

1 General Introduction

1.1 Conservation and Distribution of the Koala

The koala (*Phascolarctos cinereus* (Goldfuss 1817)) is well known both within Australia, and internationally. This recognition means the koala is economically important to Australia with its value to the tourism economy estimated to be \$1.1 billion per year (Hundloe and Hamilton 1997). The welfare of the koala is also important to many people, as evidenced by the number of conservation and carer groups specifically focusing on koalas, for example the Australian Koala Foundation (AKF) and the Port Macquarie Koala Hospital (Starr *et al.* 1990).

Flannery (1990) has argued, however, that as the koala is currently in a better position, from a conservation standpoint, than many other Australian mammals, that resources should be directed towards conserving species that are critically endangered. Although the conservation status of koalas varies from state to state within Australia (Martin and Handasyde 1999), the koala is classified as vulnerable in New South Wales (Threatened Species Conservation Act 1995). Furthermore, because of the koala's charismatic nature, it can act as a flagship species to raise awareness of the importance of habitat conservation amongst the community (Lunney *et al.* 1995, New 2000).

Koalas are found along the east coast of Australia from the southeast corner of South Australia, through Victoria, New South Wales and into Queensland (Strahan and Martin 1982). The koala has been grouped into three sub-species, with state boundaries roughly delineating the areas of transition. Koalas occurring in South Australia and Victoria are *P. c. victor*, in New South Wales they are *P. c. cinereus*, and in Queensland they are *P. c. adustus* (Strahan and Martin 1982).

1.2 Sub-species Differences

The three sub-species have been described on the basis of body size and fur colour, with *P. c. victor* being larger, and darker in colouration than *P. c. adustus*, and with *P. c. cinereus* being intermediate in both size and colouration (Melzer 1994). Although no alternative subspecies classification has been suggested, a number of authors have commented that the current classification may not reflect true genetic differences

(Cocciolone and Timms 1992, Worthington Wilmer *et al.* 1993, Melzer 1994, Takami *et al.* 1998). Furthermore, Takami *et al.* (1998) found three different koala mitochondrial cytochrome *b* genes, but these haplotypes were inconsistent with the current classification.

Houlden *et al.* (1999) examined haplotypes in the ≈ 860 bp mitochondrial DNA control region and concluded that the results were consistent with adaptation to a latitudinal cline in the koala. Melzer (1994), however, compared morphological data from koalas captured in Springsure (central Queensland) and southeast Queensland, and found that the Springsure sub-population ran contrary to the assumed latitudinal trend. Both body size and skull dimensions of koalas collected from Springsure were significantly greater than comparable measurements for koalas captured in southeast Queensland, whereas if the animals were following the latitudinal cline, the Springsure population should have been smaller (Melzer 1994).

Thus, there is currently some ambiguity about the appropriateness of the subspecies classifications for the koala, but nonetheless it is clear that there can be both morphological and genetic differences between local populations.

1.3 Energy

The koala has a metabolic rate that is lower than expected for its body size, based on a regression analysis of other marsupial species (Ullrey *et al.* 1981b), and has a low level of activity, sleeping or resting for approximately 19 hours per day (Smith 1979, Nagy and Martin 1985). However, the metabolic rate of the koala is not as depressed as for other folivores, such as the three-toed-sloth, *Bradypus variegatus* (Phillips 1990).

Unlike many arboreal animals, the koala does not normally utilise hollows or other crevices for shelter (Degabriele 1980); instead, the koala relies upon its fur for insulation. The insulative properties of the koala's pelage are excellent, and it is highly wind resistant. The dorsal surface is darker, and the fur in this area is thicker (Degabriele and Dawson 1979). In very cold or windy conditions koalas will curl up and become almost spherical (Lee and Martin 1988). In hot weather, koalas will often sprawl out on tree limbs, exposing the surfaces of their limbs. However, the main

method of heat loss is through panting (Degabriele and Dawson 1979) and licking of the forelimbs (Melzer 1994). Koalas in hot conditions may also move into the shade of a tree-trunk, or into vegetation with greater foliage cover (Lee and Martin 1988).

The low metabolic rate, excellent insulation, and long periods of inactivity allow the koala to survive on a low energy budget. Koalas also have few fat reserves, even when in good condition (Degabriele 1980, Ellis and Carrick 1992). This may have important ecological implications when the koala is disturbed, but it is unknown how long these fat reserves will last, so the capacity of koalas to survive disturbances is unclear. However, the low fat reserves indicate that koalas probably require a relatively constant supply of suitable food.

1.4 Nutrition

The koala is adapted to feed on eucalypt leaves, which are abundant in the forests along the east coast of Australia. However, eucalypt leaves provide poor nutrition, being high in fibre and low in available nutrients (Cork and Sanson 1990). As foliage is usually abundant, it's quality, and not quantity, that is crucial. The fastidiousness of the koala (Betts 1978, Harrop and Degabriele 1978, Pahl and Hume 1990, Hume and Esson 1993, Hume 1993, 1995) is consistent with the hypothesis that foliage quality is important, as is the 'wasting disease' which can affect koalas. The condition of animals affected by wasting disease can decline quickly, as if they were starving, and can result in death, although it is not uncommon to find that these animals actually had a full stomach (Wood 1978, Degabriele 1989). Degabriele (1989) proposed that the koala primarily relies upon leaf cell contents for its nutrition, and that it has specialised dentition to break open eucalypt cells. Koalas' teeth wear down over time, however, so that older koalas cannot efficiently break the leaf cell walls to release the more nutritious cell contents, and the animal faces death by starvation.

It appears that there may be threshold levels for leaf selection for water, relative nitrogen content (Pahl and Hume 1990), and essential oils (Hume and Esson 1993). The latter conclusion, however, depended upon subjective rankings by keepers on koala leaf-choice, and should therefore be treated with caution (Hume and Esson 1993).

Hume and Esson (1993) also found significant differences between leaf tips and mature leaves, with water content, nitrogen, total phenolics and the ratio of nitrogen to fibre being significantly higher, and fibre being significantly lower in leaf tips. The direction of these differences, except for the total phenolics, suggests that leaf tips would be nutritionally superior in quality to mature leaves. Other studies have also found differences between young and mature leaves in other *Eucalyptus* species (Majer *et al.* 1992, Abbott *et al.* 1993). Selection for young over mature leaves has been shown for other mammals (Degabriele 1981, Cork and Pahl 1984, Landsberg 1987, Kavanagh and Lambert 1990) as well as being observed in koalas (Betts 1978, Ullrey *et al.* 1981a).

This difference can have foraging and ecological implications. Seasonal variations in the production of new leaf growth (leaf flush) may occur, linked to climatic conditions (Melzer 1994). There is some indication that habitat utilisation may change in response to leaf flush (Hindell 1984, Melzer 1994), but responses of koalas to leaf flush are not well documented.

1.5 Water Balance

Although certain important leaf components may have threshold levels below which the browse may not be acceptable for koalas, there appears to be no simple single factor upon which fodder selection is based (Hume and Esson 1993). Leaf water content, however, seems to be particularly important (Eberhard *et al.* 1975).

The koala appears to obtain the water it requires from the water content of the leaves consumed and dew, or rain, present on leaves (Nagy and Martin 1985). In addition, koalas have rarely been seen to drink standing water in the field, although they will do so in captivity (Degabriele 1980).

Melzer (1994), in a Queensland study, found that during summer, subdominant males used woodland ridge *E. crebra* communities less, and open *E. tereticornis* forest communities in the valley floor more. This corresponded with a higher leaf water content in *E. tereticornis* than *E. crebra* (Melzer 1994), and highest levels of water flux recorded in summer, indicating a greater water intake being required in summer for thermoregulation (Ellis *et al.* 1995). That is, subdominant animals appeared to utilise

the *E. tereticornis* forest communities in summer in order to gain access to leaves with a higher leaf water content, despite the risk of encountering dominant animals (Melzer 1994). The importance of water is further emphasised by the finding of Gordon *et al.* (1990b) that in Queensland, koala population sizes are mainly limited by responses to annual rainfall via its effect on food abundance.

