Byron Coast Koala Habitat Study

Report to Byron Shire Council

March 2012

biolink pty ltd
ecological consultants

PO Box 3196 Uki NSW 2484
T 02 6679 5593
F 02 6679 5523
www.biolink.com.au

Project Team

Principal Ecologist Stephen Phillips

Project Manager / Senior Ecologist Marama Hopkins

Field staff Bree Fern, Asha Igoe, Dan Pollard

Acknowledgements

We commend Byron Shire Council for initiating this study and thank PRG members and Council staff, particularly Mr Eli Szandala and Mr Angus Underwood, for their enthusiasm and support. Funding for this study was provided by the Office of Environment and Heritage, North East Branch.

Document Control

Draft 1		**Date**
Prepared by	M. Hopkins	16th December 2011
Reviewed by	S. Phillips	16th December 2011
Final		
Prepared by	M. Hopkins	7th March 2012

Table of Contents

Executive Summary

The Byron Local Government Area covers an area of approximately 56,000ha between the Tweed LGA in the north, Lismore to the west and Ballina to the south. This report describes the results of a koala habitat and population assessment with a focus on the coastal portion of the LGA, an area of approximately 13,790 hectares comprising lands including the entire coastal strip extending from Billinudgel Nature Reserve to south of Broken Head, and west to Mullumbimby. The specific aims of the study were to:

1. examine current and past koala distribution within the whole LGA;
2. determine the preferred koala food trees for the study area;
3. map *potential* and *core koala habitat*;
4. examine key threats to koalas including road mortality black-spots;
5. identify important linkage areas;
6. provide an assessment of population size and local population viability, and recommendations to inform preparation of a Comprehensive Koala Plan of Management for the study area.

Analyses of 1,471 records of koala sightings over the period 1900 to 2011 revealed that koalas have a long history of occupation in the LGA and are more widespread today than they have been in the past. A 17% increase in Extent of Occurrence was recorded for both the LGA and the study area, while an apparent doubling in Area of Occupancy has occurred over the last three koala generations. At the LGA level, population expansion has generally been from the west to the south and east, whilst a contraction of range has occurred in the north. Current areas of generational persistence are widespread across the LGA when compared to those that existed in previous decades.

Koala population assessments involved application of a systematic habitat sampling strategy that gathered data on koala presence and activity, food tree preferences, and koala density. Sixty three field sites were sampled, 18 of which recorded evidence of habitat use by koalas. Koala activity was restricted to that area between Brunswick Heads and West Byron, with four disjunct sub-populations occupying an area of approximately 1,470ha within which habitat is highly fragmented and of variable quality. Two major koala population centres were identified; Myocum – Tyagarah, and West Byron. Field data provide a broad population estimate of approximately 240 koalas existing within currently occupied habitat. No evidence of

the persistence of the historical source population at Billinudgel Nature Reserve was recorded.

Data from 1,565 trees collected during the course of the study were augmented by that from other studies in order to identify preferred koala food trees. Collectively, a total of 2,543 trees comprised the tree use data set. Supported by previous work, four species – Forest Red Gum *Eucalyptus tereticornis*, Swamp Mahogany *E. robusta*, Tallowwood *E. microcorys* and Grey Gum *E. propinqua* – were identified as the most preferred species within the BCSA. Swamp Mahogany, Tallowwood and Forest Red Gum were confirmed as primary food tree species across the majority of the study area, while Tallowwood and Grey Gum were expected to act as secondary food trees when growing on low-nutrient soils. Tree preferences, existing vegetation mapping and soil landscape mapping informed classification of koala habitat which identified approximately 2,060ha of potential koala habitat in the habitat classes Primary, Secondary (A) and Secondary (B) within the BCSA.

The persistence of koala populations is surprising given the extent of habitat fragmentation on the coastal plain, and the barriers presented by both the predominantly cleared hinterland and the Pacific Highway. The low occupancy rate and level of isolation of sub-populations however suggest that coastal populations may be unsustainable in the absence of improved connectivity and an increase in habitat cover. The enhancement of linkages to allow gene flow between coastal and hinterland populations will be a fundamental tool for increasing their probability of persistence. Road mortality is also identified as a major contributor to the impedence of recovery potential and the isolation of coastal koala populations.

Currently, Byron's coastal koalas survive in a highly fragmented habitat matrix that, whilst containing patches of high-quality habitat, is largely discontinuous and lacks large contiguous habitat patches. Continued isolation will leave populations vulnerable to stochastic processes and the pressures of inbreeding, elements of which are already known to occur. The requirements to reduce incidental koala mortalities due to road-strike and the creation of meaningful connectivity both within existing coastal populations and extending west to large hinterland source populations have been recognised as priorities. A number of mechanisms by which this can be achieved form the basis of conclusions and associated recommendations arising from the report, including the establishment of cadastrally-based Koala

Management Areas, habitat restoration/rehabilitation works, development controls, standardised ecological assessments, and fire management.

Preliminaries

Aim of this report

This report details the results of a koala habitat assessment project undertaken on behalf of Byron Shire Council (BSC) that has the primary aims of:

1. analysis of current and past koala distribution, population size and dynamics;
2. analysis of preferred koala food trees;
3. mapping of areas considered to be *potential* and *core koala habitat*;
4. mapping and assessment of key threats to koalas and their habitat including road mortality black-spots;
5. identification of preferred regional and local corridors including areas suitable for habitat restoration and revegetation;
6. assessment of local population viability; and
7. provision of recommendations based on the above to inform preparation of a Comprehensive Koala Plan of Management (CKPoM) for the eastern portion of the Byron Local Government Area (BLGA).

.

Structure of this report

This report is presented in six parts as follows:

Part 1	Introduction	Provides a general introduction to koala ecology, an overview of SEPP 44 and other relevant legislation, and an introduction to the study area, relevant previous work and regional conservation status.
Part 2	The historical record	Provides outcomes arising from analysis of historical and contemporary koala records for the BLGA including distributional trends estimates of key range parameters, generational persistence and likely areas of high road mortality.
Part 3	Contemporary koala populations	Details field survey methodology utilised for the study, and the resulting outcomes in terms of estimating the current range and occupancy rate of koalas in the nominated study area, the current distribution and extent of habitat

		occupied by resident koala populations, and population size.
Part 4	Food tree preferences and habitat mapping	Examines koala food tree preferences [and associated influences of soil landscape on these preferences]. Existing vegetation mapping is utilised along with the results of this section to construct a map of potential koala habitat for the study area.
Part 5	Threatening processes	Presents a brief discussion of threatening processes operating within the study area and provides the background for discussion on their mitigation.
Part 6	Conclusions and recommendations	Summarises the above work, provides discussion on population viability and offers a prognosis for the future of koala populations within the study area. This part concludes with a series of recommendations intended to inform the next stage of the overall process towards drafting a CKPoM for the study area.

Part 1

Introduction

Introduction

The study area

The BLGA covers an area of approximately 56,600ha in the far north coast of NSW between Tweed Shire in the north, Lismore City to the west and Ballina Shire to the south. The BLGA is diverse in terms of landform and topography, bordered in the east by the Pacific Ocean and rising to above 800m above sea level in the Koonyum Range in the west. A diverse variety of vegetation communities and fauna habitats are supported by these landscapes; at least 38 distinct vegetation associations are recognised within the BLGA, including rainforests, coastal heathlands and wetlands, mangroves, eucalypt forests and woodlands, many of which are depleted, inadequately conserved and/or listed as Endangered Ecological Communities for purposes of the *Threatened Species Conservation Act 1995* (Landmark et al. 1999).

Excluding National Park estate, approximately 50% of the BLGA is vegetated, with the majority of forest cover occurring in the western hinterland areas. Severance of the coastal strip from the hinterland forests has resulted from large-scale historical clearing for agriculture, and the remaining vegetation along the coastal plain is largely present as isolated fragments and narrow linear riparian strips. Native vegetation remnants in general are highly disturbed and are strongly influenced by the presence of exotic species, particularly Camphor Laurel *Cinnamomum camphora*.

The study area for this project has been identified by a technical committee comprising representatives of Council, Office of Environment and Heritage (OEH) and the Department of Planning and Infrastructure. The boundaries of the study area encompass the area within which the greatest level of perceived future urban growth is expected and thus greatest potential impact on koala populations. The study area is located on the coastal strip of the Byron Shire (hereafter referred to as the Byron Coast Study Area (BCSA)) and extends from the BLGA's boundary with Tweed Shire in the north at Billinudgel Nature Reserve to its boundary with Ballina Shire in the south. The study area includes the major urban and residential centres of Byron Bay, Brunswick Heads, Ocean Shores, Broken Head, Mullumbimby and Myocum, an area of approximately 13,790 hectares (Figure 1.1). The Pacific Highway bisects the study area between Yelgun and Tyagarah in the north.

Koala ecology – a brief overview

The koala – Australia's largest arboreal marsupial – is an obligate folivore that feeds primarily on trees of the genus *Eucalyptus*. The distribution of koalas in eastern Australia extends from far north-eastern Queensland to the Eyre Peninsula in South Australia (Strahan and Van Dyck 2008). Throughout this range, koalas have been reported as utilising a diverse range of *Eucalyptus* species (Hawkes 1978; Lee and Martin 1988; Hindell and Lee 1990; Phillips 1990; White and Kunst 1990; Melzer and Lamb 1996; Lunney et al. 1998). Within a given area however, only a few of the available *Eucalyptus* species will be *preferentially* browsed, while others, including some non-eucalypts, may be incorporated into the diet as supplementary browse or utilised for other purposes (Lee and Martin 1988; Hindell and Lee 1990; Phillips 1990; Phillips 1999; Phillips et al. 2000, Phillips and Callaghan 2000).

Koalas do not have a high reproductive output; females reach sexual maturity between eighteen months and two years of age and can theoretically produce one offspring each year. On average, most females in wild populations breed every second year over the term of their reproductive lives (McLean and Handasyde 2006). The longevity of individuals in the wild also varies but probably averages 8-10 years for most mainland populations. Phillips (2000a) has estimated the generation time for koalas to be 6.02 ± 1.93 (SD) years.

While the socio-biology of koalas is a critical aspect of their management, it remains an issue that tends to be overlooked or ignored in the majority of planning studies. Factors that influence the distribution of koalas at the population level are more complex than that simply represented by habitat considerations alone. Long-term fidelity to a home range area is generally maintained by each adult koala over the term of its natural life (Mitchell 1990; Phillips 1999). Studies of free-ranging koalas have established that those in a stable breeding aggregation arrange themselves in such a way that these home range areas overlap those of one or more other koalas' home range areas (Lee and Martin 1988; Faulks 1990; Mitchell 1990). Home range areas vary in size depending upon the quality of the habitat (measurable in terms of the abundance of preferentially utilised food trees) and the sex of the animal (males have larger home range areas than do females). Dissolution of social structure in koala populations has been identified as a possible contributing factor to population decline in some areas (Phillips 2000a), hence maintenance of existing social structure must be a primary consideration in terms of developing conservation and management strategies for free-ranging koala populations.

Habitat fragmentation is also a contributing factor to population decline and dissolution. Recent research by McAlpine et al. (2005; 2006; 2007) into the landscape ecology requirements of koalas suggests that the chances of koalas being present declined rapidly as the percentage of koala habitat or overall forest cover fell below 60-70% of the landscape. There is also some evidence of critical patch size requirements for koalas, with koalas more likely to be absent from patches of primary and secondary habitat that are less than 50ha in size, while the probability of koala presence starts to decline below a habitat patch size of around 150ha (McAlpine et al. 2007).

Threatening processes

Free-ranging koala populations are threatened by a variety of processes:

- Destruction of koala habitat by ill-advised clearing for urban development, roadwork, forestry, agricultural and mining activities.
- Fragmentation of koala habitat such that barriers to movement are created that isolate individuals and populations, hence altering population dynamics, impeding gene flow and the ability to maintain effective recruitment levels.
- Unsustainable mortalities caused by dog attacks and road fatalities.
- Mortalities caused by stochastic events such as fire (including high fire frequency for the purposes of fuel reduction).
- Degradation of habitat by logging of preferred food trees.

There are also indirect impacts that often arise as a consequence of the above, most notably elevated levels of disease.

Conservation and legislative context

The conservation status of koalas varies across Australia, from supposedly secure in some areas to Vulnerable, Rare or Extinct in others (NRMMC 2009). In NSW, the Koala is listed as Vulnerable for purposes of the *Threatened Species Conservation Act 1995* (TSC Act). This listing initiated preparation of a Koala Recovery Plan which was approved by the Minister for Climate Change and the Environment in November, 2008. The NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) also provides for the creation of State Environmental Planning Polices (SEPPs).

Operating within this legislative framework, SEPP 44 (Koala Habitat Protection) encourages the conservation and management of naturally vegetated areas across the state which provide suitable koala habitat, with the stated objective of reversing the current trend of (koala) population decline. SEPP 44 aims to achieve this by:

a) requiring the preparation of plans of management before development consent can be granted in relation to areas of *core koala habitat*;
b) encouraging the identification of areas of *core koala habitat*; and
c) encouraging the inclusion of areas of *core koala habitat* in environment protection zones.

For the purpose of SEPP 44 *core koala habitat* is defined as (NB underlining is author's emphasis):

" *.. an area of land with a* <u>*resident*</u> *population of koalas, evidenced by attributes such as breeding females (that is, females with young) and recent sightings of and historical records of a population*."

The report on a senate enquiry into the koala and its status was released in September 2011, and a nomination to have the koala listed for purposes of the Commonwealth Government's *Environmental Protection and Biodiversity Conservation Act 1999* is currently being considered by the Minister.

