The third female, released in 2010 moved 4 km west and settled into a home-range.

Overall, most aspects of dispersal and home-range selection and maintenance vary greatly within and between different locations. The consistent patterns, despite the differences in sites, are:

1) Most dispersal occurs before Koalas are 3 years old.
2) Dispersal patterns vary between individuals in all locations, with some animals not dispersing and others moving 10 km or more.
3) Koalas disperse farther on average at some localities than others.
4) Both males and females disperse, though usually a higher proportion of young males do so.
5) Males tend to disperse slightly farther on average than females at some sites.
6) Breeding and dispersal always occur in a distinct season, usually spring to early summer, but slightly later in southern populations.
7) Home-ranges vary from site to site in their average size, the degree they change from year to year, and the difference in these between males and females.

4.1.5 Koala Distribution and Habitat in the Coffs Harbour Area

The most comprehensive description of local Koala distribution and tree and habitat choice in areas surrounding the Bonville study area occurs in the *Coffs Harbour City Koala Plan of Management, (November 1999)* (Lunney *et al.* 1999) (CHCKPoM). Relevant information has been extracted from that publication and appears below in italics.

The 1995 EIS for the Coffs Harbour/Urunga forestry management areas found Koalas to be locally common in the lower level coastal forests and uncommon on elevated ridges and escarpment forests in the region. State Forests recorded Koalas frequently in Pine Creek State Forest (PCSF) which was identified as the most important area of Koala habitat, and less frequently in other coastal forests. The sandstone areas of Conglomerate State Forest and the Nana Glen-Glenreagh areas, as well as the wetter forests of Tuckers Nob and Brooklana State Forests had only occasional Koala sightings.

The field-based survey for Koalas conducted for the CHCKPoM was primarily based on searches for Koala scats. Evidence of Koalas was found mainly in the south-east sector of the LGA. There was less evidence of Koala activity around Moonee and to the west of the LGA indicating that Koalas do occur in these areas but probably at a lower density.

State Forests' Koala records, provided in 1991 to the NPWS indicated that in the local forests Tallowwood, Blackbutt, Flooded Gum and Forest Oak were the major Koala tree species.

Koala scats were found during the CHCKPoM survey in 21 different vegetation units. Vegetation units on quaternary deposits averaged significantly higher activity levels than units on other geological types. Tallowwood E. microcorys was identified as the tree species most preferred by Koalas. This is consistent with other site-specific Koala surveys (Moon 1989, Smith and Andrews 1997). Other species identified as preferred trees were Swamp Mahogany E. robusta, Broadleaved Paperbark Melaleuca quinquenervia, Flooded Gum E. grandis and Blackbutt E. pilularis. Whilst Blackbutt and Broad-leaved Paperbark are often used as rest trees, they may be eaten occasionally and can be important to individual Koalas in particular locations. Other tree species used at lower levels by Koalas include White Mahogany E. acmenoides, White Stringybark E. globoidea, Swamp Turpentine Lophostemon suaveolens, Grey Ironbark E. siderophloia and Camphor Laurel Cinnamomum camphora. White Mahogany and Grey Ironbark are known to be utilised by Koalas in the Coffs Harbour area and occur on the interim list of tree species utilised by Koalas found in Fisher et al. (1996). The largest areas of primary habitat are concentrated around the urban areas of Coffs Harbour and Sawtell/Bayldon/Toormina, generally in the area south of Korora and east of the coastal range down to Pine Creek State Forest.

4.2 Koala Ecology in the Study Areas

4.2.1 Koala Populations in Pine Creek State Forest / Bongil Bongil National Park

The Bonville study area is in the former Pine Creek State Forest (PCSF), most of which became part of Bongil Bongil National Park in 2003. Several Koala surveys have been conducted in the PCSF. Smith (1996) undertook a spotlight survey, and the method was developed for Koala censuses in 1998 and 1999 (State Forests of NSW 1999). In 1996, most of the search effort (15 out of 20 transects) was conducted on compartments directly west of the Bonville Deviation area. Between two and 13 Koalas were seen or heard per transect with approximately one Koala seen per 5 ha of spotlight area. In 1998 transects were added more widely across the Forest when 17 Koalas were seen and 88 heard from walked transects and 34 Koalas were seen from spotlighting. Calls were heard widely across the Forest, while sightings were recorded most often in the central regions. In 1999, during walked transects 14 Koalas were seen and 86 were heard, while 29 were observed during spotlighting. The results for the 2 years were remarkably consistent and showed that Koalas were using most of the Forest, although the densities were patchy. Spotlighting from 1998-1999 revealed 37 adults, nine sub-adults, four juveniles and eight joeys, indicating that the Koalas were breeding, and that it was therefore likely that young Koalas would be dispersing across the Bonville Deviation area from both the east and west.

Those surveys also recorded, where possible, whether the Koalas had visual symptoms of Chlamydia (infected eyes or wet bottom). From 34 animals, three had infected eyes and three had a wet bottom. This is probably a significant infection rate because it is likely that only the most severely infected animals would have been detected. Radford *et al.* (2006, 2010) verified the infection problems. Their clinical study of 54 Koalas in PCSF over 3 years revealed a high prevalence of clinical and subclinical chlamydiosis, anaemia of unknown origin, a high mortality rate and a low reproductive rate. During 1999 there was a 72% prevalence of Chlamydia bacteria and a 44% incidence of symptomatic disease (keratoconjunctivitis), a 90% incidence of chronic otitis externa (inflammation and infection of the ear pinnae), and several animals were diagnosed with severe illness after examination of clinical pathology results post release. Radford *et al.* (2010) associated the poor health with the high prevalence of chlamydiosis but considered that elevated ectoparasitism, reduced structural diversity of the forest and reduced plant species diversity of the forest understorey may have contributed.

The minimum number of Koalas in the PCSF was estimated to be between 350 and 450 with the population density varying from one Koala per 8 ha to 50 ha (0.125 to 0.02 Koalas per ha) (Lunney *et al.* 1999). Assuming that the sex ratio is equal, females breed between the ages of 2 and 10 years and produce a young every second year, then a population of this size could produce a maximum of 70 to 90 young per annum. Of these, 35 to 45 would be females and 17 to 22 of them would be required to replace females dying at the age of 10. The margin required to replace premature deaths from accidents, predation and disease is therefore not large. However, these figures may be conservative. For example, at Campbelltown most resident females live beyond 10 years and produce young yearly (R. Close, unpubl. data). However, the Campbelltown Koalas lack Chlamydia.

The numbers of Koalas seen (33) and captured (23) for the purposes of this study during the capture survey in 2000 were much higher than in any other year. The numbers were lower in 2001 (3 new sightings and 11 captures) prior to the suspension of the program for 4 years. Capture surveys in 2006 to 2009 recorded a maximum of nine Koalas seen and 11 captured in any one year. With the exception of the first year, the other years are all fairly consistent. The surveys were not intended to quantify the number of animals in the study area so they were not entirely consistent in their efforts and methods. However, the intention was to find as many Koalas as possible, and it is unlikely that survey effort was sufficiently dissimilar to account for the differences observed between 2000 and 2006-2009 (and may have been greater in Phases 2 and 3 than in Phase 1, because of the imperative to find animals for the study). Regular radio-tracking work in the study site throughout each year consistently suggested that there were not many unknown Koalas in the study area that might have been missed during the 2006 to 2009 capture surveys.

The scat transect survey data show a similar trend to the capture survey data. The number of scats recorded were much higher in 2000 compared with 2006, 2008 and 2009. The lower density of scats in later years could reflect a lower density of Koalas in the study area.

The data suggest that the population size was reduced considerably between 2000 and 2006. Possible reasons for the decline in numbers include the effects of:

- forestry logging activities (selective logging was undertaken in a compartment near the highway in 2005);

- extended drought leading to a reduction in the carrying capacity of the local forests for Koalas (e.g. through changed leaf chemistry or water-balance stress);
- disease.

It is possible that several factors were involved or interacting.

The mortality rate of Koalas tracked in this study was high while the recorded birth rate was low. In the first year of the study, five (36%) of 14 collared Koalas died and in the second year four (40%) of 10 died (one 3 weeks after his collar was removed). In 2006-2007 none of four collared Koalas died. Subsequently, four (67%) of six died in 2007-2008, two (29%) of seven died in 2008-2009, and one (11%) of nine died in 2009-2010. Three other captured Koalas were euthanased by vets over the course of the study. Meanwhile, during the 6 years of active study only six captures were made of mothers with a joey (pouch-young): three in 2000, and one each in 2006, 2008 and 2009.

The 19 mortalities resulted from the following factors:

- old age (presumed) 3
- disease (confirmed) 3
- natural causes (undetermined) 7
- construction impacts 1
- euthanasia of sick animals 3
- road-kill 2

None of the deaths appear to have been caused inadvertently by the study. The techniques employed have been used widely in other studies and are proven to be safe. Strict capture, handling and hygiene protocols were in place, and widely experienced scientific advisors were present during all capture and collaring processes.

An important implication of the apparent population decline at Bonville is that it confounds many of the investigations into the impacts of roads on Koalas from this study.

4.2.2 Koala Habitat in the Bonville Study Area

Previous studies classified Koala habitat into four quality zones in the PCSF (modified after the PCSF KPoM State Forests of NSW 1997). This showed that although Koalas were seen across the forest in all zonings, most were sighted in the highest quality category areas (Zonings 1 and 2). Overall, most of the forest west of the highway consisted of Zones 1 and 2, while to the east, Zone 2 predominated, but with scattered patches of the other three categories. The mapping for the AMBS study area showed that east of the road, all four zonings were represented but Zones 2 and 4 comprised the largest areas. West of the Highway and east of the power-line easement, Zone 1 was the largest area with small patches of Zones 2 and 3. West of the easement, Zones 1, 2 and 4 were approximately similar in area.

The Bongil Bongil National Park has most of the features for providing optimal habitat for Koalas. The area includes a rich mixture of vegetation types and ages on different topographies that support varying densities of Koalas by providing dietary choice for supplying nutrients and water, and for coping with toxins. The trees also provide shade and protection from predators. The more densely occupied areas correspond to higher densities and a richer variety of preferred food trees. The widespread presence of swampy areas indicate that the water table is high so that maintaining water balance should not be a critical factor for Koala survival. The areas are contiguous with habitat where Koalas are in lower densities but which, nevertheless, would provide a source for replenishment and genetic variation and a link to other populations. The Bongil Bongil National Park is an important area for the Koalas of the region consisting of habitat that is likely to support Koalas even during extremes of weather and climate.