1.6 Plant Defences, Soil Fertility and Herbivory

Herbivory causes significant impacts upon plants. On average, more than 10% of plant production is consumed by herbivores, which is greater than the average amount of energy plants allocate to reproduction (Coley *et al.* 1985). Leaves, which are crucial for providing plants with chemical energy, can suffer significant damage from herbivores. Abbott *et al.* (1993) found that leaf damage after 12 months for *E. marginata* in Western Australia averaged 11.8%, and ranged from 9 to 25% of leaf area. Stone and Bacon (1994) studied *E. camaldulensis* in southern New South Wales and found that an average 13.9% of leaf area was lost to herbivores.

To deter herbivores, plants defend their leaves by using secondary metabolites, also called allelochemicals or antinutrients. The secondary metabolites found in eucalypt leaves are of two types: those which interfere with animal digestive processes (e.g. lignin), and toxins (e.g. tannins and essential oils) (Hillis 1966, Dement and Mooney 1974, Foley *et al.* 1987, Landsberg 1987, 1990a, b, Cork and Foley 1991, Cork 1992, McArthur and Sanson 1993, Stone and Bacon 1994, Hume 1997, Agar *et al.* 1998, Lawler *et al.* 1998).

The number of secondary metabolites occurring in *Eucalyptus* leaves is large. This means that the interactions between eucalypt defences and koala herbivory are complex and are not completely understood (Cork and Sanson 1990, Hume 1997). However, an important factor, on a broad scale, appears to be the impact of abiotic factors upon eucalypts, which is discussed below.

1.6.1 Resource-Availability

Plants vary in their relative investment in defensive compounds (Cork and Foley 1991). Although the factors influencing investment in defences against herbivores are

numerous and hard to differentiate, the “resource-availability” hypothesis proposes that plant species adapted to living in nutrient-poor environments will have higher relative investments in antiherbivore defences than species from nutrient-rich environments (Coley *et al.* 1985). The reasoning is that the cost to replace resources lost to herbivory for species in nutrient-poor environments is greater than for species living in higher nutrient environments. Thus, greater antiherbivore investment for species adapted to nutrient-poor environments allows these species to maximise their production, albeit at a lower level than can be achieved by species adapted to environments with a higher availability of nutrients (Coley *et al.* 1985).

Cork (1995) found that foliage polyphenols, defensive compounds against herbivores, increased for *Angophora floribunda* and 18 species of *Eucalyptus*, when soil nutrients decreased. Thus, the nutritional quality of these plant species for folivorous marsupials declined as soil fertility decreased, which is consistent with the resource-availability hypothesis.

If the resource-availability hypothesis is correct, the density of folivorous mammals should also be positively related to the soil fertility, through the intermediating reactions of plants to soil nutrient levels. Braithwaite *et al.* (1984) investigated the relationships between faunal densities, foliage nutrients and soil parent materials at Eden, NSW, and found that more arboreal marsupial species and individuals were concentrated in communities rich in foliage nutrients, and these plant communities tended to occur on higher nutrient soils.

There are also marked differences in koala population densities, with densities being reported from a low of 0.005 koalas ha⁻¹ (Melzer & Lamb 1994), to a high of 8.9 koalas ha⁻¹ (Mitchell & Martin 1990, see Chapter 3 introduction for more detail on koala densities). Some authors have suggested that soil fertility is an important determinant of habitat quality for koalas (Cork *et al.* 1990, Cork and Braithwaite 1996), and this may account for much of the observed variation in koala population densities. However, other factors, such as climate, are also important (Gordon *et al.* 1990b).

1.7 Social Behaviour

Koalas are usually solitary (Mitchell 1990b). However, only socially dominant males appear able to maintain a home range with access to females (Mitchell 1990a, 1990b). Koalas are territorial with the home range being scent marked from the sternal gland, and possibly urine (Smith 1980b, Thompson and Fadem 1989, Mitchell 1990a). Vocalisations are also used to communicate, and bellows probably function as a general broadcast vocalisation, and are used mainly by males (Smith 1980a).

With regards to social behaviour, there appear to be two seasons of approximately equal duration: the breeding season from October to March and the non-breeding season from April to September (Mitchell 1990b). During the breeding season vocalisations (Smith 1980a), aggression (Smith 1980d), and sexual behaviour (Smith 1980c) are more common and adult males move more frequently and have larger home ranges (Mitchell 1990b). These changes in behaviour enhance a male's chance of encountering females, and for females, it enhances their chances of mating with a dominant male (Mitchell 1990b).

To be able to compete for females in an established population, males must be of sufficient body size, as a greater body size is advantageous in fights for dominance. As body size is related to the age of the koala, males must generally be at least four years old to compete for a home range and to gain access to females (Martin and Handasyde 1990a, Mitchell 1990a). This may result in a bimodal population structure for males (Gordon *et al.* 1990a), with mature, socially dominant animals utilising optimal habitat, and juvenile, subordinate individuals dispersing into suboptimal habitat (Gall 1980, Gordon *et al.* 1988). A study at Blair Athol in Queensland, Ellis *et al.* (2002), however, found that 'resident', presumably dominant males, did not have any advantage over 'transient' males in siring offspring. Further research is needed to ascertain whether this is true of other populations.

1.8 History

Broad trends in koala numbers may be discerned through naturalists' reports (Strahan and Martin 1982, Lee and Martin 1988, Phillips 1990), and these indicate that koala numbers were probably low at the time of white settlement, due to hunting pressure

from Aborigines (Home 1808 and Gould 1863, cited in Strahan and Martin 1982). As whites progressively colonised Australia they disrupted the Aborigines' traditional existence and the hunting pressure on the koala eased. This relaxation allowed koala numbers to increase, until a fur trade was established in the 1880s to 1920-30s (Pearse and Eberhard 1978, Melzer *et al.* 2000). The harvesting of koalas for fur appears to have been intensive, and significantly reduced koala numbers until they were protected. It is difficult to estimate the number of koalas killed, as records from this period are not reliable. For example, some hunters listed koala pelts as being "wombat skins", after bans on the hunting of koalas were imposed (Phillips 1990). However, although an accurate estimation is not possible, the total number of koalas killed is thought to have been well in excess of 2-3 million, and the koala probably became extinct in most locations in Victoria and South Australia (Phillips 1990).

Reintroduction of koalas to mainland Victoria and South Australia occurred after this period, from island colonies, which were established from only a few individuals. This is reflected in the lower genetic variation of Victorian and South Australian populations compared to Queensland and New South Wales (Taylor *et al.* 1991, Coccoione and Timms 1992, Timms *et al.* 1993, Gale *et al.* 1995, Houlden *et al.* 1995).

The other major impact on koalas has been the extensive clearing of forests (Pearse and Eberhard 1978, Carrick 1990, Hume 1990, Pahl *et al.* 1990, Reed and Lunney 1990, Smith and Smith 1990, Starr 1990, Faulks 1991, Martin and Handasyde 1999, Melzer *et al.* 2000, Phillips 2000). Graetz *et al.* (1995) used satellite imagery to estimate that, Australia wide, 33-92% of forests where *Eucalyptus* is the dominant overstorey species has been cleared, depending on the forest type.

1.9 Threats to Koalas

Continued clearing is the greatest threat to koalas, and clearing rates within New South Wales and Queensland are particularly high, estimated at 150,000 and 300,000 ha year⁻¹ in each state respectively (Glanzig 1995, cited in Melzer *et al.* 2000). Although clearing is the greatest concern, there are other threats to koalas, which include overbrowsing, drought, fire, habitat fragmentation, mortalities due to vehicles and dogs, and chlamydial infections.