The conservation status of koalas within other LGAs in the region is varied, with a relatively high level of knowledge resulting from recent habitat studies. By example, in the coastal portion of the Tweed Shire to the north, the recent decline of koala populations has been such that the population of koalas is below viable levels and considered eligible for listing as endangered (Phillips et al. 2011). In contrast, analysis of historical data for koalas in the Lismore LGA suggests a strong recovery trend over recent decades (Phillips 2011).

Given the preceding legislative context, and the disparate status of koala populations on the north coast, sustainable planning for koalas must endeavour to minimise the potential for adverse impacts in known koala habitat by ensuring that adequate areas of suitable habitat, and that linkages to assist ongoing processes of recruitment and dispersal, are maintained or restored.

Part 2

The historical record

Introduction

The Office of Environment and Heritage maintains a database of flora and fauna records for NSW to which those working under OEH licenses are obligated to contribute; the general public is also able to submit records to this database. Coupled with records kept by carer groups and local Councils, increased reporting rates in recent years have resulted in substantial data sets now available for use.

Analyses of historical flora and fauna records are increasingly being used to inform management and conservation decisions. The koala is an iconic Australian mammal with a high public and political profile; as such it has been the focus of one national survey (Phillips 1990) while at least three statewide surveys have also occurred (Gall 1978; Reed and Lunney 1990; Lunney unpub. data). Gordon et al. (2006) assessed the decline in the distribution of koala populations in Queensland utilising such data, while in NSW analysis has also proved useful for informing planning outcomes at the Local Government Area level (Lunney et al. 1998; Phillips et al. 2007; Phillips and Hopkins 2010).

Such is the time span over which records are available, these datasets increasingly lend themselves to analysis for the purposes of examining distributional trends over time. However, inconsistency in reporting rates, and the non-systematic nature of data collection and reporting results in a number of statistical issues which makes analysis of such data problematical, thus mandating that results be interpreted cautiously.

In this section we undertake an analysis of historical koala records for the BLGA with a view to examining the following issues:

(i) identifying broad trends in the geographic distribution of koalas over time, and

(ii) the identification of likely historical source populations to enable current distributions to be put into a broader spatial and temporal context.

Methods

Koala records were obtained from the OEH's NSW Wildlife Atlas, Friends of the Koala (FoK), and Byron Shire Council's databases. Location information associated with Atlas records was utilised at face value, whilst records sourced from FoK's database were manually assigned location coordinates based on associated locality (typically street address) information. A record was only utilised if a location could be ascertained to within approximately 2.5km.

Once collated, records were subjected to a vetting process that removed duplicates and restricted records to those that were located within 1.25km of the shire boundary. Records were then sorted chronologically and assigned to one of 11 'generations', dating backwards from 2011. A koala generation is defined as six years (Phillips 2000a), and used in order to place results in the context of International Union for Conservation of Nature (IUCN) criteria which assess perceived population declines over a time period of three generations (IUCN SPS, 2010).

The resulting data set consisted of 1,471 records dated from 1900 to 2011, strongly skewed towards later years (Figure 2.1).

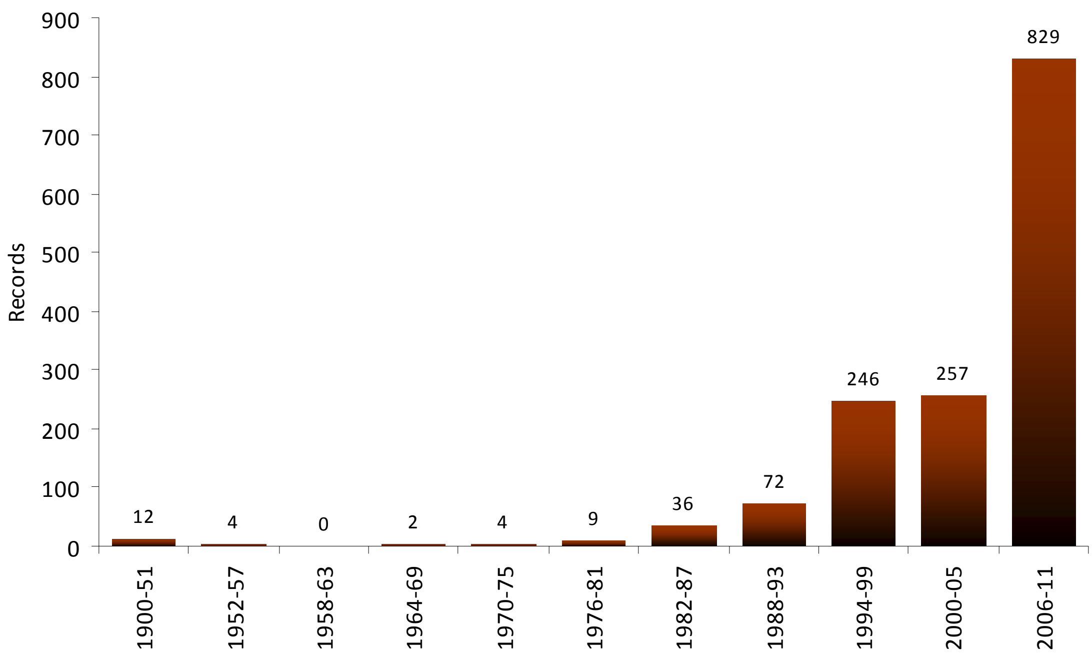


Figure 2.1 Chronological distribution of 1,471 koala records for the BLGA over the period 1900 - 2011.

The range parameters "*extent of occurrence*" (EoO) and "*area of occupancy*" (AoO) are two key measures of the spatial distribution of a species, EoO being that area within the outermost limits of the area within which the species occurs. *Area of occupancy* is the actual area within the EoO over which the species is found (Gaston 1997), usually approximated by the number of occupied grid cells. The AoO is typically determined by enumerating the number of occupied grid cells and is therefore sensitive to sampling parameters such as area and grid cell size. We chose to utilise both measures when attempting to quantify changes in the geographical distribution of koalas over time due to the ability of each to demonstrate differing features of distribution.

For analysis of EoO and AoO, we were interested in changes in distribution between the 'historical' distribution of the koala and that of the most recent three koala generations. Thus the data set was partitioned into those records from prior to 1994 and the timeframes 1994-1999, 2000-2005 and 2006-2011.

Extent of Occurrence

The historical EoO was determined as the total area enclosed by a Minimum Convex Polygon (MCP) derived by connecting the outer-most koala records over time. This was followed by EoO determinations for each koala generation for which sufficient data was available. The area encompassed by the historical EoO was compared to the average individual EoO for each of the most recent three koala generations.

Area of Occupancy

A 2.5km x 2.5km grid overlay constrained by both the historical EoO and the BLGA boundary resulted in a series of 625ha sampling cells; this size considered the minimum necessary to accommodate spatial uncertainty in the data such as use of different mapping datums, observer error and various reporting methods.

For this analysis, the records in the dataset required further vetting to remove the disproportionate influence of large numbers of records reported from a small number of properties over the past decade.

Area of occupancy was calculated for the 'historical' time period 1900-1993, and the three most recent six-year periods, 1994-1999, 2000-2005 and 2006-2011. For the first time period, all available records (n=166) were used, and to ensure equitable area comparisons for subsequent generations, 166 records were randomly selected for analysis from the post-1993 datasets. For each analysis, ten random samples of fifty percent of the grid cells were taken, and the AoO calculated based on the number of grid cells occupied by at least one koala record. Differences in the means of the AoO for each time period were analysed using two-sample *t*-tests.

Generational persistence

Derived from our earlier work in south-eastern Queensland and elsewhere in NSW (Phillips et al. 2007; Phillips and Hopkins 2010), we also employed the concept of “Generational Persistence Analysis” (GPA) to describe repeated records of koalas within a localised area over overlapping generational time spans and so identify the likely presence of resident and/or source populations. “Localised” was considered to include that area defined by the 2.5km grid cell within which a koala record is located, with generational persistence inferred by records occurring over the course of three or more consecutive koala generations.

Such was the quantity of records in latter years, we were able to examine patterns in distribution of generational persistence between three overlapping suites of three koala generations between 1982 and 2011 (Suite 1: 1982-1999; Suite 2: 1988-2005; Suite 3: 1994-2011), thus potentially illustrating shifts in the extent and location of occupied areas otherwise masked in the preceding two analyses.

Results

Koala records

Koala records are widely distributed across the Byron LGA. The most obvious and significant clusters of records are located in the Wilsons Creek – Goonengerry, Mullumbimby and Tyagarah areas. Smaller clusters occur at the Federal and Ocean Shores – Brunswick Heads localities. The distribution of the 1,471 koala records within the Byron LGA is presented in Figure 2.2, while the number and source of these records are presented in Table 2.1.

Table 2.1. Source of koala records for the Byron LGA used in analysis of historical records. [1]Data supplied under license on 22nd September 2011, [2]records from July 1989 to Sep 2011; [3]data supplied by Byron Shire Council; [4]records from field assessment and anectotal records from landholders.

Source	Total
OEH NPWS Wildlife Atlas[1]	500
Friends of the Koala Inc[2]	626
Byron Shire Council[3]	337
Biolink[4]	8
Totals	1,471

The earliest records of koalas in the BLGA occur in the Upper Wilsons Creek area and to the southwest of Brunswick heads. Other early records are scattered but generally located towards the western boundary of the BLGA to the west of Wilsons Creek – Goonengerry, and in the Yelgun, Brunswick and Broken Head areas. Interestingly, the earliest recorded koala from the Tyagarah area is dated 1998, and records from Mullumbimby area do not appear until 2001.

Extent of Occurrence

The historical EoO for the BLGA approximates 42,800ha, demonstrated by records collected between 1900 and 1993 (Table 2.2, Figure 2.3). Extent of occurrence calculations for the three subsequent generations indicate a fluctuating range extent, with a contraction of approximately 12% to 37,550ha for the time period 1994-1999 and subsequent reestablishment and expansion to approximately 69,860ha by 2011. The overall trend over the last three koala generations has thus been one of range expansion, approximating an average generational change of 17%. The most significant areas of expansion have been to the southwest of the LGA (Figure 2.3).

Table 2.2. Percent changes in the *Extent of Occurrence* of koalas in the Byron LGA and the Byron Coast Study Area. % change is relative to the time period 1900-1993.

Period	EoO (ha)	% change	EoO (ha)	% change
1900 - 1993	42,804	-	12,423	-
1994 - 1999	37,552	- 12.27%	11,670	- 6.06
2000 - 2005	42,846	+ <1%	13,255	+ 6.70
2006 - 2011	69,861	+ 63.21%	18,497	+ 48.89
average change 1994 - 2011	50,086	+ 17.01%	14,474	+ 16.51

The average EoO for the study area appears to have similarly expanded, with a positive change of approximately 16% over the last three koala generations.

Area of Occupancy

Area of Occupancy calculations indicate a statistically significant increase in the areas from which koalas have been recorded within the last three koala generations, when compared to that prior to 1994 (t = -13.28, 9_{df}, P < 0.05; Table 2.3 refers).

Table 2.3. Area of Occupancy calculations (± 95% Confidence Intervals) for the time periods 1900-1993 and 1994-2011 within the BLGA.

Period	AoO (ha)	AoO (%)
1900 - 1993	19,375 ± 2,032	25.00 ± 2.62
1994 - 2011	36,375 ± 2,873	46.93 ± 3.71

Generational persistence

Between 1982 and 1999, only four small and distinct localities in the north and west of the shire demonstrate generational persistence. During these three generations, koala records have been consistently reported from the Wilson's Creek/Goonengerry, Myocum, Billinudgel and Minyon Falls localities.

Analysis of records over successive years (i.e. post 1993) indicates an increase in areas of generational persistence. Specifically, and most notably, there appears to have been an expansion east from the Wilson's Creek – Goonengerry area, while relatively new areas of generational persistence are alluded to in the Ocean Shores area, at Ewingsdale, Bangalow, Mullumbimby, and between south Byron and Suffolk Park.

Some, though fewer, contractions in the area of generational persistence are also apparent. No records of koalas have recently been reported from the Minyon Falls area towards the western boundary of the BLGA. Similarly, the Yelgun – Billinudgel locality within the BCSA also demonstrates no continued occupancy over the last four generations, with koalas not being recorded in consecutive generations, and only scattered records being present from this locality since 1998. Figure 2.4 indicates the areas within the BLGA that have demonstrated generational persistence within successive sets of three koala generations over the last 30 years.

Discussion

An inherent problem associated with survey data such as historical records is that they are invariably observer biased and do not represent the results of systematic survey effort. As evidenced by Figure 2.1, the largest numbers of records have been contributed during the last two decades, a pattern that is consistent throughout all previous assessments we have undertaken. In general, this influence tends to be evidenced by concentrations of records towards the more heavily populated areas in any given LGA. In the BLGA however, the relatively unpopulated coastal strip and the distribution of small townships/villages throughout the rest of the LGA may serve to offset some of this bias.

Generational Persistence Analysis demonstrates a long history of occupation by koalas within the BLGA, but suggests that consistent occupancy of the coastal strip may be relatively recent. Although it is likely that historically, the presence of the Big Scrub hindered dispersal between these two areas, the increased and consistent reporting rate for the area between Goonengerry – Wilson's Creek and Tyagarah may suggest the establishment of a connection between these two areas that may not have existed prior to the 1980s. The contribution, current or historical, of any linkage here to persistence of coastal populations however is not determined with any certainty through this analysis. These results also suggest an expansion of occupancy in the Ocean Shores and Byron Bay areas of the coast, potentially indicating expansion from the long-standing Ewingsdale – Myocum population. Results of generational persistence are also consistent with that reported by Landmark et al. (1999), who stated that strongholds for the koala were located in the Goonengerry area, with smaller populations in the Myocum and Federal areas.

Analysis of the historical record within the adjacent Lismore LGA reported a similar trend to that seen here, with only three small source areas identified up until 1992, but a subsequent dramatic expansion of these areas in later years and the establishment of additional source populations in the area of the former Big Scrub in the northeast. It remains unclear however, whether populations in the Lismore and Byron LGAs are meaningfully connected.