In Bongil Bongil National Park, the tree species that Koalas were observed in during the night (Smith 1996, State Forests of NSW 1999) concurred well with a dietary study analysing faecal pellets (Phillips 1997). Of 90 nocturnal sightings in 15 tree species, 28 were in Tallowwoods, 14 in Flooded Gums, 12 in Grey Gums, 11 in Forest Sheoak, five in Blue Gums, four in Red Mahoganies and four in Blackbutts. Phillips (1997) identified 17 species (10 eucalypts) from faecal pellets. Tallowwood was most frequently found followed by Grey Gum, Flooded Gum, Forest Sheoak, Blue Gum, Swamp Mahogany and Red Mahogany, and occasionally White Mahogany, River Red Gum (E. *camalduensis*), Grey Ironbark, Turpentine and Brush Box (*Lophostemon confertus*). Smith and Andrews (1997) found that the tree size classes of 40-50 cm, 60-70 cm, 70-80 cm and 80-100 cm had more scats than expected beneath them and the class 10-20 cm had less than expected. This suggests that Koalas prefer larger trees.

4.2.3 Koala Health and Disease

The prevalence of Chlamydia in the local Koala population was high. Its incidence apparently doubled over two decades with a climb in the average from 15.2 incidents per year during the decade of 1991 to 2000 to 32.75 incidents per year during the decade of 2001 to 2010. Chlamydia affects the fecundity of Koalas. The disease seemed virulent in the Bonville study area, and may account for the low birth rate observed during the study. However, the rates of infection were similar to other areas in northern NSW and southern Queensland.

Tubular nephritis was found to occur at an unusually high rate. This may be due to the presence of a toxin, potentially derived from toxic residues from industrial chemicals in leaves or soil, or some other, naturally-occurring substance. Further research into this would be worthwhile.

There was no evidence of anaemia in any Koalas captured during the project including during veterinary inspections, gross findings or from pathology results. This contradicts the findings of Radford *et al.* (2006, 2010).

4.3 Koalas near Operational Roads

4.3.1 General Impacts of Roads on Wildlife

The impacts of roads on wildlife have been the subject of many studies overseas, particularly in North America (Fahrig *et al.* 1995. Forman 2000; Clevenger and Waltho 2000; Trombulak *et al.* 2000), but the issue received little attention in Australia until recently. Australian research outputs increased in the 2000s in conjunction with upgrading of the Pacific Highway between Sydney and Brisbane, and in response to other major road developments in and around Australian cities.

Taylor and Goldingay (2010) reviewed 244 relevant international publications of the last decade, with 75% of these studies conducted in North America and Europe, and 17% in Australia. They found these publications to be dominated by studies on mammals (53%), attributed to the insurance and medical costs of collisions with large mammals. Many studies described the negative effects of vehicle collisions on wildlife, for example, by using mortality counts. Population impacts appeared to be poorly-described in general, although some studies indicated that the barrier effect of roads has an adverse genetic effect on some species (i.e. carnivores in North America). Road crossing structures (underpasses and overpasses) appeared to be commonplace worldwide, and although an understanding of how these benefit populations is deficient, they appear to be a useful impact mitigation strategy because a wide variety of taxa use them. The review indicated that much remains to be learned about the impacts of roads on wildlife populations.

A number of direct and indirect impacts from the construction and operation of roads can affect wildlife populations. In general, these can be classified into eight main factors (Taylor and Goldingay 2010; Trombulak *et al.* 2000):

1) Mortality from collision with vehicles.
2) Mortality from road construction activities.
3) Loss and alteration of the physical environment.
4) Alteration of the chemical environment.
5) Barrier effects to dispersal and gene flow.
6) Modification of animal behaviour.

7) Spread of exotic species (including weeds and predators).
8) Increased use of habitat areas by humans.

The first two are direct impacts and the rest are largely indirect. All of them are relevant to Koalas and roads in NSW. As is the case for other wildlife, roads have a range of direct and indirect impacts on Koalas (Nattrass and Fiedler 1996; Lunney, *et al.* 1996; Prevett, *et al.* 1995; Fanning 1992; Dique, *et al.*, 2003a). Indirect impacts include the removal of habitat, creation of barriers, and providing predators such as dogs and foxes easier access to Koalas while on the ground. Roads alter animal behaviour by causing changes in home-ranges, movement, reproductive success, escape response, and physiological state. Evidence indicates that these sorts of indirect impacts may be particularly acute in the case of Koalas.

4.3.2 Road Mortality

The most direct and obvious impact of roads on Koalas is the death of individuals from vehicle collisions. The rate of collisions of vehicles with Koalas is often very high. Studies conducted on the Koala Coast (a 375 km^2 area in the Greater Brisbane region) reported more than 300 Koala road accidents annually, over 80% of which resulted in death (Kraschnefski 1999; Dique *et al.* 2003a). These accidents represented approximately 30% of admittances to the local Koala hospital. Preece (2009) found that vehicle collisions were responsible for 35% of Koala mortalities in South-east Queensland, the single largest cause of death. At the Port Macquarie Koala Hospital more than 30% of the animals that died in care had been struck by cars (Canfield, 1987). On Phillip Island (Victoria), road mortality is regarded as the major threat to the Island's Koala population, and in some years, accounted for more than 60% of total mortality (Backhouse and Crouch 1990). A NSW National Parks and Wildlife Service study at Iluka, NSW, concluded that all Koalas whose home-ranges included a road were eventually killed by vehicle collisions (D. Lunney, pers. comm.).

Road mortality was monitored at the Bonville study area across the three experimental phases of this study. As would be expected from studies elsewhere, and prior anecdotal evidence from the study area, this population suffered high rates of road mortality. The road mortality rate declined over the course of the study (Figure 13), but the trend was not statistically significant due to the high variability in the data set (linear regression model R^2=0.303; n = 11; P=0.08). (N.B. Another couple of years of low or zero mortality post construction could provide a significant trend). Mortality was highest during Phase 1 and may have shown a second peak during Phase 2. Initially, exclusion fencing erected during Phase 2 was not entirely effective at curbing road mortality. The apparent absence of road mortality in 2010 indicates that the permanent exclusion fencing may be effective once it is complete and without gaps, but data over a longer term should be collected in order to confirm that it is the case.

There was a strong seasonal pattern of road deaths in the Bonville study area clustered in August to October (Figure 14). The pattern was the same for males and females, and for adults and sub-adults. The timing corresponds to the established pattern of a coinciding breeding season and a dispersal period for young Koalas leaving their maternal home-ranges. The link between peaks in public sightings and road-kills with the dispersal and mating period is obvious: the more Koalas that are moving, the more often they will be on the roads and seen by the public or hit by cars.

The Koalas at Bonville showed a tendency to disperse along tracks (Lassau *et al.* 2008; this study). Tracks will frequently lead Koalas onto main roads. The main mitigation measure for preventing Koalas from entering main roads is exclusion fencing. However, exclusion fencing is not installed everywhere and is often not practical at the intersections of roads and tracks. The sections on Mitigation Measures (below) explore this important issue further.

Amongst the 47 Koalas captured in this study, 18 were recorded to die. Only two of these died on the road from vehicle collisions. Conversely, there were 65 Koalas killed on the highway in the study area between 2000 and 2010. Radio-tracking was not underway for all of this period, but 43 Koalas were road-killed during the radio-tracking study period. Since many of the Koalas in the study area were being radio-tracked, it suggests that the vast majority (41/43) of Koalas killed on the highway were not those living within 500 m of the highway.

Therefore, most of them were likely to be dispersing animals from farther away and were possibly naive to the existence and hazards of the highway. In turn, this suggests that Koalas resident beside the road are able to learn about and avoid the hazards of the road (AMBS 2001a; Lassau *et al.* 2008), at least when it is narrow and two lanes only. Two animals in this study were tracked for four years while living alongside the highway, one male crossed it several times, one female never crossed it, and neither were killed on it. Additional anecdotal observations made during this study raises the possibility that some Koalas may watch the road from roadside trees and come to understand it gradually. This contradicts the finding from the Iluka study that roadside Koalas eventually die on the road.

Although Koalas that are resident beside roads may adapt to roads and manage to avoid collisions, this does not negate the overall negative impact of collisions on populations. However, it would disperse the impact over a much larger pool of animals than those resident beside the road. It is possible that most of the Koalas killed on Pacific Highway in the Coffs Harbour district originate from locations away from the highway and normally may not seem to be at high risk from vehicle collisions.

4.3.3 Home-ranging

At the Bonville study area, Koalas and their scats were observed in forest up to the edge of the highway, while the highway was operational but prior to any construction work. Furthermore, several of the animals captured alongside the highway and shown (by radio-tracking) to be resident there were quite old, as determined from tooth wear, bodyweight and activity of the sternal gland. These observations suggest that some Koalas can be resident close to the highway, avoid being killed on the road, and live long lives there.

The Koala population in the Bonville study area maintained home-ranges up to the edge of the Pacific Highway. During Phase 1 four collared Koalas crossed the highway on multiple occasions, while others living right beside the highway never crossed. However, no Koalas maintained a territory clearly split across both sides of the highway, when the highway was under normal operating conditions (Phase 1). Home-ranges of individuals overlapped slightly. Males had territories about twice the size of females. These results are consistent with other studies of Koalas away from roads.

The home-ranges of two female Koalas (42.2 ha and 22.5 ha) in the Yelgun to Chinderah study area were large compared to values recorded elsewhere in NSW (AMBS 2002; 2003). The fragmented nature of the habitat in this study area may cause some Koalas to move longer distances to source suitable resources. This may lead to larger home-ranges, lower population densities and greater overlap between neighbouring home-ranges. Overlapping was observed in the home-ranges of these two female Koalas although individual trees were not occupied at the same time.