Overbrowsing is associated with high koala densities, where koalas consume more foliage than the food trees can sustain, and many subsequently perish. Overbrowsing has primarily been reported from Victoria and South Australia (Martin 1985a & b, Mitchell *et al.* 1988, Robinson *et al.* 1989, Copley 1994), though it has also been reported in New South Wales (Frith 1973, Gall 1980).

Droughts significant enough to affect koala populations have only been reported from Queensland. Gordon *et al.* (1988) conducted a study in the summer of 1979-80 during drought and heatwave conditions in Queensland. They found that koalas living near permanent water-holes had good body condition and a low mortality rate, but that a population crash, mainly consisting of juvenile animals, occurred in locations where permanent water-holes were not present. Gordon *et al.* (1988) considered that this type of event could reduce koala population sizes to those occupying optimal habitat, with a slow increase in population size after the disturbance, and with animals again dispersing into sub-optimal habitat until the next disturbance event.

Little information exists about the effect of fire on koalas. Despite this, the Water-board and Forestry Commission considers that the effects of fuel-reduction control burns programs have minimal impacts, and are advantageous to koala populations in the longer term as they reduce the intensity of wildfire events (Currans *et al.* 1990, Tilley and Uebel 1990, Faulks 1991, Ridley 1993). Frequent burning may, however, have caused the local extinction of koalas in some coastal areas of South Gippsland in the early 1900's (Martin 1983, cited in Martin 1989). Large, intense wildfire events are a greater threat in the short term, although it is possible for koala populations to survive these fires. Robinson *et al.* (1989) reported that a koala population survived the April 1980 and February 1983 Ash Wednesday bushfires in the Adelaide Hills.

Habitat fragmentation tends to break up a population into smaller subsets. As smaller populations have a greater risk of being lost (see section 7.1.2), this can increase the extinction risk for a regional population. The impact of fragmentation of habitat appears to increase with isolation. This is illustrated by comparing two studies conducted within New South Wales. In Warringah shire, Sydney, a koala population located on Barrenjoey Peninsula became isolated by urban expansion. The estimated population declined from 123 in the 1970's to 8 in 1989 (Smith and Smith 1990).

Habitat loss was low, although the tree species composition may have changed over this period. Hence, Smith and Smith (1990) concluded that the population decline was due to the isolation of the colony. This contrasts with the Tucki Tucki nature reserve, which was studied from 1972 to 1976 (Gall 1980). This reserve was only 4ha in size, but the adult population was steady at around 11-13 adult residents. The individuals making up this population varied, and most young dispersed, indicating that the reserve was not isolated from other habitat.

Mortalities caused by vehicles and dogs can be high around urban environments and freeways (Butler 1978, Starr 1990, Summerville 1990, Prevett 1991, 1993, Le Page 1993). Koala fatalities caused by vehicles may be concentrated at certain ‘black spots’ along roads (Prevett 1993, section 4.1.3.2). Harassment of koalas by dogs may also disrupt movement patterns, as the koala may not be able to descend until the dog leaves, and this may cause some stress (Prevett 1991).

Infection by chlamydial bacteria, which appears to be widespread throughout koala populations (Lee and Martin 1988), can reduce condition, and the two main clinical symptoms are corneal conjunctivitis and urinary tract infection. More serious, however, is the fact that chlamydial infection can cause infertility in female koalas, and this can reduce fertility rates within populations (Obendorf and Handasyde 1990, see section 4.1.3.3).

1.10 Are Human Impacts on Sydney Koalas Increasing?

The area investigated in this study was close to Sydney, a major metropolitan area. The human population in areas where koalas occur (see section 7.1.1) increased between 1986 and 1996 (Table 1.1). Notably, the human populations in those LGAs with large numbers of known koalas: Campbelltown, Wollondilly and Wingecarribee LGAs, increased, respectively, by 18.5%, 30.5% and 34%, from 1986 to 1996 (Table 1.1). Given these large increases in human populations it is therefore reasonable to assume that impacts upon koalas have increased, and that as the human population continues to grow, the pressure will continue to increase. Thus, there is a need for good koala management to control increasing impacts in the study area, and this management should be based on good ecological data, which this study addresses.

Table 1.1. Increase in human populations from 1986 to 1996 for Local Government Areas in the study area where koalas were found. Data for 1986 are from Hugo (1992) and for 1996 from Australian Bureau of Statistics (2000).

LGA	1986	1996	% Increase
Blue Mountains	63866	72506	13.5
Campbelltown	121297	143773	18.5
Hawkesbury	43629	57381	31.5
Liverpool	93215	120197	28.9
Mulwaree	4923	5625	14.3
Oberon	3845	4608	19.8
Sutherland	175191	194105	10.8
Wingecarribee	28187	36777	30.5
Wollondilly	24928	33413	34.0
Wollongong	167863	177009	5.4
Total	726944	845394	16.3

1.11 SEPP44

State Environment Planning Policy 44 (SEPP44) is a legal instrument which seeks to use the koala's preference for certain tree species to identify, assess and control development within koala habitat in listed New South Wales council areas (Anon 1995).

For case by case development applications affecting remnant vegetation >1ha in size, councils are required to follow a three-step process. Step 1 is to assess whether the land is "potential koala habitat". If the land meets the criteria for potential koala habitat, step 2 is to assess whether the land is "core koala habitat". If the land doesn't meet either the potential, or core koala habitat definitions, then council may approve the development. If, however, the land is core koala habitat then step 3 is for a plan of management to be prepared which *"aims to encourage the proper conservation and management of areas of natural vegetation that provide habitat for koalas"*, before development approval may be given (Anon 1995).

Potential koala habitat is defined in SEPP44 as: *"Areas of native vegetation where the trees of the types listed in Schedule 2 constitute at least 15% of the total number of trees in the upper or lower strata of the tree component"* Anon (1995).

Core koala habitat is defined in SEPP44 as *“An area of land with a resident 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”* Anon (1995).

As well as providing for assessment of development proposals on a case by case basis, SEPP44 also allows a Koala Plan of Management (KPoM) to be prepared for all, or part, of a council area. To prepare a KPoM the land to which it applies should be surveyed to identify potential and core koala habitat areas. A plan should then be prepared which includes core koala habitat in environmental protection zones and has provisions to control development of such land. Consideration should also be given to preparing a development control plan for land that adjoins core koala habitat (Anon 1995). Effectively, this means as well as applying on a case by case basis, that a council may prepare a KPoM for the whole council area, thus clarifying which areas are potential and core koala habitat.

Prior to this study, there were anecdotal reports of koalas in the Sutherland shire, which is not included under SEPP44. Thus, there were concerns as to whether, in its current form, SEPP44 was appropriate to control impacts on koalas in the Sydney region, and in chapter seven I make recommendations to improve this important legislation.

1.12 Low Density Koala Populations: Reasons for a Paucity of Information

Despite the wide range in koala population densities, most of our current knowledge of koala ecology comes from higher density populations due to the difficulties of researching low density populations (Martin and Handasyde 1999). Information about low density populations is important as these types of habitats cover large areas, and thus may constitute large populations, despite the low density of animals. Only relatively recently have some researchers begun to look at low density koala populations (White and Kunst 1990, Close 1993, Melzer 1994, Melzer and Lamb 1994, Jurskis and Potter 1997). Thus, some information is now available about koalas in low density populations, but relatively little information has been published on the health, breeding success, movements and tree use of animals from these populations, and there

remain difficulties in the application of koala survey methods to low density populations.

A number of survey methods have been used to search for koalas (see sections 3.1.2 and 3.1.3), but there remain logistical problems in locating koalas. The difficulty in detecting animals may be due, at least in part, to Aboriginal predation (see section 1.8). That is, human predation may have produced a selective pressure for koalas to be difficult to detect by humans. The solitary nature of the koala (see section 1.7) also means animals must usually be located individually.

1.13 The Value of the Study Populations

The populations investigated in this study were to the south and west of Sydney, a major metropolitan area of approximately 3.7 million people (Australian Bureau of Statistics 2000). Furthermore, in regions where koalas occur the human population is increasing (see section 1.9). Therefore, there are impacts from the large human population already present, as well as pressure for further development.