Landmark et al. (1999) identified the Marshalls Ridges (Billinudgel Nature Reserve) area as a likely 'core' population area, also reflected herein by generational persistence analysis for the earlier koala generations. The apparent recent decline in reporting rate for the far north of the coastal strip however is consistent with that recorded during koala habitat assessment for the adjacent Tweed LGA to the north (Phillips et al. 2011). Analysis of historical records for the Tweed Coast indicated a contraction in koala distribution from the south within the most recent koala generation, a result mirrored by field surveys in the area which found no evidence of significant koala activity in the northern portion of Billinudgel NR. Although scattered recent records exist, habitat sampling during this study (see Part 3) also confirms that no large source population remains within this habitat area.

The fluctuating trend of distribution is well supported by analysis of changes in the range parameters EoO and AoO. Following a small decrease in range across the BLGA between the periods 1900-1993 and 1994-1999, both analyses indicate a period of progressive increase over the last two generations. The current EoO for koalas in the BLGA approximates an area of 50,080ha, broadly approximating the area of the LGA, whilst the occupancy rate suggests that koalas are currently distributed across approximately 47% of this area. Optimal occupancy rates for free-ranging koala populations are estimated to be approximately 50% of available habitat (Phillips et al. submitted), which, due to these relatively recent range expansions, may already be the case within the BLGA as a whole.

Due to the large number of records available for analysis in later years, analysis of historical records is becoming an increasingly useful tool for examining trends in distribution and the identification of both where source populations existed historically and are likely to currently occur, and will become more reliable over coming decades. It must be noted however that these techniques tend to be insensitive to changes occurring more rapidly than in the time spanned by one koala generation, and can more reliably detect declines than increases (Mitchell 1990, Gordon et al. 2006). Thus patterns of contemporary koala distribution must be determined by systematic, on-ground assessment of koala activity.

Key Outcomes

- The historical record indicates that koalas have a long history of occupation in the BLGA. The number of records available for analysis has increased substantively over the last three decades, and markedly so within the last decade.

- Expansions in the *extent of occurrence* of koalas within the BLGA and the BCSA of approximately 17% have occurred over the last three koala generations. Population expansion is most notable in the southwest of the BLGA.

- There has been a correspondingly significant doubling of the *area of occupancy* across the BLGA over the last three koala generations, with analyses suggesting an occupancy rate of approximately 50% overall.

- Areas of generational persistence are currently widespread across the BLGA, and appear to have resulted from an expansion from historical core areas of Goonengerry, Myocum, Billinudgel and Ewingsdale, and are suggestive of a potential link between Goonengerry , Mullumbimby and Tyagarah.

- While able to illuminate general trends, results of analysis of the historical record must be interpreted cautiously even when utilising relatively large data sets, due to inconsistency in reporting rates over time and the non-systematic nature of data collection.

Part 3

Contemporary koala populations

Introduction

Analysis of historical and community-sourced koala records alone is unable to reflect the true contemporary distribution of koala populations within a given area. In order to best inform landscape-scale koala population conservation and management programs, it is equally, if not more important to determine the extent of current koala population distribution across the planning landscape. Hence the integration of historical record analysis with contemporary data on distribution is ideally combined to identify key areas and thus form the basis for the focusing of management effort.

Standard approaches to addressing issues of koala distribution on a landscape scale variously rely on the extrapolation of localised survey data, broad-scale habitat modelling based on tree preference data, patch size and configuration, community reports and anthropogenic influence (eg. Bryan 1997; Lunney et al. 1998; Gordon et al. 2006; McAlpine et al. 2006; Rhodes et al. 2006). At a local scale, a finer level of detail is required to identify areas of greatest importance to koala populations. Ideally, any approach to providing such information at both levels of investigation should be unbiased and systematic and thus scientifically defendable (MacKenzie and Royle 2005; Phillips et al. submitted)

We have applied Regularised, Grid-based Spot Assessment Technique (RG-bSAT) sampling throughout a number of areas in eastern Australia, repeatedly demonstrating its ability to provide detailed information about koala population size, distribution and habitat use either at the landscape scale or within localised areas (eg. Phillips and Pereoglou 2004; 2007; Phillips and Pereoglou 2005; Phillips and Hopkins 2010a; 2010b); it is this technique which formed the basis for field sampling throughout the BCSA.

Field surveys were designed in order to address a number of objectives simultaneously. Specifically, the aims of the field survey component of the project were:

(i) to obtain a field-based estimate of both the EoO and AoO within the BCSA;

(ii) to locate areas currently occupied by resident koala populations (i.e. *core koala habitat)*;

(iii) to obtain an estimate of population size; and

(iv) to obtain a representative tree-use data set for analysis of koala food tree preferences.

Methods

Site selection

To ensure a uniform and unbiased distribution of survey effort across the BCSA we used a 1,200m x 1,200m point grid overlay, the resulting points then adopted as primary field sites where they intersected areas of remnant vegetation. Recent (2009) aerial photography supplied by Byron Shire Council coupled with vegetation mapping of Landmark et al. (1999) (updated by Byron Shire Council in 2007), were utilised for the purposes of making an *a priori* determination regarding the potential suitability of a site for sampling. Sites were excluded where any point fell within watercourses or cleared areas (not containing trees). Aerial photography for the immediate area surrounding each primary field site was inspected to determine the potential suitability of each for sampling by ensuring sufficient vegetation existed for the application of the sampling protocol. Sites for which insufficient information was available were inspected in the field to determine their suitability for sampling.

Universal Transverse Mercator (UTM) coordinates for the location of selected sites were uploaded into a hand-held GPS receiver navigating on the GDA datum. In the field, a level of flexibility was allowed in determining the exact position of the centre point of the site to enable the repositioning of a site into an area determined to be more suitable for sampling (from a koala habitat perspective), if this location was within 50m (5% of the sampling intensity) of the original site.

Assessment of habitat use

Once located in the field, each site was sampled using the Spot Assessment Technique (SAT) of Phillips and Callaghan (2011), modified to increase sampling efficiency by inferring application of a default *high use* activity level to a site as soon as ten trees scored positive for koala faecal pellets. Conversely, if the first 25 trees scored negative for faecal pellets, a default *low use* activity level was inferred. At each SAT site a 25m fixed radial search was also conducted for koalas, irrespective of the faecal pellet search result. If koala faecal pellets were recorded, an additional larger search area (approximating one hectare where practical) was surveyed for koalas. These searches involved three observers walking approximately 10m apart (depending upon visibility and terrain) and were conducted along transect-lines generally measuring 125m in two directions from the central point of the field site. The aim of both the radial search and transects were to enable area-based koala density estimates to be derived.

Population modelling

Koala 'activity' for each field site was determined by dividing the number of trees which scored positive for koala faecal pellets by the total number of trees searched in the site. For this project we adopted the *east coast med-high* population density activity thresholds of Phillips and Callaghan (2011) (see Table 3.1) whereby an activity level of greater than or equal to 22.52% at a site indicates use by a *resident koala population*, the key determinant of *core koala habitat* for the purposes of SEPP 44.

Table 3.1. Categorisation of Koala activity into Low, Medium (normal) and High use categories based on use of mean activity level ± 99% confidence intervals (nearest percentage equivalents) for each of three area/population density categories. (Source: Phillips and Callaghan 2011).

Activity category	Low use	Medium (normal) use	High use
Area (density)			
East Coast (low)	-	≥ 3.33% but ≤ 12.59%	> 12.59%
East Coast (med – high)	< 22.52%	≥ 22.52% but ≤ 32.84%	> 32.84%
Western Plains (med – high)	< 35.84%	≥ 35.84% but ≤ 46.72%	> 46.72%

Koala activity levels for each site were then used to inform surface analysis using a combination of regularised splining and contouring to interpolate koala activity patterns. This process ultimately produced an activity contour map which – based on the above activity level thresholds – delineates important "source" areas supporting resident koala populations. Based on previous studies (Phillips and Forsman 2005; Phillips and Pereoglou 2005; Phillips et al. 2007; Phillips et al. submitted), this modelling invariably encapsulates those areas known to be occupied by approximately 85% of all contemporary koala records and 100% of the breeding females within that population (another indicator of *core koala habitat*).

Population estimates for areas within population boundaries were derived from the number of koalas sighted during radial and transect searches and the total area searched to derive a density estimate and so the number of animals resident within such areas. Given the fragmented nature of the sampled landscape, population estimates were adjusted to account for the amount of available habitat in each cell.

Results

Habitat assessment

Sampling was undertaken in October 2011 during which time a total of 1,565 trees from 63 field sites were assessed. Forty-nine sites were located on privately-owned land, 14 within National Park estate.

Evidence of koala activity (i.e. faecal pellets recorded beneath at least one tree within the site) was recorded at 18 of 63 sites within which koala activity levels ranged from 3.85% to 100% [mean activity level (active sites only): 40.72 ± 34.22% (SD)]. Ten of the 18 sites returned activity levels at or above the 22.52% activity threshold that is indicative of use by a *resident koala population*. The majority of koala activity was recorded from sites within privately-owned land, with only one site in national park estate returning evidence of koala activity.

Active sites were clustered in two main localities; an area between Myocum and Tyagarah in the central portion of the study area, and to the south west of Byron Bay, (Figure 3.1). Significant activity was also recorded from one site at Mullumbimby and another between Mullumbimby and Brunswick Heads on the Brunswick River. No koala activity was recorded north of the Brunswick River, and no significant activity was recorded south of Byron Bay.

These results translate to a contemporary EoO approximating 11,200ha when sites returning koala activity are enclosed in a MCP (incorporating a buffer of 500m to account for sampling intensity). The AoO derived from field sampling is of 28.57 ± 11.15% (95%CI).

Table 3.2 provides a summary of total survey effort accumulated during field sampling. Locations of field sites and associated activity levels are provided in Appendix I.

Table 3.2. Summary of koala habitat sampling effort undertaken during field sampling within the Byron Coast study area.

Field sites	63
Active sites	18
Sites with significant activity	10
Trees sampled	1,565
Area searched for koalas (ha)	24.98

Population modelling

The spatial clustering of active sites in discrete areas provides confidence that the sampling intensity was appropriate to detect the main occupied areas. The resulting model (Figure 3.2) identified a series of population 'cells' generally located in the central portions of the study area between Brunswick Heads, Mullumbimby and Byron Bay.

1. Myocum – Tyagarah

Two large cells of significant activity comprise the majority of the metapopulation within the BCSA. Located between Tyagarah and Myocum, and crossing the Pacific Highway, a population cell of at least approximately 850ha occurs in this area. Lands utilised by this population include the Bluesfest site and Andersons Ridge in the east, and extend west through a narrow bottleneck for approximately 3.5km across the highway towards Myocum. Metapopulation boundaries were not extrapolated beyond that area for which field sampling was undertaken, thus its western extent remains undefined; the area of uncertainty in the western portion of this cell is indicated by dotted lines in Figure 3.2. The modelling process also identified a cell of approximately 272ha to the south of Tyagarah Airfield, extending into predominantly cleared land to the south (Figure 3.2). Vegetation cover within these cells is highly fragmented, comprising approximately 39% of the total area.

2. West Byron

Located west of the Byron Bay urban centre and extending towards Ewingsdale, this population cell extends through Cumbebin Swamp in the east to the West Byron Urban Release Area. The precise location of the southwestern boundary can only be tenatatively defined due to the lack of suitable habitat sampling sites, but is modelled as extending to the western boundary of the study area. This cell is approximately 963ha in size, approximately 56% of which is vegetated lands.

3. Mullumbimby – Brunswick River outliers

The fragmentation of habitat in the western portions of the study area resulted in difficulty in obtaining adequate sampling coverage to comprehensively inform the modeling process in these locations. However, the presence of significant activity to the immediate west of Mullumbimby indicates the presence of a resident population in the area. Broadly, this site is indicative of a population resident within an area of approximately 100ha, however it is likely that the activity recorded in this area is part of a larger population cell that extends west beyond the study area boundary.

A small outlier cell of approximately 136ha also occurs west of the Pacific Highway on lands adjoining the Brunswick Heads Nature Reserve to the west. Approximately 84% of this cell is vegetated, and is located predominantly on privately-owned land.

Population estimate

During field sampling at 63 sites, a total of 27.18 hectares were surveyed for koalas (9.18ha during radial searches at primary field sites and a further 18ha associated with transect searches). Two koalas were observed during these searches. Using the 10 field sites that returned significant koala activity levels, this outcome allows a coarse overall density estimate of 0.07 koalas ha^{-1} to be determined for the study area and a density of 0.2 ± 0.12 (SE) koalas ha^{-1} within the boundaries of modelled population cells. We remain aware that the standard error associated with the preceding estimate results in a 95% confidence interval as large as the density estimate itself, thus resulting in a large measure of uncertainty around the estimate. This aside, the result otherwise infers a total population size of approximately 240 koalas for currently occupied areas of the BCSA.

Discussion

Patterns of koala distribution in the BCSA are consistent with those indicated through the analysis of generational persistence (see Part 2), with field sampling confirming the current location of resident populations at Mullumbumby, Myocum and Tyagarah. The presence of a resident population cell at West Byron was also alluded to by the analysis of historical records, confirmed by field sampling and supported by previous work in the area (Phillips and Hopkins 2010b).

The absence of koala activity in the north of the study area mirrors similar outcomes in the Tweed which suggest the likely demise of the historical source population once known to occur in the Billinudgel Nature Reserve and immediately adjoining areas. This is not to say that koalas no longer exist in the area, indeed records suggest that koalas are sighted on an occasional basis, but all available evidence now suggests that there is no longer a significant population of resident koalas between Brunswick Heads and Dunloe Park (in the south of Tweed Shire). When considered in the context of the historical records analysis, the loss of the Billinudgel population has only occurred recently (i.e. last 1-2 koala generations), can be linked to fire frequency/intensity, and explains the reason for the relatively low occupancy rate of the BCSA recorded by the field assessment when compared to that estimated by historical record analysis. Accordingly, this northern portion of the study area has been included in a nomination currently being prepared to list the Tweed-Brunswick Coast koala population as endangered under the auspices of the TSC Act.