A major finding of this study is that Koalas appear to recognise linear features (the highway and powerline easement) as boundaries to their home-ranges, and seldom cross them. A similar fidelity to boundary features has also been noted in Koalas at Campbelltown, NSW (R. Close in Lassau *et al.* 2008). This study found no evidence that the highway altered home-ranging behaviour in any other way prior to the upgrade.

Home-range maps of all animals for the entire study are presented in Appendix.

4.3.4 Movements

It has been suggested that roads may provide a barrier or filter effect to dispersal of animals and ultimately gene flow within animal populations (reviewed by Taylor and Goldingay 2010). The subject has not been widely studied in relation to Koalas but it is theoretically possible.

As noted above, this study found that roadside Koalas appear to recognise the highway as a boundary feature, but at least some were able to cross it successfully. In other words, the operation two-lane highway was not an absolute physical barrier to dispersal of Koalas during Phase 1 of the study.

4.3.5 Disease

The incidence of disease in the Bonville study area Koala population was very high. The disease level existed at the outset of the study and was present throughout the study period.

4.3.6 Population Genetics

The genetic component of this study found no evidence of genetic differences between the eastern and western sides of the highway. This indicates that the operation of the two-lane highway at Bonville did not present a barrier to genetic flow prior to the study period.

The original aims of the DNA study project were mostly fulfilled. However there were some limitations in the amount of data that were collected. These included:

- Insufficient loci available to accurately determine genetic diversity.
- A relatively small study area at Bonville (only 500 m either side of the existing Pacific Highway).
- Few areas with active Koala 'populations' in the fragmented habitat in the Yelgun to Chinderah study area.
- Limitations in the ability to retrieve usable DNA from scat samples.

Despite these limitations, the information gathered helped clarify four important questions, and is summarised as follows.

1) *What are the relationships of animals living close to the highway?*
Results indicated a pattern populations structured along matrilines (Fowler et al. 2000), i.e. where daughters occupy home-ranges close to those of their mothers. These home-ranges could be close to the highway and there was no evidence that the highway impacted on the matriline structures. Meanwhile, males appeared more likely to disperse away from their maternal home-ranges.

2) *Are road-killed younger animals the offspring of resident parents or are they dispersing from points further away?*
Results indicated that most of the animals killed were dispersing from more distant areas, although these results could be due to the small sample size.

3) *Were the population genetic profiles different on either side of the highway?*
Genetic profiles on the east and west sides of the highway were similar, within study areas. This indicates that there was adequate gene flow across the highway prior to the study, to maintain a normal genetic profile. In other words the highway had not fragmented the population genetically up until the time of the upgrade.

4) *How much genetic variation is there in the sampled areas?*
Genetic variation was high at both the Yelgun to Chinderah and Bonville study areas and surrounds, compared to other populations that have been studied, for example, near Sydney (Lee *et al.* 2010). There appeared to be four geographic clusters of genetically-similar animals at Yelgun to Chinderah, and six such clusters at Bonville. However, some clusters were defined by very few animals and studies of additional animals from both areas more broadly may remove these local differences.

There were no matches of individuals found between DNA extracted from tissue versus faecal pellets. However, the project did establish profiles for other animals at Bonville, including four on the western side of the highway, and eight on the eastern side. This helps to provide a good baseline or reference information for further studies in the Coffs Harbour area or further afield.

This was the first test of the faecal DNA methods using pellets collected under field experimental conditions by a contractor. Estimates of freshness were not a reliable guide to whether usable DNA would be obtained. Amplification of DNA from these scarce epithelial cells is often inadequate and difficult to interpret. However, during 2003, six of the tissue profiles were similar to pellet profiles found in the expected area for a particular animal and not found in pellets elsewhere. Consequently we consider that the relevant animal was alive and in its expected area. In addition there were at least six other animals from across the study area that were not represented in the tissue profiles.

4.3.7 Population Dynamics

The low level of road mortality in the roadside Koalas at Bonville is interesting. It seems that the operational highway was not having a significant mortality impact on the Koalas that were resident in the study area. However, these Koalas were only a small subset of the local population occupying the Bongil Bongil National Park forest block. Nevertheless, road mortality was still high, but apparently it was mostly affecting dispersing animals that were coming from outside the study area (Lassau *et al.* 2008). These animals would still be part of the same population of Koalas, but the impact of the road deaths would be spread over a much larger area and affect a larger proportion of the overall population at a lower rate than might be expected. It appears that road mortality may affect a significant proportion of a relatively small annual cohort of Koalas dispersing from and within the Bongil Bongil National Park forest block (Lassau *et al.* 2008).

4.4 Koalas near Road Construction

4.4.1 Road Mortality

Road mortality in the Bonville study area was slightly lower during Phase 2 (construction period) than it was in Phase 1, though the difference is not significant. However, temporary exclusion fencing was erected gradually during Phase 2, and it had been expected that this would reduce road mortality by a significant amount. Evidently many Koalas managed to find their way past the fencing and onto the roads. However, it cannot be determined whether the construction process lead to an increase in road mortality or not, since the background levels vary so much from year to year.

Road mortality during Phase 2 was concentrated in the months of August to October, as it was in other years of the study. The initial clearing of the new highway alignment occurred in December 2006 to February 2007. Part of the reason for this timing was to avoid the peak period of Koala dispersal. There was no peak in the number of road mortalities coinciding with the vegetation clearing process. This aspect of the construction process, at least, did not have a measurable effect on the road mortality rate. This is important because it is surely the most impacting stage of the construction process for Koala habitat.

There are no data to determine whether vegetation clearing would have increased road-kills had it been undertaken during the Koala dispersal period of August to October. However, since there was no observed affect from the December to February timing, it can be recommended that clearing activities be undertaken outside the Koala breeding and dispersal period during future road constructions.

4.4.2 Home-ranging and Movements

In the Bonville study area the clearing works extended from 8 December 2006 to 15 February 2007. Only three Koalas were wearing radio-collars at this time, when the impact of construction works is most extreme.

One female with a home-range on the eastern side of the highway maintained a relatively regular home-range throughout Phases 2 and 3. She showed slight irregular movements when the vegetation clearing activities were nearby. She successfully weaned joeys in 2006 and 2008. One male with a home-range beside the highway was recorded in the vegetation clearing works zones on six occasions. He lost quite a bit of his original home-range, crossed the highway several times, and ultimately relocated from the eastern side of the highway. His home-range was reduced and remained unsettled for a period, but he survived. The third Koala, a female, appeared to move away from the highway after the vegetation clearing, but her radio-tagged failed soon after that. She was found alive in 2008, close to her original home-range.

In 2007, four additional Koalas were tracked in Bonville. One female had a stable home-range next to the highway until she was unexpectedly found dead inside the construction site. One male showed unusual ranging behaviour, patrolling the exclusion fences for some time before managing to cross them and the highway. He died soon after crossing of unknown causes. Another male who had a jaw infection and seemed emaciated maintained a very small home-range near a swamp. The third male died before clear patterns could be established.

In the Yelgun to Chinderah study area three Kolas being radio-tracked during the vegetation clearing and the rest of the construction phase showed different responses. For two, the response was that they moved away from construction activities and adjusted their home-ranges. However, some Koalas can respond differently. One Koala did not move away from the habitat disruption and died, apparently as a result of extreme stress. This response may be more likely for female Koalas than males, owing to smaller home-ranges of females and the need for adult females to live in habitats that are suitable for successfully raising young.

AMBS (2001a) predicted that the loss of 30 ha would kill or displace four to five Koalas and reduce the home-size and quality of up to 18 others. It seems that by 2006 the local population had fallen such that there were probably not 18 Koalas in the study area that could be impacted this way. Apparently only one Koala died as a direct result of the construction, but this was not due directly to habitat clearing or loss. The scant evidence suggests that animals moved or adjusted their home-range boundaries in response to vegetation and habitat loss. Most apparently survived, initially. However, the adjustment of home-ranges probably had a domino effect of displacing or disrupting neighbouring territories and disrupting local social structures.

4.4.3 Social Structure

Lassau *et al.* (2008) considered that prior to the vegetation clearing there were at least 13 Koalas living in the 120 ha western section of the Bonville study between the highway and the powerline easement. They predicted that an estimated 65 ha loss of habitat for the road construction from this area would be likely to have a significant effect on several of the resident animals.

By the time the clearing commenced (December 2006) the population had declined somewhat; only four had been captured in the entire study area in September 2006, though 11 were captured in September 2007. No Koalas appear to have died as a direct result of the vegetation clearing. One Koala (an unknown individual) was killed on the highway during the clearing period, but there is no reason to conclude that this was related to the vegetation clearing. Nor did they leave the study area. Of four Koalas radio-collared prior to the clearing, one sub-adult female left the study area before the clearing commenced and three adults remained in the study area and adjusted their home-ranges. If they were to leave, theoretically all suitable Koala habitat in the vicinity should already be occupied by resident Koalas. The only likely scenario is that Koalas whose home-ranges were lost or reduced by the clearing expanded their home-ranges into their neighbour's home-ranges and the local population became condensed and crowded. This might partly explain why more Koalas were captured in the survey after the clearing than the one before it, even though the amount of habitat in the study area was much reduced.

The process of crowding may have allowed the population to avoid significant direct impacts from the clearing. However, the next issue would be how long could they tolerate the crowding? Presumably they would eventually require the same home-range spatial patterns that they had before the clearing. Since the habitat will not be returned, it can only mean a reduction in the number of Koalas. The data suggest that this eventuated through a domino effect of altered home-ranges leading to short-term overcrowding, adverse social interactions, stress and ultimately the indirect death of several roadside Koalas at Bonville over the 12 months or so following the clearing.

Late in 2007 (after the vegetation clearing had been done) there were three male Koalas with radio-collars occupying a narrow wedge-shaped forest block in the north-west of the study area between the highway and the powerline easement. At least one adult male (Scapula) had moved into this location during the vegetation clearing phase. His home-range was quite small and judged as 'marginal', and in September 2008 he was found to bear the scars of considerable fighting. Another (Leonard) seemed to patrol the exclusion fences continuously until he was able to cross the highway, but he then died. A third was ill and showed very little movement until eventually dying of his ailments. Within 12 months, Scapula was the only male left in this area.