Genetically, the koala population in the region has been found to constitute an independent unit from fourteen other Australian populations based on mitochondrial analysis (Houlden *et al.* 1999). It is important to maintain genetic diversity, which helps to prevent abnormalities from becoming commonly expressed (Emmins *et al.* 1996), and allows populations to survive environmental change (Frankham 1996). Thus, the koala population in the region is facing considerable pressures and its genetic variability should be conserved to enhance the long-term viability of the koala. To do this, knowledge of the koalas' habits, preferences and behaviour in the region is required, and such information was gathered in this study.

1.14 Objectives

The objectives of this study were:

1. To develop and evaluate search methods applicable to low density koala populations (Chapter 3).
2. To review the quality and usefulness of community reports of koala sightings (Chapter 3).

3. To use appropriate search methodologies to investigate the distribution of koala populations in the southern and greater Sydney regions (Chapter 3).
4. To develop a database to store public sightings, historical reports, capture and radiotracking data (Chapter 3).
5. To locate koalas for subsequent capture and data collection, and to place radiocollars on selected animals, which would also facilitate monitoring the success of females in raising young to independence (Chapter 4).
6. To follow the diurnal movements of koalas via radiotracking, and to investigate koalas' home ranges (Chapter 5).
7. To investigate koala tree usage and preferences (Chapter 6).
8. To make management recommendations for the study area (Chapter 7).
9. To review the applicability of SEPP44 to the study area, and, if required, to make recommendations for improvements to this legislation (Chapter 7).

2 Site Characteristics

2.1 Two Study Regions

During the course of this study, reports of koala sightings were collected from the community, with most reports being received from the Campbelltown and Sutherland areas. These reports sometimes allowed opportunistic captures and fitting of eartags and radiocollars to captured animals. As a result, I refer to two study areas, or regions: the southern Sydney region, which includes the Campbelltown and Sutherland areas, and the greater Sydney region, which yielded fewer community reports and captures, and was not used for radiotracking (Fig. 2.1).

Image unavailable due to copyright restrictions.

Please refer to print copy

The southern Sydney region is approximately 100km long and 50km wide (Fig. 2.1). Most sighting and capture data came from this region, and all radiotracking was conducted in this region, close to Campbelltown.

The greater Sydney region extended to approximately 50km north, 100km south, and 120km west of the Sydney city centre, but excluded the southern Sydney region (Fig. 2.1). This region included all but the most widespread reports gathered during this study, but most survey effort in this region occurred between Bowral and Sydney.

As only sighting and some capture information was gathered from the greater Sydney region, relationships between soil parent materials and koala distribution, health and habitat were investigated in the southern Sydney region only. The geology of this region is discussed below.

2.2 Soils

The predominant parent material for soils in the southern Sydney region are Hawkesbury Sandstone (Fig. 2.2), which produces low fertility soils. In the western portion of the southern Sydney region, the more fertile Wianamatta group shales can be found (Ashfield and Bringelly shales). In some areas, small lenses of shale occur amongst areas that are predominantly sandstone. These shale lenses can be found in some of the northern and eastern areas of the southern Sydney region, in Darkes Forest and near Sutherland (Fig. 2.2). Narrabeen group shales are also found near the coast in the Helensburgh area, along the headwaters of the Hacking River, in the Royal National Park.

Thus the geology of the southern Sydney region can be summarised as being dominated by low fertility soils derived from Hawkesbury sandstone, with areas of more fertile shale or clay sediments primarily on the boundaries of the study area, and sometimes occurring as scattered lenses of varying size.

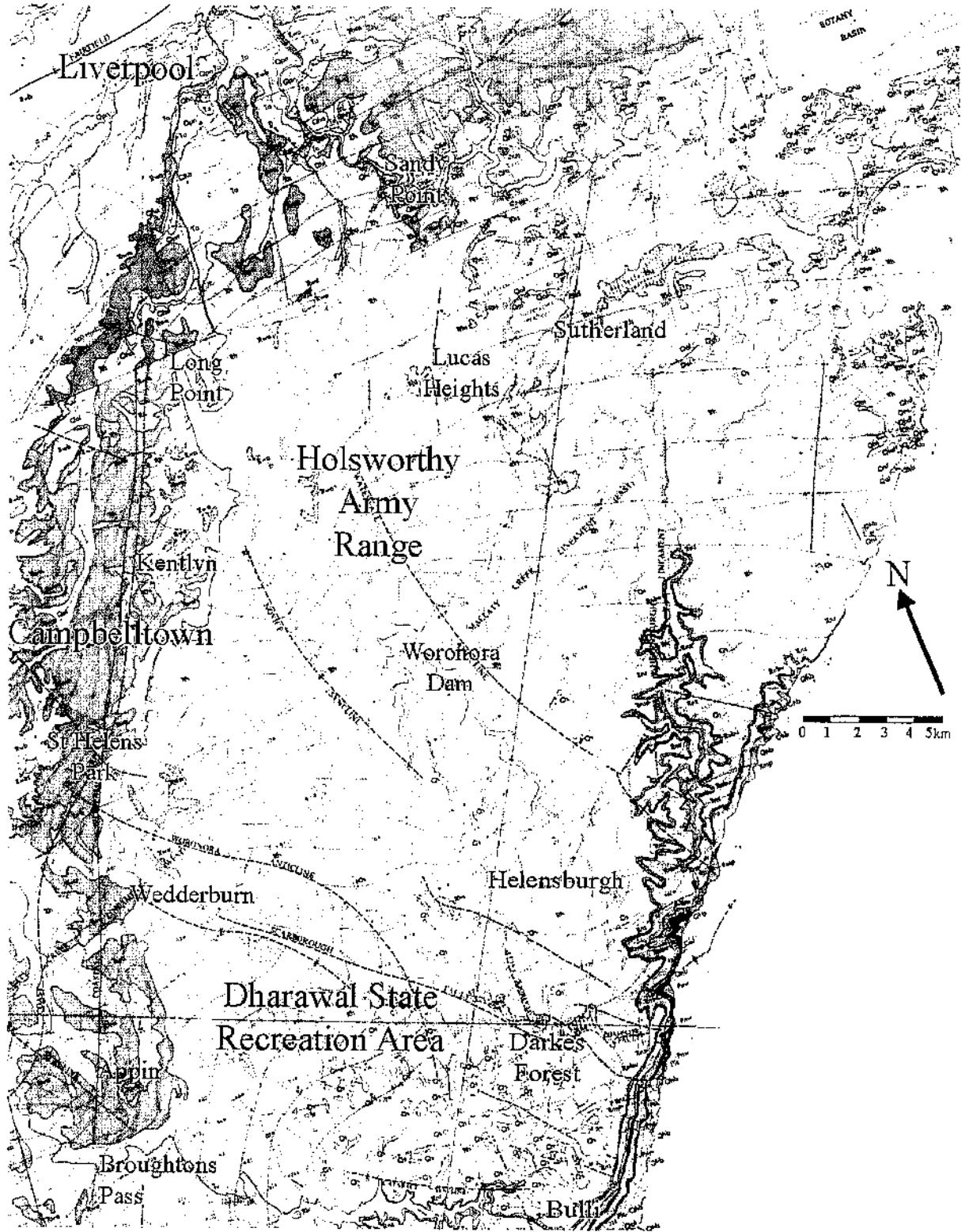


Figure 2.2. Geology of the southern Sydney region. See the following page for the legend. Acknowledgment: Original map courtesy of Department of Mine and Mineral Resources. Crown copyright ©. All rights reserved.