The scale of sampling undertaken for this project and the extent of habitat fragmentation in some of the western portions of the study area resulted in poor coverage in areas such as Myocum and west of Ewingsdale. Consequently, the western boundaries of some areas of significant activity could not be determined with certainty. Further targeted sampling in these areas may assist in defining these boundaries and would potentially also contribute to a more robust estimate of population size.

Having said this, the spatial autocorrelation observed between active sites provides confidence that the sampling intensity applied across the landscape was appropriate for the detection of larger areas occupied by resident populations. Areas of scattered activity outside of currently modelled population cells predominantly in the south of the study area may be a result of population cells too small to be detected using the primary sampling intensity but for which long term individual viability is unlikely due to small population size and degree of isolation. South of Byron Bay, only two active sites were recorded out of the 15 sampled, where activity thresholds indicated that any population cell(s) in the locality are currently too small to be likely to be contributing as source populations. Recent records of females with joeys from the Broken Head area suggest however that a small resident population does exist in the area. Indeed, historical record analysis indicated that the area through south Byron and Suffolk Park has experienced generational persistence in the most recent three koala generations, with a concurrent southward expansion in EoO (see Part 2). The presence of a relatively large, contiguous area of potential koala habitat west of Broken Head (see Part 4) also provides potential for future population expansion, and as such, provision should be made in any subsequent CKPoM for continued and increased availability of this area to koalas.

It is also the case that a proportion of these lower use areas represent that koala population cohort not permanently associated with resident populations, these being dispersing animals and vagrant individuals; the nature of their ranging behavior resulting in activity levels recorded at sites that do not reach the threshold of resident populations. While transient koalas ultimately contribute to overall population size, the primary focus of conservation and management efforts must be to maintain and ultimately increase those areas currently occupied by the main resident (source) populations of the area. Thus it remains that the bulk of the BCSA's koala population is contained within the Myocum – Tyagarah, West Byron and Mullumbimby localities. The collective population estimate of approximately 240 koalas and the density estimate of 0.20 koalas ha^{-1} would suggest a favourable prognosis for population viability in the area. Indeed, these density estimates are in the general range of those calculated for various populations on the Tweed Coast, of between 0.14 and 0.18 koalas ha^{-1} (Phillips 2002, Phillips and Pereoglou 2004, Phillips et al. 2011).

In light of the collective knowledge now available however, the situation of the coastal koala populations may not be as secure as the above data would indicate. For the BLGA as a whole, the area of occupancy was estimated at approximately 50%, the nominal 'ideal' occupancy rate for koala populations as suggested by Phillips et al. (submitted). In reality, the area of remaining habitat on the Byron coast exists only as a narrow, discontinuous band between largely cleared farmland to the west and unsuitable near-coastal vegetation communities to the east, and it may be the quality of this habitat, not its extent that has allowed the persistence of coastal koala populations. The influence of isolation on the fitness of the coastal koalas has also been observed, the population at Tyagarah exhibiting a large degree of inbreeding manifesting in high levels of disease and mortality (Hopkins and Phillips 2010). We speculate that it is likely that the other coastal cells are similarly compromised such that without increased gene flow input into these cells, their long-term viability cannot be guaranteed.

Although not assessed here, it is clear that a significant population exists in the Wilsons Creek – Goonengerry area (see Part 2), the most extreme eastern outlier of which is likely to be represented by the Mullumbimby cell we have identified. Historically however, and as evidenced by the high levels of inbreeding represented in the Myocum – Tyagarah area (Hopkins and Phillips 2010) it is unlikely the western and coastal populations are meaningfully connected at this point in time. Ensuring persistence of the coastal koala population thus appears reliant on the maintenance and improvement of connectivity between the two aforementioned population cells. Ideally, the establishment of a stable linkage to the west with the intention of allowing gene flow would greatly increase the likelihood of viable coastal population persistence.

Key outcomes

- Distribution of koala activity within the study area is restricted to that area south of the Brunswick River in the north and West Byron in the south. Field data indicates a significantly lower occupancy rate than that supported by the BLGA as a whole, a fact attributable to the documented decline and likely loss of the Billinudgel population in the last 1-2 koala generations.

- Patterns of koala distribution in the BCSA are consistent with those indicated through analysis of generational persistence.

- Population modelling based on koala activity data has resulted in identification of four disjunct areas within which the currently resident koala populations exist, collectively comprising approximately 1,470ha. The extent of effective connectivity between populations is unknown but considered to be low. Resident populations are located at Mullumbumby, Brunswick River, Tyagarah – Myocum, and West Byron, with the latter two comprising the majority of the population.

- A density estimate of approximately 0.20 koalas per hectare has been derived for areas currently supporting resident koala populations, resulting in a population estimate of approximately 240 koalas inhabiting *core koala habitat* within the BCSA.

Part 4

Food tree preferences & habitat mapping

Introduction

Koala habitat mapping provides an essential basis for (i) understanding the distribution and abundance of koalas, (ii) for effective conservation planning, and (iii) priority setting. In order to define the quality of koala habitat it is important to have some understanding as to what elements of the vegetated landscape most influence use by koalas and invariably these are the species' preferred food trees. It is widely recognised that koalas prefer a relatively small number of the *Eucalyptus* species in any given area (e.g. Hindell and Lee 1987; Ellis et al. 1999, 2002; Lunney et al. 1998, 2000; Martin and Handasyde 1999; Phillips et al. 2000; Phillips and Callaghan 2000; Smith 2004; Moore et al. 2004; Callaghan et al. 2011). The identification of preferred tree species across large and heterogenous landscapes can be a complex process, as it is recognised that a number of factors influence the way koalas utilise their preferred suite of eucalypts, including the extent of habitat fragmentation, historical disturbance, stochastic events such as fire, and the nutrient status of the soil (Moore and Foley 2005; Phillips and Callaghan 2000; McAlpine et al. 2006). This variability is also recognised in the Approved Recovery Plan for Koalas in NSW (DECCW 2008) which provides for identification of region-specific lists of preferred koala food trees, whilst also requiring – in common with SEPP 44 – that food tree use by koalas be thoroughly investigated for a given region.

The ability to produce an ecologically-meaningful map of potential koala habitat is not only contingent upon unambiguous identification of preferred food tree species as a means of categorising habitat in the first instance, but is subsequently dependent on the accuracy and detail provided by the associated vegetation and soil mapping layers. Subject to such qualifications, the analyses described in this section provide the basis for understanding the utilisation of eucalypts by koalas throughout the BCSA, our objectives for this component of the study were:

(i) to identify preferred koala food trees for the BCSA, and
(ii) to produce a map of *potential koala habitat*.

Methods

Due to the low incidence of koala activity within the BCSA, the number of trees available for analysis comprised a relatively small data not particularly suited to statistical analysis. In order to increase sample sizes for each tree species, additional data from two recent studies within the BCSA were combined with data collected during this study. Data from the koala habitat assessments of the Bluesfest site (Hopkins and Phillips 2010) and the West Byron Urban Release Area (Phillips and Hopkins 2010b) was collected using identical methodology to that described above and thus was directly applicable to the purpose of providing a larger data set for analysis. These studies added potential tree-use data from an additional 30 and 14 SAT sites respectively, for a total of 107 sites collectively.

Taxonomic uncertainty

Any individual *Eucalyptus* tree species for which there was taxonomic uncertainty was excluded from the data set as were all non-eucalypt tree species identified only to genus level.

Identification of preferred koala food trees (PKFTs)

For each tree species sampled within the BCSA, the results from each 'active' field site were pooled to obtain a proportional index of utilisation "*P*" – hereafter referred to as the 'strike-rate'. (a site was termed 'active' if one or more koala faecal pellets was recorded below one or more trees in a particular site) Strike-rates were calculated by dividing the number of trees which had one or more koala scats at their base, by the total number of sampled trees (see below).

$$\text{Strike rate for species x} = \frac{\text{Number of species x with pellet}}{\text{Number of species x}}$$

Strike-rate data was subsequently divided into primary and secondary data sets, the primary data set consisting of tree species for which the number of sites from which it was sampled was greater than five, and n_iP_i and $n_i(1-P_i)$ was greater than or equal to 15, where n is equal to the number of trees sampled. Thus, the primary data set contained the most commonly sampled tree species as well as those being most frequently utilised by koalas and thus most likely to be of some importance in sustaining the population.

The extent of variation amongst strike rates within resulting data sets was examined using log-likelihood ratios.

Habitat categorisations

The vegetation mapping work of Landmark et al. (1999) along with OEH and Northern Rivers Catchment Management Authority mapping provided the basis for koala habitat classifications. Vegetation communities were categorised in accord with Appendix 3 of the Approved Recovery Plan for the Koala (DECC 2008), the definitions of which are detailed below. The terms “Primary”, “Secondary” and “Supplementary” food tree species are based on the mathematical models and associated definitions of Phillips (2000b).

Potential Koala Habitat	**Primary Habitat**	areas of forest and/or woodland wherein primary food tree species comprise the dominant or co-dominant (i.e. ≥ 50%) overstorey tree species
	Secondary (Class A) Habitat	areas of forest and woodland wherein primary food tree species are present but not dominant or co-dominant and usually (but not always) growing in association with one or more secondary food tree species.
	Secondary (Class B) Habitat	areas of forest and woodland wherein primary food tree species are absent, habitat containing secondary and/or supplementary food tree species only.
Other habitat	**Other**	Vegetation communities within which koala food trees are absent.
	Unknown	Areas for which insufficient information regarding community composition was available to make a determination on habitat quality.

The ecologically-based criteria upon which Primary and Secondary habitat classifications are based are considered to better reflect the extent of *potential koala* *habitat* for the purposes of SEPP 44 than that otherwise applied using the “15% rule” (see SEPP 44, Part 1, 4 Definitions).

Soil landscapes

The majority of the study area is located on the alluvial, swamp, estuarine, aeolian and barrier soil landscapes associated with the coastal plain, while erosional and residual soil landscapes of lower fertility occur in the west of the study area. The soil landscape mapping of Morand (1994, 1996) was used to intersect vegetation mapping for the purposes of determining habitat classifications where necessary.

Results

Preferred koala food trees (PKFTs)

From a total dataset of 2,543 trees, a sub-set of 1,193 trees from 54 active sites was available for analyses (Table 4.1), comprising 10 species of *Eucalyptus* and at least 12 non-eucalypt species.

Table 4.1. Summary of the tree-use data set used for determination of preferred koala food tree species in the Byron Study Area. [1] Hopkins and Phillips 2010; [2]Phillips and Hopkins 2010.

	This study	**Bluesfest[1]**	**West Byron[2]**	**Totals**
Active sites	18	24	12	54
Inactive sites	45	6	2	53
Total number of sites	63	30	14	107
Trees in active sites	428	486	279	1193
Trees in inactive sites	1137	160	53	1350
Total number of trees	1565	646	332	2543

Swamp Mahogany *Eucalyptus robusta* was the most frequently sampled eucalypt species, with 343 trees at 58 sites searched for koala faecal pellets. The most frequently sampled tree species was Broad-leaved Paperbark *Melaleuca quinquenervia* of which 453 trees were sampled at 62 independent sites. These two species comprised approximately 50% and 25% of the eucalypt and non-eucalypt data sets, respectively. Table 4.2 provides a summary of tree species sampled within active sites, whilst table 4.3 summarises tree species sampled within inactive sites.

Table 4.2. Summary of tree species recorded in active SAT sites. Tree species are arranged in alphabetical order. *P*=strike rate, *n*=number of trees, SE=standard error. "Other species" category includes species from the Genera *Acacia, Banksia, Melaleuca, Leptospermum, Pinus* and various rainforest species. Tree species are in alphabetical order.

* indicates inclusion in primary data sets.

	Sites	*n*	*P* ± SE
Eucalypts			
E. carnea	1	2	0.00 ± 0.00
*E. grandis**	6	39	0.33 ± 0.08
*E. microcorys**	6	19	0.74 ± 0.10
*E. pilularis**	5	17	0.29 ± 0.11
E. propinqua	3	3	0.67 ± 0.27
E. racemosa	4	22	0.14 ± 0.07
E. resinifera	1	1	1.00 ± 0.00
*E. robusta**	44	272	0.54 ± 0.03
E. siderophloia	1	5	0.00 ± 0.00
E. tereticornis	2	5	0.60 ± 0.22
Other *Eucalyptus* species	1	1	0.00 ± 0.00
Non-eucalypts			
Acacia species*	17	47	0.36 ± 0.07
Allocasuarina torulosa	5	44	0.07 ± 0.04
*Callistemon salignus**	16	60	0.28 ± 0.06
Casuarina glauca	3	30	0.03 ± 0.03
*Cinnamomum camphora**	9	28	0.46 ± 0.09
*Corymbia intermedia**	7	16	0.44 ± 0.12
*Lophostemon confertus**	15	76	0.26 ± 0.05
*Lophostemon suaveolens**	14	32	0.59 ± 0.09
*Melaleuca quinquenervia**	34	231	0.35 ± 0.03
Other species*	26	240	0.23 ± 0.03
Total trees			

Table 4.3. Summary of tree species sampled from inactive SAT sites within the study area. Sites= number of SAT sites each tree species was recorded in, *n*=number of trees. “Other species” category includes species from the Genera *Acacia, Melaleuca, Leptospermum, Pinus* and various rainforest species. Tree species are arranged in alphabetical order.