At the same time, on the eastern side of the highway there was one male Koala with a radio-collar and several sightings of another male Koala in the same general area. The two were seen in the same tree only days apart, which is unusual. Shortly after this the collared Koala was found dead on the ground with broken bones and haemorrhaging, indicating a fall. It is not clear what caused the fall, although we suspect it might have been a fight.

A collared female had been in a stable and predictable home-range until she was unexpectedly killed in the construction site. It is not clear what caused her to suddenly and fatally stray from her home-range.

It is possible that the habitat loss led to localised overcrowding, displacement and intolerant social interactions associated with competition for reduced resources. In turn this eventually contributed indirectly to the deaths of several Koalas, mostly males but perhaps also one female. There is insufficient evidence to confirm or refute this hypothesis.

4.4.4 Habitat Use

During the construction period (Phase 2) there was a significant shift in the tree species selected by radio-collared Koalas for daytime resting (AMBS 2007b). However, in Phase 3 (post-construction) the pattern was similar to Phase 1 (pre-construction). The most likely explanation is that it this reflects stress amongst the roadside Koalas as a result of habitat clearing and construction activities.

The findings are consistent with a hypothesis that Koalas are more selective of daytime trees when they are under stress. Specifically, they choose larger, taller trees which allow them to rest higher off the ground. After disturbance levels abated, tree-selection returned to the pre-disturbance pattern.

A change in tree selection during stressful times is not an impact on the Koalas but is apparently a symptom of increased stress.

4.4.5 Population Genetics

Population genetics is something that can only change over many generations. The 2-year construction period is too short to have any lasting impact on genetic diversity.

4.4.6 Population Dynamics

The construction process directly contributed to one known Koala death in each of the two study areas. In the Bonville study area a female radio-collared Koala was apparently killed by construction machinery after finding her way past temporary exclusion fencing during Phase 2. In the Yelgun to Chinderah study area a female Koala remained in her home-range as it was cleared around her, and apparently died from extreme stress. These figures represent minimum estimates of direct impact from the construction process. Whilst it is desirable to avoid this form of impact, from a population perspective it appears to be a low source of mortality in the studied populations compared with disease and road-kill.

The indirect impacts of the road constructions of the populations were not quantified. It is possible that habitat loss may have made a significant indirect contribution to four Koalas in the Bonville study area up to a year after the vegetation was cleared.

4.5 Mitigation Measures

4.5.1 Roads in Operation

Exclusion Fencing

After the permanent fauna exclusion fencing was erected at Bonville, there were few records of Koalas near to the highway. The scat transects along the fence lines recorded the highest levels of scats in September 2009, although it was still low. This time corresponds to the Koala breeding and dispersal season (Dique *et al.* 2003; Lassau *et al.* 2008).

After the completion of the permanent Koala exclusion fencing there were still five road mortalities in 2009, which is close to the 11-year average of six per annum (2000-2010). This indicates that the fences, though theoretically complete, were not operating effectively in 2009. Some adjustments and refinements were then made to the fauna fences to remove as many potential weak spots as possible. Subsequently there were no road mortalities in 2010. It is tempting to conclude that the fences operated effectively in 2010 to eliminate all road mortality in the Bonville study. However, due the variability of data set during the years prior to fencing, it would be desirable to have a longer data set after fencing to confirm this result.

A limitation of fences is that they must end eventually and there must be gaps in them at locations like road intersections. During Phase 3 some radio-tracked Koalas that were evidently trying to disperse appeared to move along the fence lines and some (not radio-tracked) animals were killed on the road just past the southern end of the fence. Koalas also appear to follow side tracks that sometimes lead them onto roads. This appeared to be the case at Hunters Road in the Bonville study area, where a large number of road-killed Koalas were found near the intersection of this local dirt road. In 2008 the RTA placed a gate across Hunters Road to plug the hole in the fence. Locals were required to open and close the gates manually when using Hunters Road, and with appropriate signage, the gate operated well. Trial and error during this study provided the following valuable insights:

- Fences should extend well beyond the edge of forested habitats into cleared country, wherever possible, so that Koalas following the roadside fence cannot easily turn onto the road when they reach the end of the fence.
- Where fauna fences must end at the edge of habitat and cannot extend into cleared country they should have return ends that run along the edge of the habitat away from the road.
- Side roads should have return edges to turn Koalas back into the forest and away from the highway.
- Where possible, side roads should have gates with signage indicating the importance of their purpose.
- Movement structures across the highway should be located to give Koalas easier or 'earlier' options to get through the fence before reaching its ends.

One radio-collared Koala apparently scaled an exclusion fence by climbing an adjacent tree fern, and then crossed the highway. This highlights the requirement for fences to be away from abutting vegetation as much as possible and be maintained free of debris such as fallen branches and choking vines, over the fence allowed this Koala to get over the fence. Fences either need regular maintenance or designs that require less maintenance.

Movement Structures

Roads without exclusion fences do not provide significant barriers to movement. However, once exclusion fencing is in place it is specifically designed to restrict movement across the surface of the roadway. Thus, while mitigating one impact, exclusion fences create another. A range of movement structures have been designed to implemented to mitigate this secondary impact.

The use or avoidance of movement structures can be related to various factors. Sparse vegetation on a land bridge may be a deterrent to its use by wildlife, particularly small mammals, as may be a gap between the structure and nearby vegetation (Mata *et al.* 2005). There may be a habituation period for wildlife for new structures (Clevenger and Waltho

2004) and there can be seasonal differences in fauna using structures. Small mammals and reptiles were recorded less during cooler months at movement structures in south-east Queensland (Bond and Jones 2008), and general movement patterns for female Red-necked Wallabies (*Macropus rufogriseus*) are significantly larger in winter than summer when food resources are scarce (Johnson 1987). Also, the movements of one species may affect the movements of another. Studies of cougars at highway wildlife structures in North America (Gloyne and Clevenger 2001) found their movements were associated with the movements of their prey, particularly deer.

Movement structures provided for Koalas in the study areas consist of three main types:

- Overpasses, which are vegetated bridges over the roadway designed to look like natural habitat.
- Underpasses, which are typically purpose-constructed box-culverts passing underneath the roadway.
- Underpasses where roadway bridges span natural landscape features such as gullies and waterways.

Since 1999 the fauna movement structures were used at least 31 times by Koalas in the Bonville study area with at least 12 successful crossings:

- Three complete and one unconfirmed crossings through the Raleigh underpass in 1999-2003.
- Nine complete and 17 incomplete or unconfirmed crossings through underpasses in 2008-2011.
- One set of scats found on the Bonville overpass in 2008-2011.

The most number of Koalas using the fauna movement structures were recorded during September and October, corresponding with the breeding and dispersal seasons.

At least twelve crossings of the highway were made through underpasses. This is likely to be a sufficient rate to prevent genetic isolation and physical isolation of Koala living on opposite sides of the highway and maintain adequate migration rates between them.

The remote cameras provided observations of the behaviour of individual Koalas in the underpasses. On several occasions Koalas were photographed at the entrance to the Raleigh underpass pausing or retreating. Some photographic series have shown Koalas entering and exiting at the same end several times before they made a complete passage. In some cases individuals did not make a complete passage. The cameras recorded similar behaviour with other species; for example a Swamp Wallaby (*Wallabia bicolor*) and a juvenile Lace Monitor (*Varanus varius*).

Other studies have recorded Koalas utilising underpasses in NSW:

- 4 Koalas used underpasses along the Brunswick Heads bypass (AMBS 2000).
- 2 Koalas used underpasses along the Bulahdelah to Coolongolook section of the Pacific Highway upgrade (AMBS 2001).
- 2 Koalas used underpass along the Taree section of the Pacific Highway upgrade (AMBS 2002).
- 2 Koalas used a 2.4 m x 1.2 m culvert near Brunswick Heads (Taylor and Goldingay 2003).

The remote cameras have allowed some observations to be made regarding the behaviour of individual Koalas within the underpasses. Koalas have been photographed at the entrance of the Raleigh underpass on several occasions, appearing to pause and then exit, rather than continuing through to the other side (Appendix). There are photographic series which suggest individual Koalas made several attempts to pass through the underpass. The cameras have also recorded similar behaviour with other species; for example a Swamp Wallaby (*Wallabia bicolor*) and a juvenile Lace Monitor (*Varanus varius*). Both individuals were photographed entering and exiting the box culvert at the entrance, suggesting they were also hesitant to make a complete passage through the box culvert. However, most Lace Monitors have made a complete passes through the box culvert.

Several studies have discussed the attributes of underpasses including the varying designs and dimensions suitable for various fauna groups. Generally it has been suggested that larger animals prefer larger structures (Mata *et al.* 2005), although standard dimensions have yet to be developed. It has also been suggested that an unimpeded view of the habitat at the exit of an underpass is very important (Foster *and* Humphrey 1995). The images to date suggest that the Raleigh underpass is not perfectly suited for facilitating Koala movement, most likely due to its length. However, the underpass has provided a safe passage across the highway for Koalas on four occasions (Appendix).

One Koala was photographed entering and exiting the Raleigh underpass on the wooden furniture rails. This suggests that furniture may facilitate the use of the underpass by some individual Koalas. However, seven other Koalas completed passages across the floor of the underpass.

The preliminary results from the camera surveillance indicate a range of native and introduced fauna have utilised the fauna movement structures, including the target species. The number and diversity of fauna using the structures may improve over time. The need for wildlife habituation to large-scale landscape change has been discussed during other research into the use of fauna movement structures (Clevenger and Waltho 2004). Habituation periods can often take several years, depending on the species and the location, as they adjust their behaviours to the wildlife structures (Clevenger and Waltho 2004). Other authors have suggested similar results (Hunt *et al.* 1987; Mata *et al.* 2005).

Little evidence was collected of Koalas using the constructed overpasses at either the Bonville or Yelgun to Chinderah study areas. There are several possible explanations for this:

- The monitoring period may have been too brief and at a time when the overpasses were new and had not been discovered by the local Koalas.
- The lack of established vegetation on and adjacent to the new overpasses may have been habitat that was not enticing to Koalas.
- The overpasses may have been located in positions that make their discovery by dispersing animals infrequent.
- At Yelgun to Chinderah the low density of Koalas might mean that there were few Koalas seeking to cross the highway in the area near the overpass.