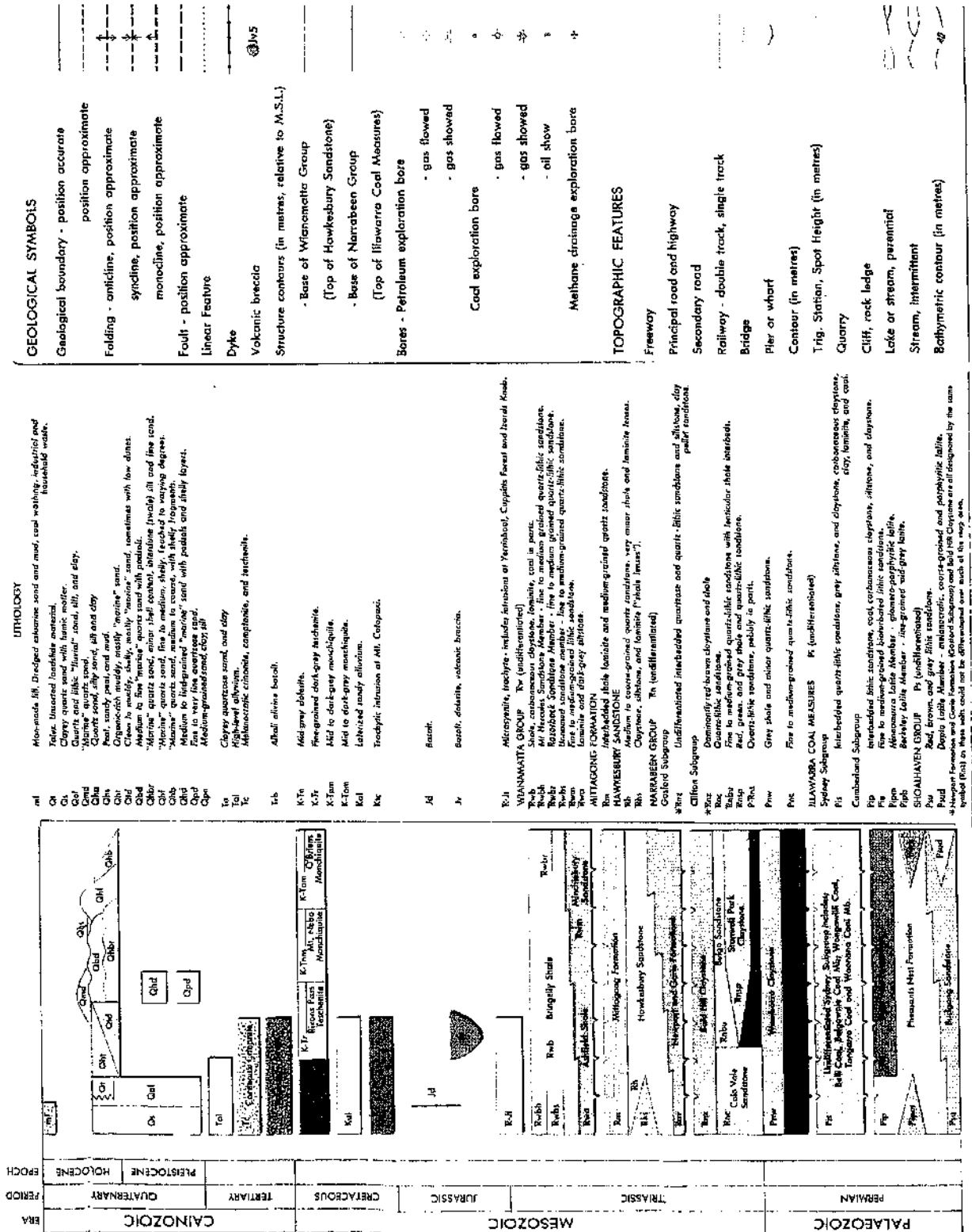


Figure 2.2 (continued). Legend for geology map of the southern Sydney region. Acknowledgment: Map courtesy of Department of Mine and Mineral Resources. Crown copyright ©. All rights reserved.

2.3 Rivers and Topography

In both study regions a number of waterways have created gullies (Figs 2.3 and 2.4). These gullies may be 100m or more deep, often with steep sides. Human habitation usually occurs on relatively flat areas on the ridgetops, rather than in the steep gullies.

In the southern Sydney region, the Georges river and its tributaries flow generally northwards, until turning east at the northern end of the southern Sydney region. Lake Woronora occurs amongst the headwaters of the Woronora River, which runs northeast until it joins the Georges River. The Hacking River also flows northeast through the Royal National Park to the suburb of Sutherland, where it turns east to become Port Hacking. The Cataract River flows northwest into the Nepean River, from the Cataract Dam, which occurs at the southernmost end of the southern Sydney region (Fig. 2.3).

In the greater Sydney region, the Cordeaux, Avon and Nepean dams occur to the south of the southern Sydney region and the rivers of the same names flow roughly north or northwest, all joining with the Nepean River. The Nepean River then winds northwest to join the Warragamba River, just below the Warragamba Dam in the Blue Mountains, then flows north and east to join the Hawkesbury River, which meets the sea north of Sydney (Fig. 2.4).

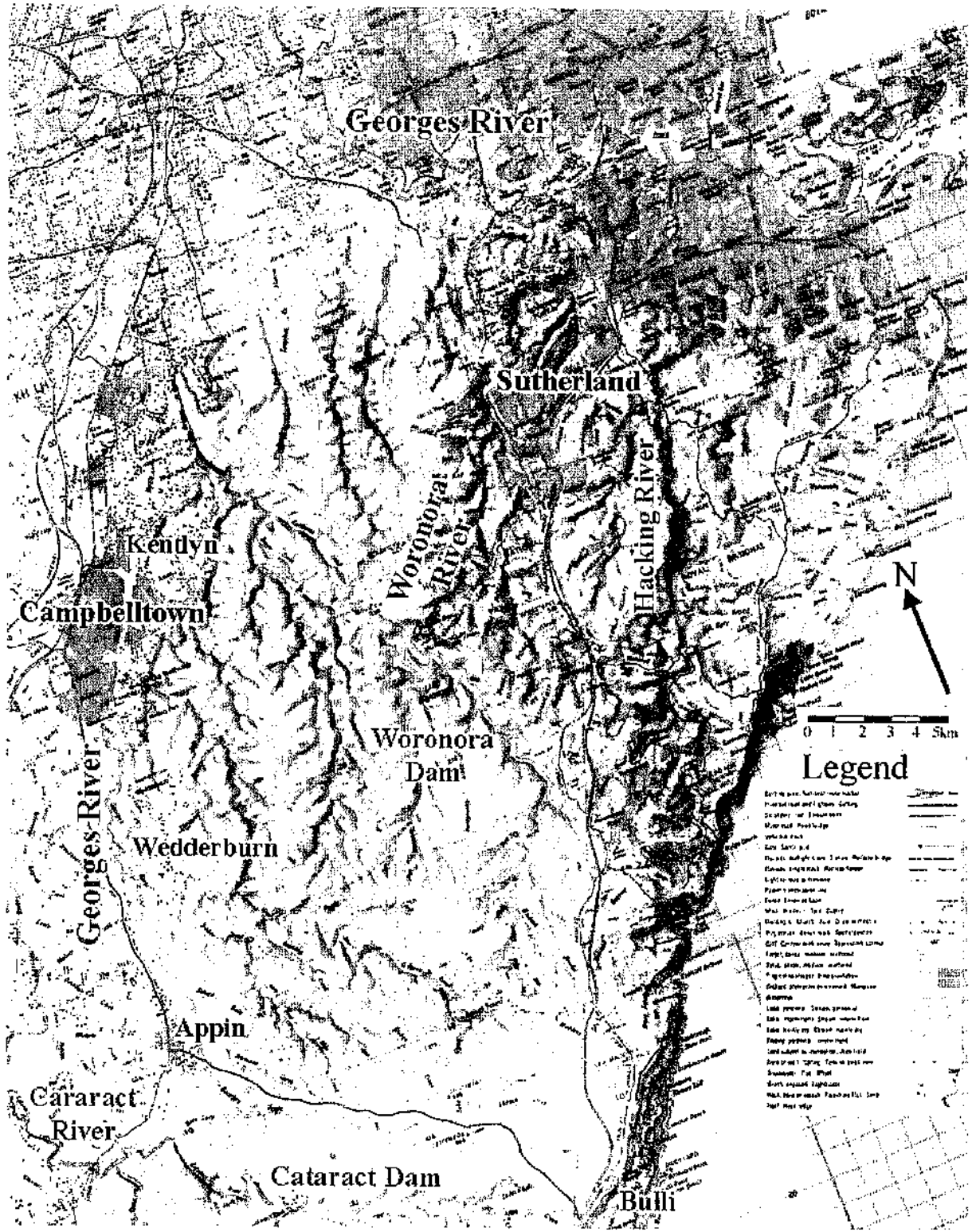


Figure 2.3. The topography of the southern Sydney region (note that the legend is enlarged for clarity on the following page). Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