	Sites	*n*
Eucalypts		
E. grandis	10	40
E. microcorys	8	14
E. pilularis	8	62
E. propinqua	2	8
E. resinifera	2	13
E. robusta	14	71
E. siderophloia	6	31
E. racemosa	1	1
E. tereticornis	5	11
Other Eucalyptus species	3	20
Non-eucalypts		
Acacia species	19	74
Allocasuarina torulosa	7	17
Banksia species	8	25
Cinnamomum camphora	10	46
Callitris columellaris	2	13
Casuarina glauca	4	12
Corymbia gummifera	1	17
Corymbia intermedia	15	56
Callistemon salignus	14	45
Lophostemon confertus	18	116
Leptospermum species	4	10
Lophostemon suaveolens	16	96
Melaleuca quinquenervia	28	222
Syncarpia glomulifera	2	10
Other species	41	319
Total trees		

Without regard for sample size, the tree species Tallowwood *Eucalyptus microcorys,* Grey Gum, Forest Red Gum and Swamp Mahogany *Eucalyptus robusta* are clearly the most preferred tree species. The large standard error associated with *E. propinqua* and *E. tereticornis* is due to their lack of representation in the field sites. Figure 4.1 illustrates the relative utilisation of each tree species with a sample size sufficient to meet the criteria for statistical analysis. Tree species are arranged by decreasing strike-rate for eucalypt and non-eucalypt data sets respectively.

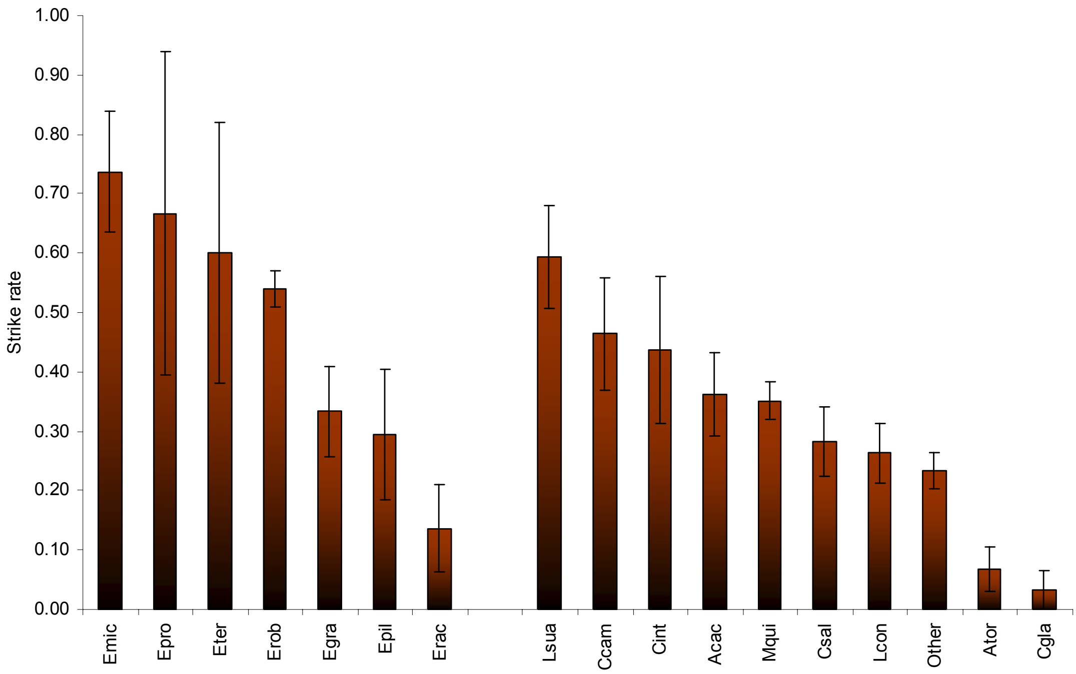


Figure 4.1. Summary of strike-rate data from active SAT sites within the Byron Coast Study Area. Strike rates are presented as the pooled proportion of each species sampled that were recorded with faecal pellets, for species sampled in two or more active field sites. Vertical bars represent standard error. Emic=*E. microcorys*, Epro=*E. propinqua* Eter=*E. tereticornis*, Erob=*Eucalyptus robusta*, Egra=*E. grandis*, Epil=*E. pilularis*, Erac=*E. racemosa*, Lsua=*Lophostemon suaveolens*, Ccam=*Cinnamomum camphora*, Cint=*Corymbia intermedia*, Aspp=*Acacia* spp., Mqui=*Melaleuca quinquenervia*, Csal=*Callistemon salignus*, Lcon=*Lophostemon confertus*, Other=species including *Melaleuca linariifolia*, *Pinus* spp., *Leptospermum* spp, *Banksia* spp. and *Corymbia torelliana*, Ator=*Allocasuarina torulosa*, Cgla=*Casuarina glauca*.

The primary data set contained four *Eucalyptus* species and eight species of non-eucalypt with percentage equivalent strike rates ranging from 74% for Tallowwood to 23% for the 'other species' category (Table 4.2). Utilisation of the three most utilised species, Tallowwood, Swamp Mahogany and Swamp Box *Lophostemon suaveolens* was significantly greater (G = 109.8, 11_{df}, P<0.001) than that of the remainder of the tree species in the data set, which showed no heterogeneity between strike rates.

The secondary data set contained the eucalypts Grey Gum, Forest Red Gum and Scribbly Gum *E. racemosa,* and two non-eucalypt species. Percentage equivalent strike rates ranged from 67% for Grey Gum to 3% for Swamp Oak *Casuarina glauca* (Figure 4.1). While an expected trend towards higher levels of use of Grey Gum and

Forest Red Gum was apparent, variation amongst the strike rates for these species was not significant (H_{adj}=2.98, 4_{df}, p>0.05).

In general terms strike-rates for the remaining eucalypts and non-eucalypts indicate levels of non-preferential and/or opportunistic browsing, the higher level of the non-eucalypts *Lophostemon suaveolens, Cinnamomum camphora and Corymbia intermedia* associated with proximity to the more preferred species, particularly Swamp Mahogany. Swamp Box *Lophostemon suaveolens* was present in only two sites without Swamp Mahogany or Forest Red Gum and thus could not be tested for independence. However, we expect that the relationship between its high strike-rate and proximity to Swamp Mahogany could be demonstrated with a sufficient sample size.

Habitat categorisations

Vegetation mapping by Landmark et al. (1999) described 38 vegetation associations within Byron Shire. This work was subsequently updated in 2007 by Ecograph and Terrafocus and additionally by Byron Shire Council resulting in a current digital vegetation layer of 38 vegetation classifications. Additionally, vegetation mapping was sourced from OEH to cover National Park estate, reserves and otherwise unmapped areas. Excluding non-terrestrial vegetation, approximately 6,994ha of terrestrial vegetation is mapped within the BCSA, equivalent to approximately 50% of the study area.

Based on the tree use data set and associated analyses, the following decision rules formed the basis for habitat classification:

1. *Eucalyptus robusta* functions as a primary food tree species. This includes the naturally occurring hybrid *E. robusta* x *E. tereticornis*.
2. *Eucalyptus microcorys* functions as a primary food tree throughout the majority of the BCSA.
3. *Eucalyptus tereticornis* functions as a primary food tree throughout the majority of the BCSA.
4. *Eucalyptus microcorys* and *E. propinqua* are likely to function as secondary food tree species in vegetation communities growing on lower nutrient soil landscapes within the study area[1].

[1] Based on the work of Phillips and Hopkins (2010a) and supported by Phillips et al. (2011).

Approximately 2,060ha of *potential koala habitat* was identified within the study area, comprising all of the habitat categories; Primary, Secondary (Class A) and Secondary (Class B) (Figure 4.2, Table 4.4). There was insufficient information available in accompanying floristic descriptions to assign a koala habitat classification to an additional 300ha of vegetation. The remainder of mapped vegetation, approximately 4,640ha, was not described as containing primary or secondary koala food tree species.

Table 4.4. Mapped area in hectares for each category of koala habitat identified within the BCSA. %of total refers to total forest habitat.

	Habitat Quality	Area (ha)	% of total
Potential Koala Habitat	Primary	521.9	7.5
	Secondary (Class A)	1271.4	18.2
	Secondary (Class B)	263.4	3.8
Total Potential Koala Habitat		2056.7	29.4
Other habitat	Other	4637.5	66.3
	Unknown	299.4	4.2
Total		**6993.6**	

Primary Koala Habitat

Approximately 520ha of Primary Koala Habitat is present within the study area, comprising only 7.5% of the total mapped bushland vegetation. The vegetation communities Swamp Mahogany/Swamp Box and communities described as Mixed Eucalyptus spp comprise the majority of this category, and are limited predominantly to coastal areas. Approximately 50ha of Forest Red Gum communities are also present as scattered remnants in the northern portion of the study area.

Secondary (Class A) Habitat

Secondary (Class A) Habitat comprises approximately half of mapped *potential koala habitat*, encompassing approximately 1,270ha (18%) of mapped vegetation communities growing on higher-nutrient soils within the coastal portion of the study area. Within the four communities considered to contribute to Secondary (Class A) habitat, Tallowwood is a sub-dominant element. Grey Gum and Forest Red Gum are also present.

Secondary (Class B) Habitat

Secondary (Class B) Habitat comprises approximately 260ha (4%) of mapped vegetation communities containing *E. microcorys* and/or *E. propinqua*, growing on lower nutrient, metamorphic soil landscapes.

Unknown Habitat

A total of 300ha (4%) of habitat was unable to be classified due to a lack of information regarding floristic composition. The majority of these vegetation associations are currently typed as “Bushland – no attributes”, for which no information is currently included in the vegetation layer. It is likely that some of these areas contain *potential koala habitat*.

Other Habitat

Approximately 4,640ha of mapped vegetation was comprised of vegetation associations that do not list PKFTs within their floristic descriptors. This habitat category comprised approximately 66% of the vegetation mapped within the study area. This habitat category is comprised of vegetation communities such as exotic plantations, rainforest, coastal *Banksia* and heath communities, mangroves and Paperbark.

Details of the area of each of the mapped vegetation communities within the study area and their associated koala habitat categorisations have been provided to Council in spreadsheet format.

Discussion

Much is already known about the food tree preferences of koalas on the north coast of NSW. Appendix 3 of the approved NSW Koala Recovery Plan (DECCW 2008), lists 15 preferred koala food tree species for the North Coast Koala Management Area, within which the Byron LGA is located; four of these naturally occur within the BCSA.

Primary Food Tree Species	Secondary Food Tree Species
Forest Red Gum* *Eucalyptus tereticornis*	Grey Gum *Eucalyptus propinqua*
Tallowwood *Eucalyptus microcorys*	
Swamp Mahogany *Eucalyptus robusta*	

* includes the naturally occurring *E. tereticornis* x *E. robusta* hybrid referred to as *E. patentinervis* by Bale (2003).

Although the size of the data set does not allow detailed examination of the more complex issues of habitat utilisation by koalas, habitat assessment surveys have served to add to existing knowledge and confirm the importance of the suite of these four *Eucalyptus* species; Tallowwood, Forest Red Gum, Swamp Mahogany and Grey Gum in the utilisation of habitat across the study area.

Forest Red Gum and Swamp Mahogany are widely recognised as important koala food tree species in northeastern NSW and southeast Queensland (e.g. Lunney et al. 2000; Phillips et al. 2000; Phillips 2000b; Smith 2004), but being characteristic species of lowland and floodplain communities, have been subject to widespread clearing. Over their range, these communities tend to be poorly represented within reserves, and remain subject to clearing, fragmentation and disturbance for development within coastal areas. By example, within Byron Shire, only 64.87ha of Forest Red Gum forest remains, 58.3ha of which occurs within the study area, scattered in small patches at Brunswick Heads, Yelgun, Marshall's Creek and Tyagarah. Cursory inspection of aerial photography suggests that vegetation mapping overestimates the extent of this community. Red Gum communities are considered to be one of the most highly cleared and inadequately represented throughout their range, with an estimated 33% of the pre-clearing extent remaining in the north east region (Landmark et al. 1999). Similarly, only 35% of the pre-1750 extent of Swamp Mahogany/Swamp Box communities remain, with only small areas reserved in Billinudgel Nature Reserve, the remainder in small isolated patches on privately-owned land at Skinners Shoot, Suffolk Park, Ewingsdale, Tyagarah, Brunswick Heads, Mullumbimby and Broken Head. The long-term retention and expansion of these high-quality floodplain communities in coastal areas, particularly where they occur on private land is fundamental to the persistence of coastal koala populations.

Away from the coastal plain and foothills, the role of certain preferred food tree species becomes more complex. Although not directly examined here, analysis of larger datasets elsewhere on the east coast (Phillips and Hopkins 2010a, Phillips et al. 2011), indicate that whilst Tallowwood likely serves as a primary food tree on alluvial and other deposited soil landscapes, strike rates for this species tend to be significantly lower on the lower nutrient erosional and residual soil landscapes. Additionally, there is a reported preferential utilisation of larger sized Tallowwood and Grey Gum as opposed to smaller individuals of the same tree species (Phillips and Hopkins 2010a, Phillips et al. 2011). These patterns of utilisation indicate that the species acts as a secondary food tree in such areas, in turn dictating a relatively lower koala carrying capacity within the associated landscapes. These observations suggest that differential classification of communities containing these tree species is required dependent on soil landscape position. For example, vegetation communities classified as Secondary (Class A) due to the sub-dominant presence of Tallowwood are downgraded to Secondary (Class B) where they occur on lower nutrient soil landscapes in recognition of the lower carrying capacity of this habitat. During the habitat classification process, these considerations were applied to approximately 223ha of potential koala habitat predominantly in the west of the study area, whilst elsewhere, habitat classifications have been applied conservatively, and likely overestimate the extent of potential koala habitat within the study area.