Longer term-monitoring would be required to clarify whether overpasses are used by Koalas. Meanwhile, it is clear that underpasses are readily used by Koalas. However, some fauna species are more likely to use overpasses than underpasses.

Generally, the remote cameras provided much better data than the plot monitoring techniques did, although minor technical difficulties and environmental issues (e.g., weather events) led to data losses on some occasions (see Appendix). Camera surveillance systems are designed to be continuously active and are capable of detecting most species of fauna at any given moment. At Bonville this included Lace Monitor, Swamp Wallaby, Red Fox, Dingo and/or Wild Dog, Feral Cat, small reptiles and small mammals. They also record the date and time of the record, and the images be kept as a permanent record, unlike the tracks recorded on plots. This is valuable information and remote camera systems are highly recommended for any future monitoring. However, it needs to be recognised that they are vulnerable to theft, vandalism, flood and water damage, component failures and other limitations. Such limitations should be considered in any future monitoring.

Dropdowns

Dropdowns are one-way escape routes through fencing to give koala an exit route if they manage to cross one fence and become trapped in the road corridor. Dropdowns are risky in that they may not be entirely one-way and might therefore allow Koalas access to the fenced roadway. Dropdowns were installed in the exclusion fences at Bonville. No surveillance monitoring of these devices was undertaken, so little can be said of their effectiveness.

4.5.2 Roads under Construction

Timing of Clearing and Construction

Selecting the best time to undertake an action is frequently an effective mitigation measure, especially when there are temporal (seasonal) patterns in the value that requires protection from potential impacts. In this case, Koala behaviour is strongly seasonal, and the species potentially becomes much more vulnerable to impacts during the breeding and dispersal period. In northern NSW this season is generally in the spring (August to October) but the timing varies from place to place. It is very important to establish when this season is, so that the impact mitigation strategy can be scheduled around it. This will often require some analysis of existing data, such as local road-kill statistics from wildlife veterinary and rescue organisations, or pre-existing studies. In some instances it may require scientific investigations.

The first of the major construction process impacts and the one that removes the Koala habitat is the vegetation clearing. Therefore, this action should not be undertaken during the breeding and dispersal period, or even just before it. After clearing there needs to be time for the Koalas to adjust their territory boundaries, and this is probably best for them well before the breeding season. More importantly there needs to be time before the onset of the Koala breeding and dispersal period for construction workers to install mitigation measures such as temporary fencing. Commencing vegetation clearing after the breeding and dispersal period is therefore probably the best strategy as it allows about 5 or 6 months to get fencing and other infrastructure in place before the next season.

In addition to seasonal considerations, it is important to consider other factors that may be acting on the Koala population at the time, and in particular other developments or activities that affect Koala habitat. For example, the vegetation clearing activities that took place for the construction of the new highway alignment at Bonville were carried out within 2 years of selective logging operations conducted in the vicinity by NSW State Forests. This may have had a cumulative impact on the Koala population in the area.

Koala Surveys and Monitoring Prior to and During Vegetation Clearing

A radio-collared Koala (Scapula) at Bonville was found on six occasions in or near vegetation clearing work zones. Several other Koalas were also found in the work zones. Vegetation-clearing contractors were informed of their locations and assisted to work around them. If not for the pre-clearing surveys some or all of these Koalas may have been directly killed by the vegetation clearing process. The pre-clearance surveys were probably more affective at locating radio-collared animals. This suggests that trapping roadside residents and fitting them with collars before vegetation clearing could assist in managing the potential impact of the clearing activities.

Exclusion Fencing

Achieving temporary fauna exclusion fencing around the road construction site was challenging. It had to allow for the continuing highway traffic, the switching of that traffic to different carriageways over the course of the construction, the service roads, access points and public side roads. Requirements to minimise the vegetation clearing meant that the edge of the construction site and the edge of the vegetation line were practically abutting in many areas, so it was difficult to have the fence clear of the vegetation. Following the initial vegetation clearing the terrain was frequently difficult to work in, and there were areas that that required earthworks profiling at later stages. These challenges ultimately meant that temporary exclusion fencing went up slowly, had lots of weak points and was widely ineffective at preventing road-kills.

In April and May 2007 AMBS considered that the extent of temporary fauna fencing was inadequate to prevent high road mortality in the coming breeding and dispersal season. Recommendations were provided and a plan was agreed upon, but ultimately there was considerable focus on the difficulties, contractors vs principals responsibilities and insufficient recognition that partial fencing would not be adequate. Nine Koalas were killed on the highway adjacent to the construction site between August and October 2007. In October 2007 there were further negotiations to fortify the fencing, including much additional temporary fencing and the installation of a manually opening gate to plug a gap on a public side road. In 2008 there was only Koala killed on the highway, around the time that the temporary fences were being replaced by permanent fences. Although this Phase of the study was only two seasons long, it seems probable that the incomplete fencing in 2007 was inadequate and the almost complete fencing in 2008 was adequate.

It is important to have fauna fencing in place early in the construction period, and before the breeding and dispersal periods. The fencing must be very close to complete: it only takes one hole to make a bucket useless for carrying water. To achieve this outcome adequate design and planning must be undertaken well in advance. Ad hoc, scrambling approaches will likely be inadequate.

Movement Structures

The comparatively short-term nature the construction process means that the barrier created by temporary exclusion fencing is not likely to impact on the population structure or genetics of local Koalas. Whilst individual Koalas might be restrained from dispersing and even an entire local cohort could be disrupted in each year of construction, 2 years of this would be unlikely to have a lasting effect on the local population. Therefore, movement structures are probably not necessary to maintain population processes during the construction process.

Nevertheless, movement structures might make a valuable contribution to excluding Koalas from the road and construction site. One insight from this study is that when Koalas are motivated to disperse they can be very determined and persistent. They find the weak spots in the exclusion fences and exploit them. Providing safe and easy 'weak spots' might facilitate safe passage for many Koalas. During construction it is not practical to provide expensive, purpose built movement structures. However, in some instances, and with adequate fore planning, it may be possible to utilise existing landscape features and infrastructure (e.g. an existing bridge on the old highway) to keep a movement corridor open across the construction site and highway, while an underpass is being constructed elsewhere. Having such an underpass operating even just for the first 3-month breeding season of the construction phase could be effective in reducing road-mortality.

Speed Reduction Strategies

It is intuitive to suppose that faster traffic will lead to a higher rate of collisions between vehicles and Koalas, and that therefore speed reduction strategies will reduce road mortality. Reduced speed limits, speed cameras and signage alerting drivers to Koalas crossing the road were employed at Bonville during the construction period. These were not the subject of direct monitoring. They did not eliminate all road mortality, but whether they helped at all is unknown.

It is important to understand what kinds of vehicles are most likely to kill Koalas on the road. Probably it is more likely to be larger vehicles travelling longer distances (i.e. interstate trucks and buses) rather than smaller vehicles and local vehicles. Unfortunately there are no data on this. According to RTA data (Scott Lawrence pers. comm.), a speed camera on the highway at Bonville during the construction period was not very effective in reducing truck speeds, perhaps because making schedules was more motivating to drivers than avoiding fines.

Traffic control devices (e.g. speed humps, round-abouts, and chicanes) were not trialled. These devices might be effective on local roads but they are not practical on a high speed highway.

Koala Training and Management Protocols for Construction Personnel

Over the course of the construction process a number of strategies and protocols were developed to help avoid impacts to Koalas should they be encountered on the construction site. Separate protocols were developed for the vegetation clearing process and the rest of the general construction processes. They were developed through consultation and correspondence between the RTA (project proponents), The Department of Environment and Conservation (environmental regulators), AbiGroup (lead construction contractors), AMBS (scientific advisors) and concerned local community groups. The responsibility for collating the information and delivering generally rested with AbiGroup.

The effectiveness of the information was not directly monitored as part of this study. During the vegetation clearing process an AMBS representative was responsible for Koala surveys and was able to gauge the effectiveness of the protocols qualitatively. Clearing contractors followed the protocols, obeyed instructions and did not directly impact on Koalas as far as could be determined. The effectiveness of the protocols during general construction was more difficult to observe. Construction personnel did follow protocols, contact RTA and AMBS on some occasions when Koalas were found in the construction site. It is not possible to say whether they did this always, usually or rarely. It is clear however, that complex messages and protocols can be effectively communicated to a large proportion of the construction workforce if the appropriate effort is made.

One aspect of the protocols system that could be improved was the way they were developed. A meeting was held by the Koala Consultation Group at Coffs Harbour in September 2006, less than 3 months before clearing was due to commence. Meetings to develop and strengthen the general protocol for Koalas on the construction site were still being held as late as October 2007, almost halfway through the construction process. While it is important to be able to respond during the construction period, all parties need to be fully aware and accepting of their obligations well in advance of the construction timetable.

5 Key Findings

5.1 Overview

Impacts of existing roads

Roads can have major effects on wildlife and their habitats by reducing habitat quality, encouraging the spread of invasive species, and providing greater human access to undeveloped areas. Roads can impact populations of vertebrate wildlife by, for example:

- removing and/or altering their habitat;
- causing mortalities by vehicle collisions (road-kill);
- imposing barriers or filters to wildlife movements; and
- causing animals to modify their behaviour (Taylor and Goldingay 2010; Trombulak et al. 2000).

Data collected for this study indicate that Koalas resident in a particular area recognise existing roads as a 'natural' boundary and establish home ranges to either side. However, individuals cross the road from time to time. The genetic variation of Koalas at Yelgun to Chinderah and Bonville was relatively high. There is no indication yet that the highway has caused genetic isolation amongst Koalas.

The main impact of existing roads is therefore mortality amongst animals attempting to cross. Mortalities are higher in the months from August to November as animals either disperse, or are generally more mobile, during this period. Twenty-seven road-killed animals were aged by tooth wear: 15 adults (>3 years old), nine sub-adults (1-3 years old) and two juveniles (<1 year old). Studies by NSW National Parks and Wildlife Service on the Koala population at Iluka (on the NSW north coast) concluded that animals whose home ranges included a road, were eventually killed by vehicle collisions (D. Lunney, pers. comm.).