Built-up area; National route marker	
Principal road and highway; Cutting	
Secondary road; Embankment	
Minor road; Road bridge	
Vehicular track	
Gate; Cattle grid	
Railway, multiple track; Station; Railway bridge	
Railway, single track; Railway tunnel	
Light railway or tramway	
Power transmission line	
Fence; Levee or bank	
Mine; Windmill; Yard; Quarry	
Building/s; Church; Ruin; Drive-in theatre	
Trig station; Bench mark; Spot elevation	
Cliff; Contour with value; Depression contour	
Forest, dense; medium; scattered	
Scrub, dense; medium; scattered	
Tropical rainforest; Pine plantation	
Orchard, plantation or vineyard; Mangrove	
Windbreak	
Lake, perennial; Stream, perennial	
Lake, intermittent; Stream, intermittent	
Lake, mainly dry; Stream, mainly dry	
Swamp, perennial; intermittent	
Land subject to inundation; Rice field	
Bore or well; Spring; Tank or small dam	
Breakwater; Pier; Wharf	
Wreck, exposed; Lighthouse	
Rock, bare or awash; Foreshore flat; Sand	
Reef; Rock ledge	

Figure 2.3 (continued). Legend for topography map of the southern Sydney region. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

Image unavailable due to copyright restrictions.

Please refer to print copy

2.4 Remnant Vegetation

In the southern Sydney region, much remnant vegetation is contained within the Holsworthy Army Range, Royal and Heathcote National Parks, Dharawal State Recreation Area, Woronora and Cataract Dam catchment areas (Fig. 2.4). A biodiversity study of the native vegetation in the Georges River catchment identified 17 vegetation communities on shale soils, and 8 on sandstone (NSW National Parks and

Wildlife 2000), but most vegetation occurs on soils derived from Sydney Sandstone. Vegetation on shale soils remains to the east of Campbelltown, although mostly on private property. Keith (1994) also investigated floristic structure within the O'Hares Creek catchment, a tributary of the Georges River.

In the greater Sydney region, much remnant habitat is contained in the Cataract, Cordeaux, Nepean and Avon dam catchments immediately to the southwest of the southern Sydney study region (Fig. 2.4). A large area of remnant vegetation is also contained within the Morton National Park, but due to clearing in the Robertson area, there may be insufficient linking vegetation left to permit koala movements between the Morton National Park and the water catchment areas to the northeast.

Immediately to the west of the Cordeaux, Nepean and Avon dams is the Nattai National Park, but this vegetation is separated by the Hume Highway, Southwestern Freeway and some housing development and farmland. The largest expanse of remnant vegetation occurs along the western side of the greater Sydney study region and includes the Blue Mountains National Parks and the catchment area for the Warragamba Dam. Large areas of remnant bushland also occur to the north of the greater Sydney study region, in, and between, the Ku-ring-gai Chase National Park and Parr State Recreation Area (Fig. 2.4).

The height of canopy vegetation ranged from 10-20m on ridgetops to 20-30m in gullies.

2.5 Local History

The settlement site of the first fleet, in 1788, was in Sydney cove, approximately 10km to the north of the southern Sydney study region (Forbes 1926). The European settlers set about clearing the native vegetation so that European farming techniques could be used. The city of "Campbell-town" was established in 1820, with land grants given to settlers on condition that the land was cleared (Campbelltown City Council 1995).

Shale-derived soils in the Sydney area were favoured for wheat farming until an infestation of wheat stem rust fungus in the 1860s, and led to a change to dairying and

fruit-growing (Benson and Howell 1990). Much of this farmland has now been used for housing development, although farming and orcharding still occurs to the west and southwest of Sydney.

It is difficult to estimate what the density of Aboriginal people would have been prior to European settlement, as introduced diseases, including smallpox, syphilis, tuberculosis and measles, appear to have caused the death of many Aboriginals, and to have devastated the populations by 1850 (Kohen 1995). However, the population in the Sydney region, including the Hawkesbury River and lower Blue Mountains, is estimated to have been between 4000 and 8000 (Kohen 1995).

The Aboriginal people in the southern Sydney region were primarily the Dharawal group. This group roamed along routes from Botany Bay, south to Nowra, and inland to Camden, depending on the seasonal availability of food (Liston 1988). Although local Europeans had generally good relations with members of the Dharawal tribe, the military did not, and reprisal killings eventually resulted in an expedition killing fourteen aboriginals at Appin in 1816. In 1845 magistrate John Chisholm reported that over the previous 5 to 10 years the number of the Dharawal group had been reduced from twenty to zero (Liston 1988).

The displacement or death of many of the local Aboriginal people is likely to have occurred in other areas in the greater Sydney region as well, which would have reduced the hunting pressure upon koalas. Hunting for koala fur by Europeans also occurred in the 1900s, and possibly earlier (Close 1993, Callaghan *et al.* 1998).

Despite the hunting until approximately 1910, prior to 1986 it was generally thought, except by a few individuals who had sighted them, that koalas had been locally extinct within the southern Sydney region for approximately 50 years (Close pers. comm.). Knowledge of the koala population became more widely known when a development at Wedderburn, a suburb to the south of Campbelltown, was approved. Roads were laid and named, telephone posts brought to the site and real estate lots were advertised for sale. However, there was spirited opposition to the development including a 22,000

signature petition, and considerable publicity (Dobson 1989, 1990, Sheppard 1990, McGill 1999).

In an effort to document the claims that a viable koala colony existed in the area, members of the Macarthur branch of the National Parks Association noted details of any koalas seen from 1986 to 1990 (Ward and Close 1998). A CSIRO study of the disputed area (Cork *et al.* 1988) utilised the sightings available at that time, vegetation data, and observations of pellets or scratches. Eventually, because of the opposition, the development was stopped and media attention subsided, apart from intermittent press commentary prior to this study.

2.6 Known Koala Populations

To the north of Sydney koala populations are known to exist in the Ku-ring-gai Chase National Park (Temple-Smith pers. comm. 1998), Barrenjoey Peninsula (Smith and Smith 1990), Yengo National Park and Parr State Recreation Area (Curtin and Lunney 1995a, b, Curtin *et al.* 2002). However, because these populations occurred outside of the focal area for this study, no data were gathered from these populations.

To the west of Sydney, koalas are known to exist in the lower Blue Mountains, although no sightings of females with young have been documented (Close *et al.* 2000). To the south, koalas are known to exist in the suburbs to the east of Campbelltown (Close 1993, Callaghan *et al.* 1998), and in the catchments of the Cataract, Cordeaux, Avon and Nepean Dams (Robinson 1985, Cork *et al.* 1988, Currans *et al.* 1990, Tilley & Uebel 1990). All studies concur that the density of koalas is low, and Close (1993) estimated the density of koalas in suitable habitat in the O'Hares Creek region, 7km to the southeast of Campbelltown, to be 0.1 koalas ha⁻¹.