A wide variety of tree species are known to be used by koalas in the study area (eg Landmark et al 1999; Phillips and Hopkins 2010b; Hopkins and Phillips 2010). However, it is the aforementioned four species without which free-ranging koala populations cannot sustain themselves, and hence it must be these particular species that become the focus of habitat management.

Key outcomes

- Swamp Mahogany *E. robusta,* and Tallowwood *E. microcorys* are the most preferred Eucalyptus species within the BCSA. It was assumed, supported by data from other studies, that Forest Red Gum *E. tereticornis,* and Grey Gum *E. propinqua* form part of the set of tree species that are the most preferred by koalas in the study area.

- It is assumed, based on data from adjoining areas, that Tallowwood E*. microcorys* and Grey Gum *E. propinqua* exhibit differential selection dependent on soil type and size-class and koala habitat was classified accordingly.

- A total of 1,291ha of *potential koala habitat* is identified based on available vegetation mapping within the study area. All three habitat categories recognised by the Recovery Plan are represented. All koala habitat categories are considered poorly represented, and collectively amount to approximately 26% of mapped vegetation.

- Potential koala habitat is sparsely distributed across the study area and occurs most frequently as small isolated patches on privately-owned land. Few large habitat blocks are available within the study area.

- Approximately 70% of the study area is substantially cleared of native vegetation and was not mapped by Landmark et al. (1999). It is expected that some of these areas actually support potential koala habitat in the form of scattered preferred koala food trees and probably play a fundamental role in sustaining the area's resident koalas. A proportion of vegetation classified here as "Unknown" is also likely to comprise potential koala habitat.

Part 5

Threatening processes

1. Habitat loss & linkages

Loss of potential koala habitat continues to contribute to population decline across the koala's range. Across the Byron LGA, as is the pattern throughout much of the east coast of Australia, the hinterland and coastal vegetation have been largely disconnected through historical large-scale clearing of the coastal plain and foothills (Landmark et al. 1999). To the detriment of coastal koala populations, vegetation communities that were once supported by the highly fertile coastal and associated alluvial soil landscapes are those that provided the highest-quality habitat and greatest ability to support high-density koala populations. This pattern of clearing has resulted in large expanses of landscape devoid of native vegetation, and in general, only tentative connections remain as degraded narrow riparian strips or isolated pockets of regrowth vegetation.

The influence of patch size, patch shape and level of connectivity are also factors determining the ability of a landscape to support viable koala populations. McAlpine et al. (2007) suggest that the probability of koalas being present falls as the percentage of the landscape containing forest cover decreases, while it has also been suggested that the chance of koalas being present starts to decline once patches become smaller than ~150ha.

Connectivity of patches is also imperative; small populations that are highly isolated tend to higher extinction probabilities than do populations that are connected to each other via animal movement. Indeed, the survival of meta-populations (a group of sub-populations connected by dispersal) is heavily reliant upon the ability of animals to recolonise habitat patches where a sub-population has become locally extinct. Whilst habitat patches that are further apart are often considered less connected than patches close together, connectivity also depends upon the nature of the habitat matrix and the existence of barriers to movement.

The maintenance of habitat patches of sufficient size to support existing populations and provide for future population dynamics is elemental to koala population and habitat management. To this end a three-faceted approach will be required, consisting of the following foci.

1. Retention of potential koala habitat *in-situ* in the first instance, with a focus on occupied habitat, and adjoining areas of potential koala habitat.

2. Protection of bushland areas that contain preferred food tree species is also necessary to preserve the habitat resource.
3. Maintenance and/or creation of vegetated linkages between habitat patches and source populations.
4. Strategic revegetation work with the aim of consolidation of existing habitat patches and habitat creation. Revegetation work should focus primarily on "gap-filling" in large habitat blocks within and adjacent to mapped source populations, edges of habitat blocks and within linkage areas.

An ability to move freely across the landscape allows for the effective dispersal of sub-adult koalas between breeding populations. At the landscape scale such movements facilitate maintenance of genetic diversity, while also enabling recruitment and/or re-establishment of subpopulations where these may have died out. Koala population modelling provides guidance for the identification of linkages for the purposes of maintaining and creating these avenues for dispersal. Examining the pattern of distribution of resident koala populations invariably indicates the two key concepts underlying the management of connectivity:

a) those areas likely to be currently utilised for dispersal between population cells, and
b) optimising locations for the enhancement of connectivity between currently isolated populations.

In many cases, opportunities for linkages must be recognised in areas that would otherwise not be considered optimal habitat. This is a consideration arising from the social structuring of koala populations, which tends to override the importance of habitat quality in the arrangement of population cells, and indeed appears to be the case in the BCSA. It is currently unclear to what extent any meaningful linkages exist or are utilised between population cells on the Byron Coast, suffice to say that evidence of inbreeding in the Tyagarah population would indicate that connectivity is non-existent or limited. The provision of connectivity between the West Byron, Tyagarah and Brunswick River population cells should be the primary consideration during preparation of the CKPoM. Secondly, the enhancement of north-south connectivity between coastal populations and those in the west is likely to be key in long-term maintenance of their viability. Opportunities for linkages should be examined between Mullumbimby and the Brunswick River cell, Mullumbimby to Tyagarah, and Tyagarah through to Myocum and Montecollum. Opportunities should also be investigated for enhancement of movement across the Pacific Highway, particularly in the key area of Tyagarah. Indicative optimal linkage areas for the Byron Coast have been provided in Figure 5.1.

2. Fire

Stochastic and poorly-planned fire events continue to threaten koala populations throughout the east coast, and are increasingly being recognised as a key factor influencing long-term viability (Phillips and Pereoglou 2005, Phillips et al. 2011). Wildfire has the potential to exacerbate koala population decline (Starr 1990; Melzer et al. 2000) as each high-intensity and/or frequency fire event within areas occupied by resident populations removes a proportion of the breeding population at a rate faster than the time required for the loss to be replaced by successive koala generations. Fire removes the food resource from remaining koalas not killed by fire and widespread canopy scorch presumably results in starvation for the remaining animals (Melzer et al. 2000).

Wildfire has the potential to impede recovery, particularly when populations are small, isolated and occupancy is already low. Where populations are contained in small isolated areas, as is the case on the Byron Coast, each is highly vulnerable to the impact arising from a single major wildfire. Fire has not been completely absent from the Byron Coast; in the period 1977 to 2010, nine wildfires have been recorded within the central portion of the study area, covering areas of up to 360ha, with the major fire events occurring in 1977, 1980 and 1983. A recent (2009) wildfire occurred on the west of the Brunswick River across an area of approximately 54ha. Recent small fires have also occurred in the north of Tyagarah NR.

Excluding fire events at Billinudgel, we speculate that the absence of more frequent and recent wildfire is a key factor in the persistence of coastal populations. This is in direct contrast to the situation observed on the Tweed Coast where most key population cells have been subject to wildfire multiple occasions over a 15 year period, and with intervening intervals of as short as three years (Phillips et al. 2011). It will thus be imperative into the future, that there is continued exclusion of fire from these key areas that are currently occupied by resident koala populations.

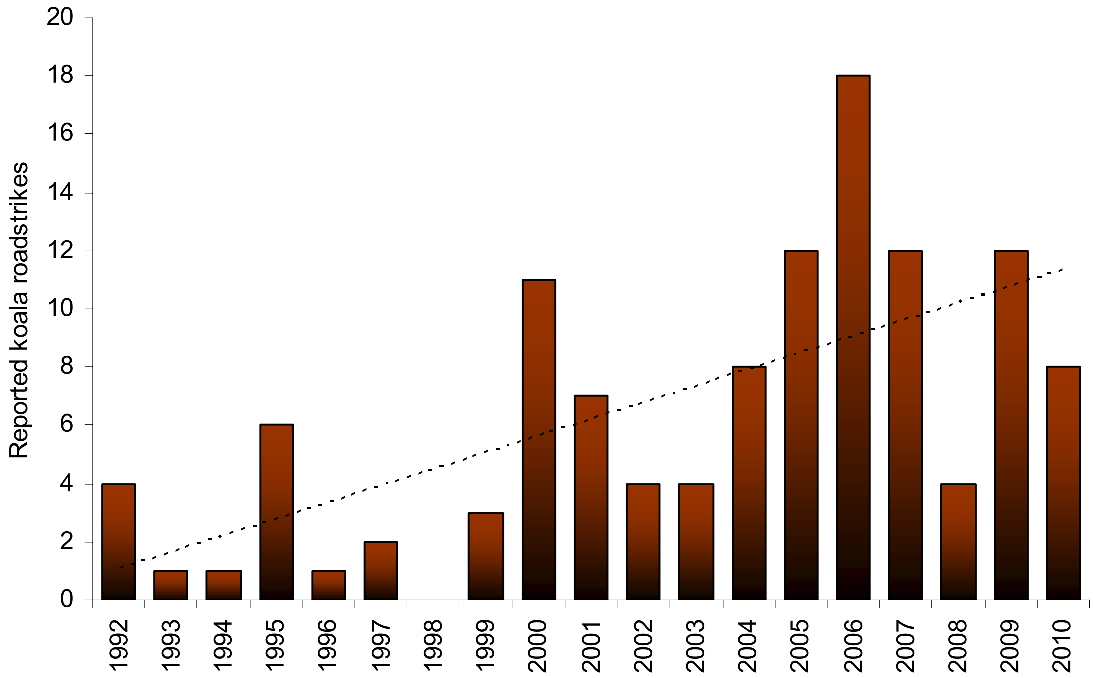
We do suggest however that fire has been the key determining factor influencing the attrition of koala populations in the north of the study area. Fires in Billinudgel Nature Reserve have been more recent, with the majority of the reserve subject to wildfire in 2004. Prior to 2004, parts of the reserve were burned on two occasions with inter-fire intervals of only three and nine years.

3. Road mortalities / koala blackspots

Of the 374 koala mortalities recorded by FoK within the BLGA for the time period 1989-2011, 19% are attributable to motor vehicle strike. A further 25 records of roadkilled koalas are present in the Atlas database for this same time period, whilst an additional 24 animals are recorded as being hit by cars but either insufficient data is available to determine whether the strike was fatal, or the animal was released after a period in care. Up to 18 cases of roadstrike have been reported in a single year for the LGA, with numbers in 2000 and 2005-2009 particularly high. Further analysis indicates that the number of koalas being killed has generally been increasing annually over the last decade (Figure 5.2).

Whilst this data equates to an average of approximately six reported koala roadstrikes per year, this should not be interpreted as the full extent of koala road-kill; the majority of database records for this time period do not have relevant information associated with them, nor are all koala road-kills ever reported. The level of simplicity in record-keeping required for maintenance of public databases generally results in a loss of informative data, however this is improving with increasing reporting rates and public interest.

Figure 5.2. Incidence of reported koala roadstrike between 1992 and 2010.



Within the study area, 54 cases of roadstrike have reliable location data associated with them. Examination of the distribution of roadsrike records clearly identifies four major blackspots where records are highly clustered.

i) Koala roadstrike is most frequently reported from that section of Pacific Highway between Gulgan Rd in the north and Grays Lane in the south at Tyagarah. Fourteen of 54 available roadstrike records occur in this area, with two further records for Grays Lane itself. This black spot coincides with the area of known *core koala habitat* in the Tyagarah locality, and the highway in this location would appear to be functioning as a physical barrier to movement of animals into or out of this coastal population.

ii) In combination with the above location, the area in the vicinity of the Gulgan Rd/Mullumbimby Rd intersection (Uncle Tom's) account for approximately 50% of koala roadstrike data for the BCSA. Twelve records of roadstrike occur within a 1km radius of this intersection, which also coincides with the northwestern edge of the Myocum – Tyagarah koala population cell.

iii) To a lesser extent, but also noticeably clustered, are six further roadstrike records from the vicinity of the highway bridge across the Brunswick River.

iv) The area in the vicinity of the northern Gulgan Rd interchange with the Pacific Highway also contains a cluster of four roadstrike records.

The remainder of recorded koala roadstrikes are scattered throughout the study area, at Yelgun, Billinudgel, Myocum and urban areas of Byron Bay. Although not indicated by the roadstrike data, two further potential blackspots are indicated by the distribution of koala habitat and likely crossing points between occupied cells.

a) Ewingsdale Road, adjacent to the West Byron Urban Release Area, and
b) Pacific Highway, adjacent to Brunswick Heads Nature Reserve

These areas are likely to become more important as development continues. The location of the above blackspots is indicated in relation to koala habitat and location of resident populations on Figure 5.3.

During the development of the Brunswick Heads Bypass in 1998, a series of 12 underpasses, pipes and land bridges were installed on the highway south of the Brunswick River Bridge (Figure 5.1). Monitoring work by Taylor and Goldingay (2003) indicated use by koalas of at least two of the underpasses. That records of roadstrikes in this location occur subsequent to the installation of these underpasses may however indicate the less-than-optimal operating efficiency of the underpasses, an issue that warrants further investigation. South of Brunswick Heads, no other dedicated fauna underpasses have been installed on the Pacific Highway. Having said this, the highway is raised via a road bridge to pass over smaller roads in a number of locations, offering the potential for fauna also to cross under, and providing (arguably) lesser risk of vehicle strike than crossing the highway itself. The highway forms a considerable barrier throughout much of the study area.

4. Dog attack

Domestic dog attack continues to be recognised as a key threat to koala populations and is a significant contributor to anthropogenically-originating koala mortality (Qld EPA 2006; DECCW 2008), the impact increasing with urban expansion and fragmentation. A higher frequency of cleared areas and roads means individual koalas are required to travel greater distances in order to continue to access resources, increasing the amount of time spent on the ground and thus susceptible to attack. Coupled with the increase in density of domestic dogs, the threat to koalas in an increasingly urbanised landscape heightens rapidly.