Of the six road-kills collected in Bongil Bongil National Park (i.e. in contiguous habitat with the study area) there were five alleles not found among the living animals captured in Bonville. This finding is consistent with the hypothesis that those animals killed are dispersing from more distant areas. However, the result could also be due to the small sample size.

Impacts of road construction

The main potential impacts of road construction or widening are direct mortality, loss of habitat, indirect mortality, fragmentation of habitat, genetic isolation and behavioural modification.

McAlpine et al. (2006) used modelling analysis to determine the importance of several variables to account for Koala occurrence. They discovered that Koala occurrence increased with the overall area of all forest habitats, Koala habitat patch size, and the proportion of preferred food species. They found that Koala occurrence decreased with increases in the distance between Koala habitat patches (i.e. habitat isolation), decreases in the density of forest patches (patches/100 ha) and increases in the density of sealed roads (metres/hectare). They found that habitats supporting lower quality food species were more important than they had expected and concluded that such habitats could support some breeding and low density Koala populations. Connected areas of even marginal habitat are therefore likely to be important for Koala movement and dispersal.

There is evidence to suggest that the upgrade of the Pacific Highway has had an impact on some Koalas within the study area. Two individuals were very close to the construction zone and it is likely part of their home-range was removed during the vegetation clearing. Both Koalas crossed the highway at least once and displayed very large home-range sizes during the construction phase (more than twice the average for male Koalas during Phase 1), with clear alterations to the home range of at least one animal. Behaviour and mortality of other Koalas suggests the potential for a 'domino effect', with increased competition for optimum habitat, territorial disputes, and increased stress levels for resident Koalas.

There is some evidence to indicate an alteration in tree species use during the construction phase of the project.

Negative impacts were not observed for all Koalas.

Mitigation
An examination of literature indicates that road crossing structures (underpasses and overpasses) appear to be commonplace worldwide, and although an understanding of how these benefit populations is deficient, they appear to be the best impact mitigation strategy at present because a wide variety of taxa use them, including Koalas.

The behaviour of collared Koalas and road kill data indicate that installation of floppy-top fencing does establish a barrier to Koala movement and, in turn, has the potential to substantially reduce road mortality. However, mortalities were observed after the installation of the fencing and the location of the mortalities indicates that some Koalas move beyond the extent of the fences or discover those areas where the fences have gaps. The results indicate that floppy-top fences should ideally be extended beyond the area of Koala habitat to both sides and gaps should be avoided. Maintenance of the fences will be required and it is recommended that fences are checked and repaired immediately prior to the dispersal season in July/August (note also that the season of dispersal may be later for southern Koalas than for northern ones).

There is evidence of Koalas using a range of road crossing structures, in particular, the underpasses at Bonville. Successful crossings were made at both the 3 x 3 metre box culvert (Raleigh) and the much broader Infra 2. There is some evidence that the length of the underpass at Raleigh is a deterrent to some animals; with some animals investigating the entrance or making a partial passage but not a full crossing. Koala scats have been detected in the middle of the overpass at Bonville and it is likely that the local road was used as a crossing by one radio-tracked animal.

Crossings were made by both animals along the ground and animals using the fauna furniture.

There was no evidence of Koalas using some crossings, although it should be noted these crossings were monitored by use of sand trays only, and for shorter periods of time. These crossings were generally located in areas of lower Koala density and/or where habitat was not as extensive.

Other considerations
It is likely the Koala density within the study area has decreased since the start of the project, due to factors other than the road. The death rate from all causes, including road kill, was high. Illness appeared to be a major factor in koala survival at Bongil Bongil National Park at the time of this study. In addition, parts of the study area had been selectively logged prior to the construction of the new highway alignment. The implications are that:

1. the results of this study were confounded to some extent by external factors;
2. construction of roads should consider the potential for cumulative impacts on Koalas.

5.2 Important Findings

Focusing on managing the impacts of roads on Koalas, the important findings of this investigation were:

1) Koalas can and do maintain home-ranges right to the edge of the highway.
2) Highways and other cleared landscape features tend to be used as home-range boundaries by roadside Koalas and are rarely crossed by the local residents.
3) Koala road mortalities are largely concentrated in the coinciding dispersal season (sub-adults) and breeding season (adults), which in northern NSW is August to October, but may be different in other parts of Australia.

4) Other sources of mortality (e.g. Chlamydia) can be much higher in roadside Koalas than road mortality is.

5) Most Koalas killed by vehicle collisions on the highway are not the local roadside residents but appear to be sub-adults dispersing and perhaps old, weak animals displaced from their former home-ranges away from the highway. Consequently the impact of road-kill affects a wider section of the population.

6) The genetic variation in roadside Koalas in the Yelgun to Chinderah and Bonville study areas prior to the upgrades was relatively high and had not been impacted by the long existence of the Pacific Highway.

7) Construction activities in the two study areas directly led to only one known death, suggesting that the direct impacts of clearing and construction are relatively minor at a population scale (when appropriate mitigation strategies are in place).

8) Construction activities (in particular habitat removal) indirectly affected individual Koalas, including the mortality of at least one animal, the alteration of home ranges and behaviour of others and possibly mortality as a result of home range adjustments.

9) Vegetation clearing and construction may operate with other factors, including other vegetation clearing or logging, to create cumulative impacts on a Koala population.

10) Scheduling of vegetation clearing to follow the Koala breeding season and allow time for the installation of fauna fences before the next season is likely to save individual Koalas.

11) Clearance surveys for Koalas prior to and during clearing operations coupled with set protocols for incident management are likely to save individual Koalas.

12) Clear and committed protocols and training procedures for construction workers on how to manage Koala incidents on work sites are likely to save individual Koalas.

13) 'Floppy-top' fauna exclusion fencing can be very effective at reducing the rate of road–killed Koalas, but gaps and other weaknesses (including side-roads) have to be eliminated, and fences that end at the forest edge are not as effective.

14) Significant levels of planning and implementation commitment are needed to get temporary fauna exclusion fencing in place and fully operational (i.e. without gaps) as soon as possible after vegetation clearing is completed and before the next breeding season.

15) Underpasses (both constructed culverts and 'natural' underpasses such as gullies) do work in providing safe dispersal routes for Koalas to cross the highway.

16) The length of underpasses may be a factor in determining whether Koalas make a successful crossing.

17) Evidence collected subsequent to this study indicates that Koalas have been present on the Bonville fauna overpass. Koalas may need time to become accustomed to this structure. Provision of vegetation cover may also improve its effectiveness.

18) Log 'furniture' in underpasses was used by a Koala but not by most; it apparently does no harm but is of limited benefit.

19) Temporary movement structures may be useful to divert dispersing Koalas safely across the road.

20) Simple gates placed across the entrances to public side roads (requiring manual opening and closing by drivers) can be very effective at plugging holes in exclusion fencing, provided traffic volumes are low and locals are consulted appropriately.

5.3 Unresolved Issues

The following items are issues that were not resolved with sufficient or complete certainty, and could benefit from further investigation:

1) It seems likely (but was not proven) that habitat clearance led to overcrowding, social intolerance and eventually the indirect deaths of several roadside Koalas. There is no obvious way to mitigate against this likely impact.

2) The effectiveness of overpasses in providing safe dispersal routes for Koalas was not determined. No evidence of their use was obtained during the monitoring period; however, evidence collected after the study suggests that the structures will eventually be used. The behaviour of dispersing Koalas suggests that they will readily use overpasses where available. Overpass structures were used by some fauna that were not recorded in underpasses, and vice versa.

3) It was not determined whether natural landscape or constructed culvert underpasses work best, though both do work. It is intuitive to assume that the natural ones will work better for a wider diversity of fauna species.

4) It was not determined whether 'dropdown' escape routes are effective at reducing Koala road deaths. However, provided that they do not allow Koalas to get onto the road they do no harm.

5) Reduced speed limits, a speed camera and warning signs about Koalas crossing the highway apparently did not eliminate the road mortality and may be of limited value in highway scenarios. However, it was not possible to monitor the effect of these measures directly.

6) This study did not have the opportunity to examine whether translocation of Koalas out of the construction footprint would be beneficial.

7) This study did not have the opportunity to assess post-construction genetic information.

5.4 Lessons for Future Research

In such a long and complex study with many factors beyond the control of the researchers it is inevitable that some things will work well and others will not:

1) Capture and radio tracking studies in the Bonville study area had their difficulties at times but ultimately provided insight into significant issues. At the Yelgun to Chinderah study area this was less successful, apparently because the Koalas were at low density and removed from the road most of the time.

2) Long series of quality road mortality data are central to investigating the impacts of roads on Koalas, not only for mortality statistics but to determine which Koalas are being killed, when they are being killed, where they come from, and whether mitigation measures are effective. The data come with significant observer biases, some but not all of which can be overcome. Recording the date, exact location and sex of road-killed Koalas and collecting the skull and a genetic sample will always help to resolve local management issues.

3) Use of scat transects to monitor population levels (indices of relative abundance) is a poor alternative to more direct methods and, though inexpensive, may not be good value for money.

4) Remote cameras provided better data for monitoring the use of fauna movement structures than sand plots, soot plots and scat quadrats did. Though they are more expensive to establish the running costs are just as low. Security and technical failure remain significant issues. These draw-backs are continually improving as the technology advances.

5) Tree use data are routinely collected during radio-tracking studies and should always be collected in studies of this nature. However, they appear to reveal symptoms of impacts that are not critical (i.e. they reveal avoidance behaviour rather than population threats), and do not reveal much about the nature or source of impacts.

6) Genetic studies achieved their main aims but could be improved in the future by following these procedures: note the weather conditions the day before collection and do not collect pellets early in the morning or the day after rain; ensure that pellets are fully dry before spraying and assessing for patina; collect each pellet in an individual

bag and group together bags from the same site for labelling and transport, wrap wet pellets in a small bit of absorbent paper such as tissue; and do not collect old pellets.

7) As disease is so prevalent in many Koala populations, collection of health information is important. In addition, autopsies of dead Koalas not killed on roads provided significant information about the sources of mortality in the study populations.

6 Recommendations

6.1 Managing Koalas during Road Operation

1) The known Koala 'black spots' on NSW highways should be monitored by ongoing collection of Koala road mortality data.