This study sought to obtain information on the distribution of koalas in the two study regions, and health, and tree usage of koalas in the southern Sydney region. Such information is important for management of the koala, which is facing increasing pressure from human development in the Sydney region. Furthermore, given the lack of knowledge about low density koala populations, methods that can be utilised to investigate these populations were reviewed. There were problems to be overcome in

answering these questions, as well as some advantageous support from a local newspaper, which are reviewed below.

2.7 Problems Arising from the Characteristics of the Study Area

Research on koalas poses logistical problems due to the difficulty of capturing arboreal animals, the time and cost of radio-tracking studies (the usual method of monitoring captured koalas) and the difficulty of detecting koalas, especially at low densities.

The low density of the koala populations being investigated proved to be the most serious problem for this study. The low densities, combined with the cryptic nature of koalas, made them extremely difficult to locate and capture, prior to gathering information such as age, sex, condition and breeding status, and fitting radiocollars to selected animals for subsequent radiotracking.

Access to some localities, such as the Holsworthy Army Range, water catchment areas and National Parks was possible, but with restrictions. A greater problem was that traversing the steep gullies was extremely arduous. The terrain, and large home range sizes of the koalas, all hindered radiotracking.

2.8 Advantages of this Study

An advantage for this study, particularly in the southern Sydney study region, was support from a local Fairfax newspaper, *The Macarthur Advertiser*. The newspaper is delivered to all homes from Wedderburn to Glenfield and has a CAB circulation of 62 602 (at 7th August 1996). The newspaper supported the research through fundraising and a \$20,000 scholarship donation, and by printing a weekly column written by Steven Ward and A. Prof. Robert Close. The column always carried a contact number to report koala sightings, and provided an avenue for education of the public about koala biology. However, not all columns were about koalas, with some focusing on other species, or ecological concepts, that were relevant to the southern Sydney region.

This assistance had two benefits. Firstly, it allowed for continued publicity of the request for koala sightings, particularly within the Campbelltown shire. Secondly, it

allowed the public to be informed about the reasons for the research and the techniques used. Because of the public education, it was generally found that members of the public were supportive of the research program and were usually keen to help. This contrasts with other research where, despite benefits to the koala populations resulting from increased knowledge, members of the public oppose the research (S. Radford, pers. comm., see section 3.1.3.4).

This positive community response led to far greater numbers of sightings being gathered than would otherwise have been possible, and to reports of eartagged animals, allowing insights into the movements, including some long-range dispersals, of these animals.

3 Search Techniques

3.1 Introduction

3.1.1 Locating Koalas

Various techniques have been used to research the lives of koalas. These include techniques that do not intrude upon the koalas themselves, for example faecal pellet searches. Whilst useful, providing information on habitat and tree usage, these techniques provide limited information. Gathering of data, such as condition, health, sex, and age estimations, as well as the fitting of radiocollars, is possible only if koalas are located and then captured. This study sought to collect such data and thus required a method of locating animals.

Developing an appropriate search technique was particularly relevant for this project due to the logistical problems of studying low-density populations. The labour invested to locate animals from low-density populations is much greater than from middle to high-density populations, so it was important that the method used be effective. Also, techniques that prove effective for low-density populations are likely to be applicable to medium to high-density populations, but techniques appropriate for medium to high-density populations might not be viable for studying low-density populations.

A search technique may also allow an estimate of the population density, and if the distribution of the population is known, it can then allow an estimate of the population size. Techniques to estimate population size also exist, and these too were considered.

There is debate over appropriate survey techniques for detecting koalas (CSIRO 1997, Allen 2000), and for estimating koala numbers (Sarre 1999). To ascertain which techniques would be useful for locating koalas, and if possible to obtain density or population estimates, a literature review was conducted and the results are discussed below.

3.1.2 Techniques for Density Estimation

Caughley (1977) published a decision tree for deciding on a suitable census method (excluding mark-recapture techniques). Following this decision tree for the southern

Sydney region leads to “Counts on unbounded transects”, or distance sampling (Fig. 3.1).

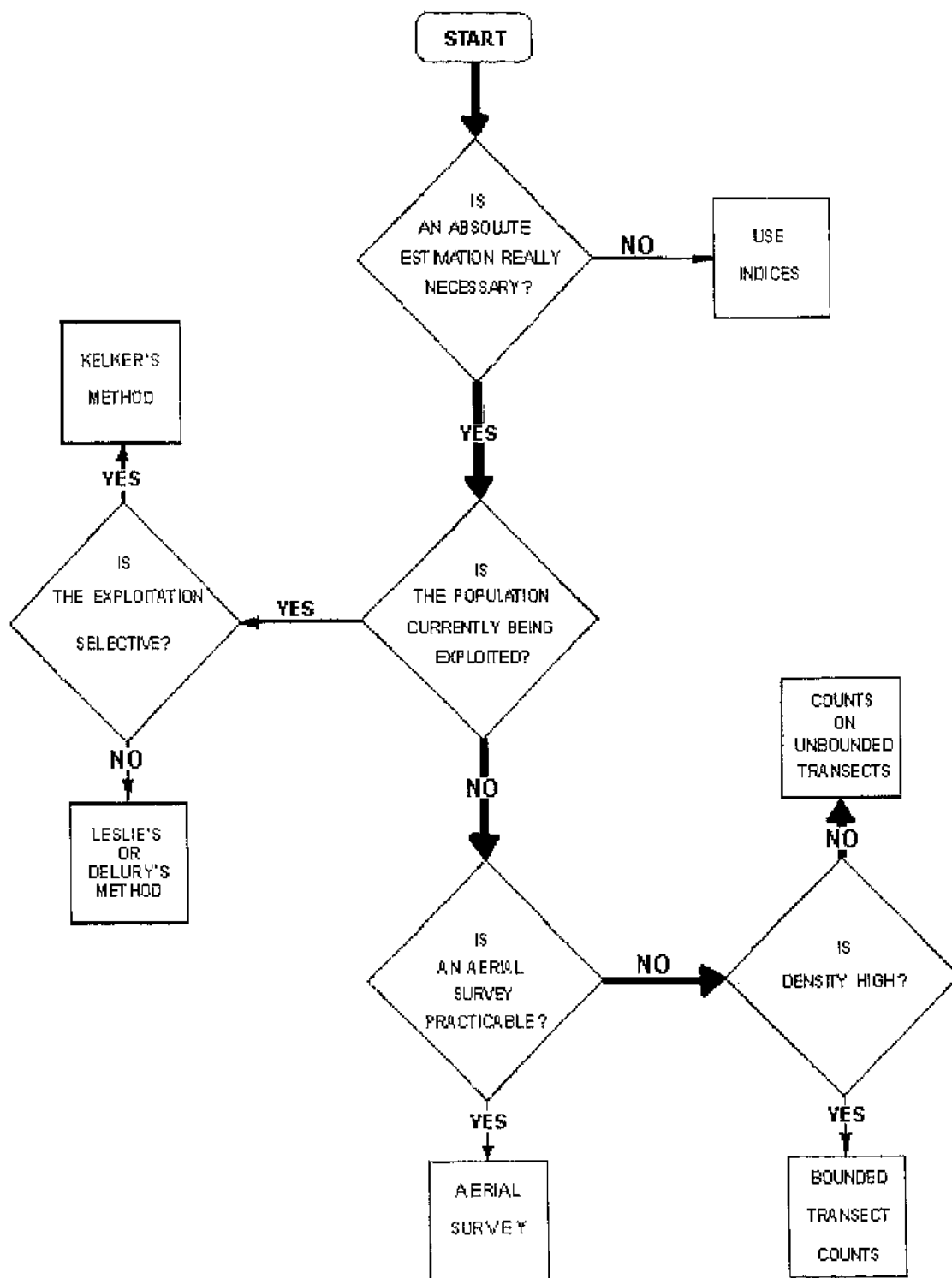


Figure 3.1. From Caughley (1977): the sequence of decisions by which a census method (other than a mark-recapture technique) is chosen. Bold arrows indicate the decisions taken for the southern Sydney region. Absolute density estimation is required to allow comparisons with other studies, the population was not being exploited, funds were not available for aerial surveys and density of the population in southern Sydney was low.