Of the 374 mortalities reported by FoK during the period for the Byron LGA, 17 are directly attributable to dog attack. The actual incidence of koala mortality due to dog attack in the BLGA is almost certainly higher than that reported herein, the majority reported from the Federal area, with additional reports from Myocum and Ewingsdale. Although scant, these data suggest the likelihood of domestic dog attack increases towards and beyond the western boundary of the study area as landuse becomes increasingly rural.

For the reasons above, data on domestic dog attack is difficult to obtain and interpret, suffice to say that the threat is larger than indicated by available records. Data from Port Macquarie Koala Hospital indicates that attacks by domestic dogs constitute approximately 15% of all admissions to the hospital (Cheyne Flanagan, pers comm.), whilst data from southeast Queensland indicates around 110 mortalities per year, the threat being ranked as the third most important in that region (DERM 2009). The extent of urbanisation and dog ownership in the BLGA is somewhat lower than that of Port Macquarie or southeast Queensland, thus the magnitude of threat is lessened accordingly.

The threat to koala populations of wild dogs, away from the urban/peri-urban interface is considered to be somewhat lower. A recent review of the available literature has identified the koala as a prey item in less than 0.04% of wild dog/dingo scats analysed therein (S. Phillips, unpublished data).

Nevertheless, attack by domestic dogs should be considered an important contributor to the suite of threats to the viability of koala populations on the Byron Coast, and mechanisms for reduction of this threat to the maximum extent possible should form a key consideration in preparation of a CKPoM, particularly within rural lands and at the urban/bushland interface.

5. Disease

Disease is a fundamental element of wildlife population dynamics and is generally recognised as a density-dependent mechanism enacting population regulation. This is also the case with koalas; reproductive output/population size is primarily affected by elevated levels of Chlamydiosis in response to reduced levels of metabolic/genetic fitness and/ immunological suppression brought about by inbreeding and/or stressors such as a reduction in the available food resource and/or elevated agonistic interactions. Unfortunately, at the urban-bushland interface such natural stressors are replaced by more anthropogenic catalysts such as habitat loss, domestic dog attack and motor vehicle strike, the consequence of which tends to manifest itself in elevated levels of clinical expression of disease, reduced reproductive output and mortality.

As with all naturally occurring koala populations in eastern Australia, both Chlamydia and Koala retro-virus (KorV) are known to be present in the Byron koalas. Mortalities due to disease are widespread throughout the current range of koalas within the LGA, accounting for 20% of all records supplied by FoK and 45% of dead or euthanased animals brought into care. Euthanasia of diseased animals accounts for over one third of known mortalities since 2003, thus highlighting the importance of disease management as a local issue.

Nevertheless, we argue that the extent to which disease contributes to overall mortality rates is more symptomatic of disturbance than the prevalence of disease in the koala community itself. Thus we do not see disease *per se* as a direct or overriding threat to long-term koala population viability in the BCSA providing that sufficiently large areas of habitat remain so as to effectively buffer key source populations from undue disturbance.

Recent work on a coastal population at Tyagarah reported particularly high disease and mortality levels, with genetic profiling revealing a high level of inbreeding, manifesting in a suppressed immunological response (Hopkins and Phillips 2010). These characteristics within this population reflect a likely long history of isolation of small coastal populations and impaired gene flow to these population isolates, predominantly resulting from, and exacerbated by historical broadscale land clearing and other barrier effects such as major roads.

6. Koala care and welfare

Given the above, there is an ongoing requirement for an effective mechanism for managing koala casualties resulting from vehicle strike and dog attack, orphaned animals, the survivors of wildfire and animals suffering from disease. Data indicates that this need is likely to increase in coming years.

In NSW wildlife welfare and carer groups are licensed to rescue, rehabilitate and release native fauna under Sections 120, 132C and 127 of the *National Parks and Wildlife Act 1974*. Friends of the Koala Inc. are the responsible organisation for the care of koalas in the Byron LGA. Volunteer koala rehabilitators are supported by local veterinarians as well as wildlife veterinary teams at Currumbin Wildlife Sanctuary (Currumbin, Qld) and Australian Wildlife Hospital (Beerwah, Qld).

Friends of the Koala Inc have identified a number of issues to be addressed in order to assist its ongoing operation and improve care for koalas ion the Byron Coast. These include the need for maintenance and extension of the existing food tree plantation at Myocum. Access to the plantation has been historically problematical and establishment of an alternative plantation should be considered if necessary. There is a need for sourcing of financial and in-kind assistance for the ongoing operation of the carer network, as well as identification of potential opportunities to enable veterinary services to be more readily available to carers.

A number of broad issues that are common to all areas in which the organisation works are also noted, these issues including increasing community awareness regarding how to recognise when koalas require assistance and what to do in this situation, the role of carers, and the need for ongoing recruitment of active carers.

Part 6

Conclusion & recommendations

Conclusion

A history of land clearing and associated habitat fragmentation has resulted in a landscape in the BLGA that is extremely fragmented, with the narrow area of coastal vegetation effectively disconnected from habitats in the west of the shire by broadscale clearing of the lowland floodplain.

A case of population expansion is a little-reported situation for koalas on the east coast of NSW, however this appears to be the case for the BLGA as a whole, in contrast to the state and national trends of decline. Given these broad recovery trends inferred from analysis of the historical record, some may argue that little action is needed for Byron’s koalas. While the recovery trend is both a positive and encouraging outcome, examination of the situation for Byron’s coastal koala populations has identified a suite of important issues, the key aspects of which are long-term isolation and anthropogenically-enhanced mortality rates.

Relatively high koala densities and a population size that is likely to be above the minimum required for long-term population viability should not overshadow the assertions that koala populations in the coastal portion reside in highly marginal, fragmented habitat with what is assumed to be little functional connectivity between patches. Continued isolation leaves populations vulnerable to stochastic processes and the pressures of inbreeding already known to be present. The presence of the Pacific Highway bisecting northern population cells further creates a formidable barrier to dispersal and population persistence. In isolation, the continued viability of the coastal populations cannot be guaranteed.

Koala conservation should ideally be based not only on scientifically sound assessments in the first instance, but also the application of solid landscape ecology/conservation biology theory. In this context two issues arise. Firstly, there is the matter of area and exactly how much land is required to sustain a free-ranging population in perpetuity. From a koala conservation perspective, an *optimal* occupancy rate is that which sees not all available habitat occupied, but in which there is allowance for population expansion (into currently unoccupied areas) and population contraction in response to stochastic events). Indeed, as evidenced by situations in places such as French Is. (Vic) and Kangaroo Is. (SA), a population existing at high occupancy levels encounters stressors related to limited resource availability, a situation considered to be far from ideal. Results from our studies elsewhere (eg. Gold Coast, Qld (Phillips et al. 2007); Byron Bay, NSW (Hopkins and Phillips 2010); Port Macquarie, NSW (Phillips and Forsman 2005)) of demographically stable, reproducing koala populations consistently return occupancy rates approximating 50% of the available habitat (Phillips et al. submitted). Conversely, for populations considered endangered such as those in Hawks Nest – Tea Gardens and the south-east forests, occupancy rates have been reported at as low as 16% and 8% respectively (Biolink 2005; Allen and Phillips 2008). While for many this variation in occupancy rate is a novel concept in terms of landscape-scale koala management, it makes ecological sense and thus underpins the need for conservation planning to both recognise *and* make allowance for koala metapopulation contraction and expansion over time in response to ongoing recruitment and attrition events.

The observed occupancy rate of 28% for the Byron Coast is below that 'optimal' level, and the pressures of habitat loss and motor-vehicle mortalities is likely to continue into the future. Currently, Byron's coastal koalas survive in a highly fragmented habitat matrix that, although contains patches of high-quality habitat, is largely disconnected and lacks large contiguous patches. It has been estimated that approximately 2,500ha of well-connected koala habitat is required to sustain the minimum viable population of ~170 koalas while also allowing for a minimum occupancy rate of approximately 50% of available habitat (Phillips et al. 2011). The estimated 1,290ha of koala habitat in the BCSA is clearly insufficient to allow for the expansion that these populations require.

The preceding prognosis reinforces the need to minimise to the greatest extent possible potential threatening processes from those areas known to be currently occupied, but also to effectively buffer such areas from further adverse impact, facilitate recovery and accommodate the need for population expansion, as well as ensuring the expansion of current habitat cover and the creation of more effective habitat linkages in order to facilitate ongoing recruitment processes. Hence the need for an appropriately informed and framed management response, the key purpose of which must be the identification of opportunities and/or actions to facilitate survival of the population in perpetuity.

Recommendations

It will be important that management actions for the Byron Coast koalas be prioritised so as to maximise the conservation benefit during CKPoM preparation. At this stage we see a clear requirement for a focus on habitat creation and the enhancement of connectivity, whilst also reducing the potential for incidental mortalities through motor vehicle strike. With this in mind, the following recommendations are provided in order to stimulate further discussion and provide a focus on the key issues to be addressed in preparation of an informed CKPoM for the Byron Coast.

1. A management framework

- We advocate identification and designation of a Koala Management Area (KMA) for the coastal area between Brunswick Heads and West Byron for the purposes of directing any future CKPoM, the intent to focus and direct management actions appropriately.

- The designation of a northern KMA should be considered, the intent to encourage recolonisation of Billinudgel Nature Reserve and surrounds, with management to be cooperatively implemented by Byron and Tweed Shire Councils and OEH.

- The designation of a southern KMA should be considered, in order to recognise high quality habitat potential and the likely presence of small resident population(s) in the Broken Head area.

- Any KMA should encompass those lands containing currently identified source populations, larger habitat blocks, areas of high-quality potential koala habitat and key linkage areas.

- The primary objective of any KMA should be the survival, in perpetuity, of a free-ranging koala population within the Byron Coast.

- Any CKPoM should identify the role of the Byron Coast in encouraging and maintaining the current trend of population expansion across the BLGA as a whole.

2. Mitigation of threatening processes

- There is a need to develop effective habitat protection measures that can be enacted under the auspices of the CKPoM, in order to address any potential for the further fragmentation and/or loss of koala habitat within the planning area. Preparation of a Tree Preservation Order (TPO) to facilitate the protection of high-quality koala habitat and/or individual preferred koala food trees should be considered.

- There is an urgent need for the investigation of measures to effectively reduce the incidence of road-strike at blackspots identified herein at key locations with particular emphasis on major interchanges associated with the Pacific Highway.

- There is a need to be aware of the potential for increased road-strike with the progression of development adjacent to Ewingsdale Road.

- There is a need to seek creation of additional opportunities for koala movement across the Pacific Highway that offer greater potential for safe passage of koalas and to achieve meaningful east-west connectivity, with particular emphasis on the Tyagarah area.

- There is a need, in conjunction and coordination with measures being implemented on the Tweed Coast, to address the issue of fire in Billinudgel Nature Reserve and surrounds so as to increase the suitability of these areas for supporting koala populations in the future.

- There is a need to increase awareness regarding the impact of dog attack on koala populations in urban and peri-urban areas.

3. Planning considerations

- There is an urgent need to identify and support the strategic establishment of effective linkages to facilitate to the greatest extent possible, the movement of koalas between currently isolated population cells. Linkage areas should be afforded an accordingly high level of importance and protection.

- There is a need to support strategic bushland regeneration for areas of koala habitat with a view to increasing the amount of high-quality habitat available, with a focus on those areas within currently-occupied areas. The overall aim being a reduction in the extent of habitat fragmentation and invasion by weeds that inhibit natural regeneration.

- Development of offset strategies as well as incentives to encourage landholder participation in these processes will be of utmost importance in the achievement of these objectives.

- In the development of the CKPoM's planning provisions, there is a need to not only recognise currently occupied areas as *core koala habitat* and implement management accordingly, but also for areas of high quality koala habitat to be afforded the highest level of importance and protection.

- There will be a need for adoption of a standard Development Control Plan to ensure that all future developments in the vicinity of the remaining areas of koala habitat and/or any resulting KMA consistently result in implementation of 'best-practice' koala-friendly planning measures.

- In accord with the above we consider that there should also be provision for progressive amendment (where such provisions exist) of any currently approved KPoMs so as to ensure consistency with any adopted DCP and/or CKPoM standard.

- There is a need to develop "minimum data set" assessment standards to ensure that a high standard of habitat assessment by ecological consultants is maintained and that it is this level of assessment that informs development and future planning on the Byron Coast.

- There is a need to develop long-term monitoring programs to form part of the CKPoM in order to enable the tracking of the success or otherwise of the above recommendations and the plan and their influence on the status of the Byron Coast koala population.

4. General recommendations

- We suggest that further targeted field sampling be carried out at the western edges of currently occupied habitat, in order to locate and define the koala metapopulation boundaries in these areas with greater certainty.

References

References

Allen, C. and Phillips, S. 2008. Grid-based SAT (RGB-SAT) sampling for the purposes of identifying areas being utilized by koalas in the South-east Forests of NSW. Project update & future directions. Unpublished report to NSW Department of Environment and Climate Change.

Bale, C. L. 1996. *Eucalypts and Angophoras of the North Coast New South Wales. A key to the indigenous species.* Department of Botany, University of New England, Armidale.

Biolink. 2005. North Hawks Nest Koala Plan of Management. Working draft No. 1. Unpublished report. Biolink Ecological Consultants.

Bryan, B. A. 1997. A generic method for identifying regional koala habitat using GIS. *Australian Geographical Studies* **35**(2):125-139

Callaghan, J. McAlpine, C., Mitchell, D., Thompson, J., Bowen, M., Rhodes, J., de Jong, C., Domalewski, R. and Scott, A. 2011. Ranking and mapping koala habitat quality for conservation planning on the basis of indirect evidence of tree-species use: a case study of Noosa shire, south-eastern Queensland. *Wildlife Research* 38:89-102.