2) Permanent floppy-top exclusion fencing should be used to keep Koalas off all NSW highways wherever they intersect Koala populations and cause recurring Koala road mortality.

3) Permanent exclusions fences must have no gaps, holes or other weak spots or they will leak and direct Koalas on to the highway. All avenues must be used to eliminate gaps, including minimising the number of side roads, placing gates on minor side roads, and using long perpendicular return wings along major side roads.

4) Permanent exclusion fences should not end abruptly at the edge of Koala habitat but should continue for a considerable distance into cleared country or (where the former is not possible) have long perpendicular return wings along the edge of the habitat.

5) Permanent exclusion fences must be accompanied by movement structures.

6) Movement structures should be located where Koalas can find them easily but also where they best help to protect any weak spots in the exclusion fences.

7) Exclusion fences require maintenance: maintain fences to remove vegetation and repair holes immediately prior to the Koala dispersal and breeding season (in July in northern NSW).

6.2 Managing Koalas during Road Construction

1) Consider the potential cumulative impacts of road construction with other developments and activities in Koala habitat.

2) Understand the local Koala breeding and dispersal season before starting road construction in Koala habitat.

2) Begin collecting detailed Koala road mortality data (including age, sex, exact location, skulls and genetic samples) as early as possible and long before construction commences and continue for several years after construction.

3) Ensure that construction contractors understand, accept and respect their responsibilities (and the community's expectations on them) to design, implement and monitor effective mitigation strategies to reduce the impact on Koalas.

4) Protocols for dealing with Koala incidents during vegetation clearing must be developed and 'approved' by open consultation well before vegetation clearing commences.

5) Protocols for dealing with Koala incidents on the construction site must be developed and 'approved' by appropriate consultation well before construction commences; these must be delivered and reinforced to site-workers through inductions and regular 'tool-box' meetings or similar.

6) Vegetation clearing should be undertaken soon after the Koala breeding and dispersal season to allow time to install temporary fencing before the following season. Leaving one month after the peak season is advisable, so for example if the season is August to October then clearing should commence in December, but the timing will vary with locality.

7) Daily pre-clearance surveys for Koalas during vegetation clearing are likely to save the lives of roadside Koalas.

8) Radio-tracking of roadside Koalas during the vegetation clearing is likely to improve the efficiency of pre-clearance surveys to save Koala lives.

9) Early and committed design, planning and scheduling are required to get temporary exclusion fences in place as soon as possible after vegetation clearing with an absolute minimum number of weak spots.

10) Temporary exclusions fences must have no gaps, holes or other weak spots or they will leak and direct Koalas on to the highway. All avenues must be used to eliminate gaps, including minimising the number of side roads, placing gates on minor side roads, and using long perpendicular return wings along major side roads, using netting or temporary bunding to block undulating terrain, etc.

11) Identify opportunities to temporarily close local access roads by engaging the community prior to commencement of the construction process.

12) Temporary exclusions fences should not end abruptly at the edge of Koala habitat but should continue into cleared country or (where the former is not possible) have long perpendicular return wings along the edge of the habitat.

13) Opportunities should be sought to make use of any existing natural landscape underpasses (i.e. bridges on the existing highway over gullies, waterways or side roads). This would be most useful during the 3-month Koala breeding and dispersal season, and particularly during the first season after temporary exclusion fencing is installed. Assess whether gates or moving fences could be used to convert day-time construction sites to night-time Koala movement passages. When construction is phased, attempt to identify opportunities to keep some gullies or streams open throughout the construction period.

14) Continue to use drop down escape routes in temporary exclusion fencing to provide opportunities for Koalas that become trapped on the road or in the construction site to escape (even though they have not yet been proved to be effective).

15) Consider any benefits of devolving responsibility to routine monitoring (e.g., collection of road-kill data and samples; operation and maintenance of remote detection equipment, etc.) to suitably qualified on-site environmental staff.

6.3 Further Investigations and Trials

1) Continue collecting basic road mortality data at the Bonville study area until it is clear that the permanent floppy-top exclusion fencing and other mitigation infrastructure are effective at eliminating road-kill.

2) Monitor the Bonville overpass (using remote cameras during a Koala breeding season) for Koala and other fauna movements, after the vegetation matures, to determine whether it is effective.

3) Monitor the underpasses at Bonville concurrently with the overpass.

4) Consider a long-term post-construction genetic study.

5) Monitor the effectiveness of drop-downs in future temporary fences to determine if the work or if they allow Koalas to access the road. With improvements to camera technology this can probably be achieved with relatively inexpensive equipment during the 3-month breeding and dispersal season.

6) Monitor gates on side roads with remote cameras to determine if they are effective at excluding Koalas from the road and how road users react to them.

7) Consider opportunities for investigating the effectiveness of speed reduction strategies in reducing koala road mortality.

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Appendix A: Individual Koala Profiles, Bonville

Phase 1

Gaze
This young male was captured September 2000. He used the original Raleigh fauna underpass to move from west to east after he was collared and released. Gaze remained outside of the study area for over 4 months, before he was removed from the monitoring project. His collar was removed in September 2001.

Aussie Joe
This older adult male was first captured in September 2000. He displayed a relatively small home range on the eastern side of the highway, overlapping with few other Koalas. His remains were found in March 2001 but were too decomposed to determine cause of death.

Kieran
This adult male was captured in September 2000 and radio-tracked for 2 years. Kieran was assumed to be one of the stronger males in the study area and had one of the largest recorded home-ranges, across both sides of the highway. Kieran was recorded crossing the highway successfully on two occasions. He did not however, cross the powerline easement and it appeared to be a boundary to his home-range.

Thorpe
This adult male was first captured in September 2000 and radio tracked for 2 years.

Klim
This adult male was captured in September 2000 and found dead in February 2002. His home-range was close to that of a younger male, Matt, whom he seemed to exclude from the core of his range (see below).

Matt
Matt was a young male captured in September 2000 and radio-tracked for 2 years. His initial movements were erratic, and shadowing an older male, Klim. At each tracking fix the two animals were often close, normally around 50 m apart. However, Matt did not venture into the "core" home-range of Klim until Klim's death in February 2002, after which he seemed to range across Klim's entire former range. Matt was killed by a vehicle on the highway 3 weeks after his collar was removed in September 2002.

Wilbur
This adult male was first captured in September 2000 and radio tracked for 1 year.

Shirley
This adult female was captured in September 2000, with a joey. Her radio-collar was found on the ground within her known range in early January 2002 and she was never re-sighted He collar had teeth marks on it. She and her joey could have been killed by a predator, or consumed by scavengers after her death.

Susie
This adult female was captured in September 2000. She was monitored in a stable home-range for 2 years.

Debbie
This adult female was captured with a joey in September 2000. In January 2001 she was found dead. The fate of her joey was no determined.

Dawn

This adult female was collared in September 2000 and found dead in March 2001. A post mortem concluded the likely cause of death to be chlamydial infection and poor body condition. Dawn had previously crossed from the eastern to the western side of the road and returned.

Betty
This adult female was captured with a joey in September 2000. In May 2001 the body of Betty was found at the base of a tree. Post mortem suggested she had died of old age. Tooth wear pattern indicated she was at least nine years old. The fate of her joey was no determined.

Shane
This adult female was first captured in September 2000 and radio tracked for 2 years.

Alison
This adult female was captured in September 2000 and radio-tracked for 2 years. Alison, an older female in the south east corner of the western forest block, utilised a very defined home-range which very rarely overlapped with any other female's home-ranges. She was recorded using trees on the immediate forest edge overlooking the existing Raleigh Upgrade and paddocks to the south. Alison was also recorded utilising a paddock tree 100 m south of the forest edge on a number of occasions.

Nikki
This sub-adult female was caught in September 2000, but she dropped her collar soon afterwards.

Jelena
This female was captured in September 2001, but was killed on the highway a few days afterwards.

Phases 2 and 3

Scapula
This was an adult male Koala first collared on 15 September 2006. Originally captured on the eastern side of the highway, he crossed to the western side on 14 October 2006. He then crossed back to the eastern side of the highway on 12 November 2006. He maintained a relatively constant home-range here until 29 July 2007 when he crossed back to the western side of the highway. During August 2007 temporary fauna fences were installed along the western side of the construction area, preventing any animals from moving onto the road. Since that time, Scapula remained west of the construction site in a home-range area altered in size and shape (see Figure B1). He made several extensive movements south, while remaining adjacent to the temporary fauna fencing. An interpretation of these movements suggests Scapula was trying to find a way to move back to the eastern side of the highway. By September 2008 he had settled in a home-range which was largely confined to the Sid Burke Forest Park area. Following the opening of the upgraded alignment and associated fauna movement structures, Scapula was recorded on the eastern side of the highway on 12 September 2009 in a location within his former home-range. It is likely he moved through 'Infra 4', a dual purpose local road and fauna underpass. He was recorded again on the western side of the highway on 16 September 2009.

A large proportion of Scapula's original home-range was contained in an area that was cleared for the upgraded highway alignment. On at least five occasions during the vegetation clearing phase he was found close to areas being cleared, and works were stopped or modified to ensure his safety. Without the pre-clearing surveys for Koalas implemented specifically for this purpose and radio-tracking it is likely that he would have been felled in a tree on 18 December 2006.

Kenny
Kenny was assessed as a healthy Koala when collared on 24 September 2007. He was found dead on the ground directly beneath a tree on 1 October 2007. His head had indented the ground slightly, suggesting that he had hit the ground hard. There was no evidence that his

collar had been hooked or caught on anything. Scats around the base of the tree indicated that he had been eating normally. An autopsy performed by Pacific Vet Care found that Kenny had been a healthy Koala. He had a red (badly bruised) eye, possibly indicating a head injury, but decomposition of the head prevented firm conclusions. There were no signs of disease, except a slightly thickened bladder. His stomach was full. There were no broken bones or ruptured organs. The most likely explanation is that he fell and hit his head. Another slightly larger (presumably male) Koala (Max) was seen in the same area on two nights (25 and 26 Sept), but was not captured. It is possible that these two had been scuffling over territory, which led to Kenny falling. The autopsy report is attached at Appendix C.