Department of Environment and Climate Change. 2008. *Approved Recovery Plan for the Koala* (*Phascolarctos cinereus*). Department of Environment and Climate Change, Sydney, NSW.

Department of Environment and Resource Management. 2009. *Koalas and Dogs. Fact Sheet. Koala Conservation*. DERM, Qld.

Ellis W.A., Carrick F., Lundgren P., Veary A. and Cohen B. 1999. The use of faecal cuticle examination to determine the dietary composition of Koalas. *Australian Zoologist* **31**:127-133.

Ellis, W. A. H., Melzer, A., Carrick, F. N. and Hasegawa, M. 2002. Tree use, diet and home range of the koala (*Phascolarctos cinereus*) at Blair Athol, central Queensland. *Wildlife Research* **29**:303-311.

Faulks, J. 1990. A preliminary investigation of the distribution of koalas and their potential habitat in the Tweed Shire, and implications for management. *Australian Zoologist* **27**(1&2):1-13.

Gall, B. 1978. Koala Distribution in New South Wales. p115 in Bergin, T. (Ed.) *The Koala – Proceedings of the Taronga Symposium*. Zoological Parks Board of New South Wales, Sydney.

Gordon, G., Hrdina, F. and Patterson, R. 2006. Decline in the distribution of the koala *Phascolarctos cinereus* in Queensland. *Australian Zoologist* **33**(3):345-358.

Hawkes, N. H. 1978. Identification and management of koala eucalypt trees in New South Wales. pp. 89-96 in Bergin, T. (Ed.) *The Koala – Proceedings of the Taronga Symposium*. Zoological Parks Board of New South Wales, Sydney.

Hindell, M. A. and Lee, A. K. 1987. Habitat use and tree preferences of koalas in a mixed eucalypt forest. *Australian Wildlife Research* **14**:349-360

Hindell, M. A. and Lee. A. K. 1990. Tree preferences of the koala. pp. 117–121 in Lee, A. K., Handasyde, K. A. and Sanson, G. (Eds) *Biology of the Koala.* Surrey Beatty and Sons, Sydney.

Hopkins, M. and Phillips, S. 2010. *Koala habitat assessment and monitoring program 2010*. Final report. Unpublished report to Bluesfest Pty Ltd. Biolink Ecological Consultants

IUCN SPS. 2010. *Guidelines for Using the IUCN Red List Categories and Criteria*. Version 8.1. Standards and Petitions Subcommittee.

Landmark Ecological Services Pty Ltd, Ecograph and Terrafocus Pty Ltd. 1999. Byron Flora and Fauna Study. Report to Byron Shire Council. Byron Shire Council.

Lee, A. K. and Martin, R. 1988. *The Koala – A Natural History*. University of NSW Press, Sydney, NSW.

Lunney, D., Matthews, A., Moon, C. and Ferrier, S. 2000. Incorporating habitat mapping into practical koala conservation on private lands. *Conservation Biology* **14**:669-680.

Lunney, D., Phillips, S., Callaghan, J. and Coburn, D. 1998. A new approach to determining the distribution of koalas and conserving their habitat: a case study from Port Stephens Shire on the central coast of New South Wales. *Pacific Conservation Biology* **4**:186-196.

MacKenzie, D. I. and Royle, J. A. 2005. Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology* **42**: 1105-1114.

Martin, R. and Handasyde, K. 1999. *The Koala: Natural History, Conservation and Management* (2nd ed). Australian Natural History Series, University of New South Wales Press, Sydney.

McAlpine, C. A., Callaghan, J. G., Lunney, D., Bowen, M. E., Rhodes, J. R., Mitchell, D. L. and Possingham, H. P. 2005. Conserving south-east Queensland koalas: how much habitat is enough? pp11-17 (Part II) in Siepen, G. L. and Jones, D. (Eds). *Proceedings of the 2005 south east Queensland biodiversity conference*. University of Queensland, Gatton Campus.

McAlpine, C. A., Rhodes, J. R., Callaghan, J., Bowen, M., Lunney, D., Mitchell, D., Pullar, D. and Possingham, H. P. 2006. The importance of forest area and configuration relative to local habitat factors for conserving forest mammals: A case study of koalas in Queensland, Australia. *Biological Conservation* **132**:153-165.

McAlpine, C. A., Rhodes, J. R., Callaghan, J., Lunney, D., P*E. tereticornis*son, A., Mitchell, D., Curran, T., and Possingham, H. P. 2007. *Planning Guidelines for Koala Conservation and Recovery-a guide to best planning practice.* University of Queensland and Australian Koala Foundation.

Melzer, A. and Lamb, D. 1996. Habitat utilisation by a central Queensland koala colony. pp93-101 in Gordon, G. (Ed.) *Koalas, Research for Management*. World Koala Research Incorporated, Brisbane.

Melzer, A., Carrick, F., Menkhorst, P., Lunney, D., and St. John, B. 2000. Overview, critical assessment, and conservation implications of koala distribution and abundance. *Conservation Biology* **14(3)**: 619-628.

Milledge, D. 1991. A survey of the terrestrial vertebrates of Coastal Byron Shire. *Australian Zoologist* 27:66-90.

Mitchell, P. 1990. The home ranges and social activity of koalas - a quantitative analysis. pp177-187 in Lee, A. K., Handasyde, K. A. and Sanson, G. D. (Eds) *Biology of the Koala* Surrey Beatty and Sons, NSW.

Moore, B. D. and Foley, W. J. 2000. A review of feeding and diet selection in koalas (Phascolarctos cinereus). *Australian Journal of Zoology* **48**:317-333.

Moore, B. D. and Foley, W. J. 2005. Tree use by koalas in a chemically complex landscape. *Nature* **435**:488-490.

Moore, B. D., Foley, W. J., Wallis, I. R., Cowling, A. and Handasyde, K. A. 2004. Eucalyptus foliar chemistry explains selective feeding by koalas. *Biology Letters* **1**(1):64-67.

Morand, D. T. 1994. Soil Landscapes of the Lismore – Ballina 1:10000 Sheet. Department of Land and Water Conservation, Sydney, NSW.

Morand, D. T. 1996. Soil Landscapes of the Murwillumbah – Tweed Heads 1:10000 Sheet. Department of Land and Water Conservation, Sydney, NSW.

Natural Resource Management Ministerial Council. 2009. National Koala Conservation and Management Strategy 2009-2014. Department of the Environment, Water, Heritage and the Arts, Canberra.

Phillips, B. 1990. *Koalas, the Little Australians We'd All Hate to Lose*. Australian Government Publishing Service, Canberra.

Phillips, S. 1999. *Habitat utilisation by the koala Phascolarctos cinereus – towards a new approach for effective conservation and management.* Ph.D. Thesis. School of Resource Science and Management, Southern Cross University, Lismore NSW.

Phillips, S. 2000a. Population trends and the koala conservation debate. *Conservation Biology* **14**(3):650-659.

Phillips, S. 2000b. *Tree species preferences of the Koala Phascolarctos cinereus as a basis for the delineation of management areas for recovery planning in New South Wales*. Unpublished report to the NSW Koala Recovery Team.

Phillips, S. 2002. *An Assessment of koala (Phascolarctos cinereus) populations of the Kings Forest area in a regional context*. Unpublished report to NSW Department of Environment & Conservation.

Phillips, S., Callaghan, J. and Thompson, V. 2000. The tree species preferences of koalas (*Phascolarctos cinereus*) inhabiting forest and woodland communities on Quaternary deposits in the Port Stephens area, New South Wales. *Wildlife Research* **27**:1-10.

Phillips, S. and Callaghan, J. 2000. Tree species preferences of koalas (Phascolarctos cinereus) in the Campbelltown area south-west of Sydney, New South Wales. *Wildlife Research* 27:509-516.

Phillips, S. and Callaghan, J. 2011. The Spot Assessment Technique: a tool for determining levels of localised habitat use by Koalas *Phascolarctos cinereus*. *Australian Zoologist.* 35(3): 774-780.

Phillips, S. and Forsman, H. 2005. *An ecological overview of koalas and their habitat on the Innes Peninsula, Port Macquarie NSW*. Unpublished report. Biolink Ecological Consultants.

Phillips, S. and Hopkins, M. 2010a. *Comprehensive Koala Plan of Management for Eastern Portion of Kempsey Shire LGA.* Unpublished report to Kempsey Shire Council. Biolink Ecological Consultants.

Phillips, S. and Hopkins, M. 2010b. SEPP 44 Koala Habitat Assessment Ewingsdale Road, West Byron (including Belongil Fields). Unpublished report to West Byron Landowners' Association. Biolink Ecological Consultants.

Phillips, S., Hopkins, M. and Callaghan, J. 2007. *Koala habitat and population assessment for Gold Coast City LGA*. Unpublished report to Gold Coast City Council. Biolink Ecological Consultants.

Phillips, S., Hopkins, M. and Shelton, M. 2011. Tweed Coast Koala Habitat Study. Unpublished report to Tweed Shire Council. Biolink Pty Ltd.

Phillips, S., Hopkins, M. and Warnken, J. Splines in the sand: Modelling metapopulation structure across the landscape to provide greater planning certainty for an arboreal marsupial (Koala Phascolarctos cinereus Goldfuss). Submitted to *Landscape and Urban Planning.*

Phillips, S. and Pereoglou, F. 2004. *Kings Forest Draft Koala Plan of Management*. Unpublished report. Biolink Ecological Consultants.

Phillips, S. and Pereoglou, F. 2005. *North Hawks Nest Draft Koala Plan of Management* Unpublished report to Crownland Developments. Biolink Ecological Consultants.

Queensland Government - Environment Protection Authority. 2006. *Nature Conservation (Koala) Conservation Plan 2006 and Management Program 2006-2016.* Queensland Government - Environment Protection Authority.

Reed, P. and Lunney, D. 1990. Habitat loss: the key problem for the long-term survival of koalas in New South Wales. pp9-31in Lunney, D., Urquhart, C. A. and Reed, P. (Eds). *Koala Summit – Managing koalas in New South Wales*. NSW National Parks & Wildlife Service, Hurstville NSW.

Rhodes, J. R., Thorsten, W., McAlpine, C. A., Callaghan, J., Lunney, D., Bowen, M. 2006. Modeling species' distributions to improve conservation in semi-urban landscapes: Koala case study. *Conservation Biology* **20**:449-459.

Smith, A. P. 2004. Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. pp591-611 in Lunney, D. (Ed.)

Conservation of Australia's Forest Fauna (2nd Ed). Royal Zoological Society of New South Wales, Mosman, NSW.

Starr, J. 1990. Management of koalas in an urban environment. pp319-321 in Lee, A. K., Handasyde, K. A. and Sanson, G. D. (Eds) *Biology of the Koala.* Surrey Beatty and Sons, NSW.

Strahan, R. and Van Dyck, S. (Eds.). 2008. *The Mammals of Australia*. New Holland Publishers, Sydney.

Taylor, B. D. and Goldingay, R. L. 2003. Cutting the carnage: wildlife usage of road culverts in north-eastern New South Wales. *Wildlife Research*. 30:529-537.

White, N. A. and Kunst, N. D. 1990. Aspects of the ecology of the koala in southeastern Queensland. pp148-151 in Lee, A. K., Handasyde, K. A. and Sanson, G. D. (Eds) *Biology of the Koala.* Surrey Beatty and Sons, NSW.

World Conservation Union Species Survival Commission. 1994. *IUCN red list categories*. Gland, Switzerland.

Appendix I

Location and activity levels recorded at SAT sites. Datum: GDA

Site	Easting	Northing	Activity Level	Site	Easting	Northing	Activity Level
BY2	558748	6822113	0.00	BY53	551720	6838057	23.33
BY3	559717	6822114	0.00	BY54	552683	6838162	76.92
BY4	558655	6823047	0.00	BY56	550827	6839142	16.67
BY5	559729	6823113	0.00	BY57	553747	6839044	100.00
BY6	556816	6823995	0.00	BY60	553771	6840108	9.68
BY7	557792	6824055	10.71	BY61	554689	6840064	0.00
BY8	558720	6824107	0.00	BY62	546723	6841136	78.57
BY10	557691	6825009	0.00	BY63	550496	6841058	16.67
BY11	558701	6825104	0.00	BY64	551699	6841085	3.85
BY12	559793	6825045	0.00	BY65	550593	6842056	0.00
BY14	558710	6826097	0.00	BY66	551803	6842208	43.33
BY15	558771	6827173	0.00	BY67	552680	6842099	13.79
BY16	559700	6827087	0.00	BY69	549826	6843097	0.00
BY17	558807	6828150	7.41	BY70	550715	6843220	0.00
BY18	559697	6827944	0.00	BY71	551703	6843208	0.00
BY19	557603	6828991	0.00	BY72	552644	6843029	0.00
BY20	558726	6829068	0.00	BY73	551712	6844109	0.00
BY21	559768	6829241	61.11	BY74	552703	6844010	0.00
BY24	557676	6830115	100.00	BY75	550707	6845054	0.00
BY27	560806	6830117	0.00	BY76	551871	6845052	0.00
BY32	560711	6831119	0.00	BY77	552700	6846162	0.00
BY34	557798	6832098	0.00	BY78	552720	6847097	0.00
BY35	561680	6832045	0.00	BY80	551727	6848081	0.00
BY36	553736	6833184	0.00	BY81	552750	6848083	0.00
BY38	556784	6833088	0.00	BY83	551540	6848958	0.00
BY39	552709	6835158	0.00	BY84	552710	6849062	0.00
BY45	556520	6835034	0.00	BY85	553745	6849094	0.00
BY46	553716	6836064	33.33	BY86	549702	6850121	0.00
BY47	554876	6836231	26.67	BY87	551752	6850067	0.00
BY49	551575	6837025	0.00	BY88	552680	6850055	0.00
BY50	553721	6837116	20.00	BY89	550876	6851022	0.00
BY52	550621	6838120	90.91				

Figures