Leonard

Leonard was a sub-adult male captured and collared on 25 September 2007 on the western side of the Highway near the corner of Twelve Mile Road. During the monitoring Leonard showed unusual ranging behaviour, patrolling the temporary fauna fence along the Highway between Twelve Mile Road and Hunters Road and as far south as Overhead Bridge Road. Around 15 October 2007, Leonard crossed the fence and the construction site and was found on the eastern side of the highway south of Overhead Bridge Road. John Pile found scats on top of the mulch piles outside the western fence in the National Park, and suspects that Leonard used a tree-fern to climb over the fence. After crossing the Highway Leonard moved south and appeared to have become settled in the area near Mailmans Track Road and Overhead Bridge Road, despite two other Koalas being sighted nearby, and a third with a collar (Tibia) also being close. He was found dead on 30 March 2008. No autopsy was undertaken because the carcass was already about 4 days old when discovered. There were no obvious scars or fractures, and the apparent cause of death is unknown. It is suspected that he fell from a tree.

Kenny, Leonard, Malcolm and Scapula

Three Koalas that were radio-tracked in the 'during construction' period died between October 2007 and March 2008 (Kenny, Leonard and Malcolm). The bodies of two of these Koalas (Kenny and Malcolm) were taken to Pacific Vetcare for examination; however, other than the fact that the body condition of both Kenny and Malcolm was poor, the results were inconclusive. There are a number of potential reasons why these animals died, some of which are related to the construction works and some of which are not. Although not conclusive, there is some evidence to suggest that mortality in these Koalas was related to fighting over territory:

- the Koalas were all males that were radio-tracked in locations that overlapped with either the current or previous home-range of the male Koala known as Scapula;
- in September 2008 Scapula was observed to have sustained injuries likely to be caused by fighting;
- the Koala known as Leonard was first detected west of the construction site in an area that overlapped with the altered home-range of Scapula. Leonard displayed unusual behaviour and appeared to be ranging along the fence. In October 2007 Leonard crossed the construction site and began ranging to the east. In March 2008 Leonard was found dead at the base of a tree;
- the Koala known as Malcolm was first detected in September 2008 west of the construction site in an area that overlapped with the altered home-range of Scapula. Malcolm then moved out of this area by crossing the powerline easement to the west, but continued to return, crossing the easement on several occasions. Malcolm was found dead in January 2008;
- the Koala known as Kenny was observed in close proximity to another male and appears to have died as a result of falling from a tree.

Ruby

This adult female captured in September 2007 when she was assessed as healthy. She was found dead on the ground in the construction site on 18 October 2007. Only the head, arms and upper torso were present. The Koala may have been dead for a number of days when found. The body was taken to Pacific Vetcare for examination. The opinion of the veterinarian who carried out the examination was that the "injury would be consistent with being chopped in half by a grader or other piece of heavy machinery". The complete autopsy report is included in Appendix C.

Tibia

Tibia was a young adult `female initially captured and collared on 15 September 2006 with a female back young (Fibula). She was the only Koala radio-tracked throughout the entire duration of Phase 2 and Phase 3. During this time she maintained a relatively constant home-range in the south eastern section of the study area, south of Mailmans Track Road. She appeared to coped reasonably well with the vegetation clearing and construction activities relating to the highway upgrade. She produced three offspring during the four years she was monitored. Tibia had moved north from her regular home-ranging area during early August 2007, from the southern-most boundary of the National Park to the area near Mailmans Track Road and Bulls Paddock Trail, east of the highway. This coincided with the opening of traffic to the service road. She remained here until late-October when she began moving south towards her original capture location. Her movements south were not long after Leonard crossed the highway and moved south into the area near Mailmans Track Road and Overhead Bridge Road.

Iris

Iris was first captured on 15 September 2006 on the eastern side of the highway. She was tracked 78 times before her collar failed in April 2007. Her home-range was centred along Balls Ridge Road in the north-east of the study area In September 2008 Iris was located with collar still attached, in the same area as her former home-range on the eastern side of the highway just off Balls Ridge Road. She died approximately 10 days after her radio-collar was replaced after a period of hot weather. The post-mortem was inconclusive and the most likely cause of death was old age. Given Iris was found in the same location as her previously known home-range, she may have coped better than other Koalas during the construction phase.

Hackett

'Hackett' was first captured and collared on 16 September 2008 close to the eastern side of the highway. He was re-collared on 24 September 2009, and the collar was removed during September 2010. He was in good condition throughout the study. During the final year of monitoring he appeared to be spending more time in the gully east of Balls Ridge Road than previously.

Sally

Sally was captured and collared on 17 September 2008 in a *Eucalyptus microcorys* (Tallowwood), on the eastern side of the Highway just off Balls Ridge Road. She was a young female approximately 2-3 years old and in good condition. Initial radio tracking results indicate a home range in the area between Balls Ridge Road and the highway, north of Overhead Bridge Road. Sally was observed close to a nearby male (Hackett) on several occasions. She was found dead on 29 June 2009 approximately 500 m north along Balls Ridge Road, and 50 m east of the track. Her death is possibly a result of extreme weather conditions (approximately 250mm rain fell in 9 days in the Coffs Harbour region), but the body was too decomposed to determine cause of death.

Samantha

Samantha was captured and collared on 20 September 2008 in a *Eucalyptus pilularis* (Blackbutt), approximately 100 m from the western side of the highway and 250 m south of Twelve Mile Road. She was a young female estimated to be 2 years old and in good condition. Initial radio tracking results indicate a comparatively small home range, with the animal remaining very close to the Highway and not more than 250 m from her capture location. She was found dead on 21 February 2009, approximately 50 m west of the Pacific Highway and 250 m south of Twelve Mile Road. Her death was possibly a result of extreme weather conditions (approximately 420 mm rain fell in 6 days in the Coffs Harbour region), but the body was too decomposed to determine cause of death.

Matilda

Matilda was captured and collared on 16 September 2008 in an *Archontophoenix cunninghamiana* (Bangalow Palm), east of the highway and adjacent to Balls Ridge Road, approximately half way between Reedy Road and Overhead Bridge Road. She was a young female approximately 2 years old and in good condition. In the first 7 days after collaring, Matilda moved approximately 2.75 km in a southerly direction, at which point she was located outside the study area in a small patch of trees between the Pacific Highway and the Old Pacific Highway. Because the animal was less than 10 m from the Pacific Highway in an area with no fauna fence, she was recaptured on 24 September 2008 and released in the original capture tree. Matilda then moved in a south-easterly direction approximately 5.4 km in 10 days, to a location well outside of the study area near Mylestom. She was then recaptured and her collar removed. After discussing the matter with DECC, Matilda was released inside the National Park well away from the highway.

Anna

Anna was captured and collared on 28 September 2009 in a *Eucalyptus microcorys* (Tallowwood), on the eastern side of the highway approximately 75 m south of the Mailmans Track gate. She was estimated to be approximately 3 years old and in average condition. At the time of capture she was carrying a pouch young, which was not examined (to minimise stress on the mother). She displayed a very small home range, occurring south of Mailmans Track near the 'Private Property Trail'. The joey was first sighted on Anna's back on 14 November, with subsequent sightings occurring intermittently. Anna's home range occurred in the core of Tibia's former home range. Her collar was removed on 7 September 2010.

Charlie

Charlie was captured and collared on 25 September 2009 below a *Eucalyptus pilularis* (Blackbutt) on the western side of highway, close to the fauna fence. He was estimated to be approximately 8 years old and was in good condition. He displayed a large home range, occurring between Twelve Mile Road and Darkys Corner Road. He appeared to prefer gully habitats rather than the slopes or ridges, with many records occurring close to drainage lines. His collar was removed on 7 September 2010.

Paul

Paul was captured and collared on 27 September 2009 in a *Eucalyptus grandis* (Flooded Gum), on the eastern side of the highway, adjacent to the local road and approximately 100 metres south of Reedy Road. He was estimated to be approximately 6 years old and in good condition. He has displayed a relatively large and defined home range. His collar was removed on 8 September 2010.

Ian

Ian was captured and collared on 28 September 2009 in a *Eucalyptus microcorys* (Tallowwood), on the eastern side of the highway approximately 200 m south of Reedy Road and adjacent to Balls Ridge Road. He was estimated to be older than 6 years and was in average condition. He appeared to be blind in his right eye but was considered healthy enough to carry a radio-collar. He displayed normal ranging behaviour, maintaining a home range on the edge of the study area. His collar was found on 21 October 2010. No signs of the koala were visible at the time, and as such his fate remains unknown.

Bob

Bob was captured and collared on 22 September 2009 in a *Eucalyptus microcorys* (Tallowwood), on the western side of the Pacific Highway, very close to the Raleigh underpass. He was a sub-adult male estimated to be 2 years old and in good condition. Upon release Bob began moving north. By 1 October 2009 he had reached Twelve Mile Road, and by 5 October he had reached Sid Burke Forest Park. Bob continued moving slowly north, leaving Sid Burke on 9 October, moving adjacent to the fauna fence on the eastern side of the service road. He continued north within this narrow strip of vegetation until he reached Pine Creek when he turned west, moving approximately 450 m west of the bridge. On 16 October Bob was recorded on the north side of Pine Creek. It was determined Bob was unlikely to establish a stable home range within the study area. Consequently, he was trapped, his radio-collar removed, and subsequently released near the corner of Hunters Road / Flying Fox trail.

Brown

Brown was captured and collared on 27 September 2009 in a *Eucalyptus grandis* (Flooded Gum), on the eastern side of the highway adjacent to the service road, approximately 100 m south of Reedy Road. He was estimated to be approximately 5-6 years old and in good condition. After release Brown's movements were erratic. On 29 September 2009 Brown had moved north close to the edge of the National Park near Pine Creek. On 30 September he was recorded on the northern side of Pine Creek and he may have swum across. On 2 October 2009 he was recorded further north adjacent to Archville Station Road. The following day he was found adjacent to the Pacific Highway and Pine Creek and on 4 October he was recorded on the southern side of Pine Creek. On 7 October he was recorded closer to the centre of the bushland referred to as Woods', north of Reedy Road. On 8 October Brown's radio-collar signal failed and has not been received since. The exact cause of his failing radio-collar is unclear, although it is possible that water leaked in during the two creek crossings. Searches in the area near Woods' were undertaken but failed to locate Brown.