With this technique, the perpendicular distance from the transect line to animals encountered is recorded for transects of measured length. Once a number of transects has been conducted, a detection curve is constructed (Caughley 1977). An assumption is that animals immediately adjacent to the transect line have a 100% likelihood of being detected (Buckland *et al.* 1993). In addition, a minimum of 60 observations of animals is needed to construct this detection curve.

In the southern Sydney region, however, there are at least two distinct habitat types, ridgetops and gullies. Constructing the two detection curves would require 120 observations, which may be greater than the total population for the southern Sydney region (see section 3.3.13). Also, the probability of detecting koalas immediately adjacent to the transect line would not be 100%, as it is easy to walk directly underneath a koala without spotting it (pers. obs.). Finally, as koalas are cryptic, different observers could have unique detection curves.

Because of these problems, techniques used by other studies to estimate koala densities were reviewed in an attempt to find an alternative method for estimating density. The published density estimates range from 0.005 to 8.9 koalas per ha (Table 3.1). Two of these papers (Gall 1980, Mitchell and Martin 1990) do not give details of their search techniques.

The estimates of koala density differ by more than three orders of magnitude. The estimate by Close (1993) for suitable breeding habitat at Wedderburn, a suburb of Campbelltown, in the southern Sydney region, is in the lower range of these estimates (Table 3.1).

For those papers that provide details of the survey methodology used, there were five main approaches: (i) adaptations of the bounded transect method, (ii) counts over time on a delineated site, (iii) large quadrats, (iv) observing koalas disturbed by clearfelling operations and (v) using the mean home range size to estimate density.

The bounded transect method involves counting all animals observed within a set distance of a transect line. This set distance, depending on the circumstances, is usually relatively low. Gordon *et al.* (1990b) and Downes *et al.* (1997) do not describe the

width of the transect used, but Close (1993) counted animals within 20m of the transect line, and Taylor (2000) all animals within 10m of the transect line. The reason for surveying only a short distance from a transect line is because, in most situations, fewer animals are detected as the distance from the transect line increases. Thus, the assumption that 100% of animals within the transect area were detected, is less likely to be violated if the distance from the transect line is kept short.

Table 3.1. Published koala densities, the location of the population studied and the method used to estimate density. The search method used has been placed into a category. Studies classified as bounded transect used various modifications of this method as described by Caughley (1977). Delineated site consists of a defined site with counts over time. Large quadrat is a count of all koalas on a 1km² site. Clearfelling consisted of volunteers walking behind bulldozers clearing forest or woodland and counting all koalas. Home range consisted of converting an average home range size estimate to a density estimate.

Location	Density (koalas ha ⁻¹)	Method	Source
French Island, Vic.	3.9 – 8.9	No details provided	Mitchell & Martin (1990)
Shepparton, Vic.	8.62 - 8.85	Bounded transect	Downes <i>et al.</i> (1997)
Lismore, northern NSW	6.62 *	No details provided	Gall (1980)
Phillip Island, Vic	5.3	Delineated site	Sharpe (1980)
Kangaroo Island, SA	0.9 – 5.5	Delineated site	St John (1996)
Springsure, central Qld	0.23 – 4.36 †	Bounded transect	Gordon <i>et al.</i> (1990b)
Walkerville, Victoria	0.7 - 3	Delineated site	Martin (1985b)
Point Halloran, Qld	1.9 - 2.5 †	Delineated site	Hasegawa (1995)
Oakey, southern Qld	0.13 – 2.48 †	Bounded transect	Gordon <i>et al.</i> (1990b)
Lismore, northern NSW	0.5 – 2.1 †	Bounded transect	Taylor (2000)
Phillip Island, Vic.	0.95 – 1.8 *	Delineated site	Every (1986)
Brisbane Ranges, Vic.	0.7 – 1.6 †	Delineated site	Hindell (1984)
Redland Shire, Qld	0.3 - 0.46 †	Delineated site	White & Kunst (1990)
Springsure, central Qld	<0.02 - 0.4	Large quadrats	Melzer (1994)
Campbelltown, NSW	0.1 †	Bounded transect	Close (1993)
Springsure, central Qld	0.015	Clearfelling	Melzer & Lamb (1994)
Eden, southern NSW	0.006 †	Home range	Jurskis & Potter (1997)
Capella, central Qld	0.005	Clearfelling	Melzer & Lamb (1994)

* = A density estimate was not given in the source but was calculated from the size of the study area and the estimated population size for Every (1986) from the mean total population for Gall (1980).

† = These estimates do not include dependent young.

A modified version of the bounded transect method was trialed in this study, but was ultimately abandoned. This method consisted of a line of volunteers, spaced 10m apart, searching all trees between each person and the next. This meant that all trees in the transect were searched by two people, from different directions. Although volunteers

performed well during tests to see if they would detect either radiocollared koalas, or toy replicas of koalas, this method was abandoned because few animals were detected, despite a considerable search effort. Furthermore, many gully areas were too rugged for volunteers to traverse, and thus the technique could not be applied to these regions.

Delineated site studies are those which use a well marked site, and usually monitor population fluctuations over time by periodic recounts at that site. However, unless the site is very large, the number of animals detected for low density populations would be low, and a very large effort would be required to gather sufficient data.

A possible problem for both delineated sites and large quadrats is that, whilst the search is being conducted, koalas may move from the area still to be searched, into habitat which has already been searched, or vice versa. Every (1986), however, found that tagged animals were counted twice on only three occasions, out of 868 sightings of both tagged, and untagged, animals (the majority of sightings were of tagged animals). Movement of koalas during day counts is thus unlikely to be a significant problem for delineated site and large quadrat techniques.

A disadvantage for the large quadrat technique, however, is that a large area of habitat suitable for searching is required. Melzer (1994), for example, used 1km² quadrats. Furthermore, because of the size of the quadrats, a large search effort, usually requiring many searchers is required, and there is the possibility of missing some areas, or searching them more than once.

Whilst large areas of continuous habitat occur in the southern Sydney region, much of it is within the Holsworthy Army Range, where unexploded ordinance (i.e. bombs) is an issue. Furthermore, if a randomly selected 1km² quadrat included a gorge, even a large number of physically fit searchers would have difficulty in searching the site in one day.

Melzer and Lamb (1994) opportunistically utilised clearfelling operations to obtain estimates of 0.0149 and 0.0048 koalas ha⁻¹ for two sites in central Queensland. However, this technique is obviously limited to sites where clearfelling is occurring and is therefore of limited usefulness.

Jurskis and Potter (1997) used average Harmonic Mean home range estimates from koalas tracked in the Eden area (2 females, 5 males), to estimate koala density. They stated that their estimated home range size is equivalent to a density of 0.006 koalas per ha. However, there appears to be no consideration of the fact that male and female koalas can have overlapping home ranges.

Goldingay and Kavanagh (1993) also used home range size to estimate density, in their case for yellow-bellied gliders (*Petaurus australis*), at Waratah Creek, New South Wales. They did this by dividing the minimum convex polygon (MCP) home range size for a family group, by the number of gliders in that group. Goldingay and Kavanagh (1993) state that the MCP method was used as it “*included the apparently unused areas between the home ranges of adjacent glider groups*”.

As home range size estimates were available from this study (chapter 5), Goldingay and Kavanagh’s technique was used to estimate density. Although I had a low level of confidence in this estimate, because little information about the amount of overlap between individuals was available, I used the home range estimate for comparison against the modified bounded transect method (see section 3.3.13).

3.1.3 Survey Techniques to Investigate Koala Distribution

So far, only survey techniques to assess population density have been discussed and I now review other methods that can be used to investigate koala distribution in a region. These include (i) faecal pellet surveys, (ii) asterix method, (iii) pre-logging surveys, and (iv) community surveys.

3.1.3.1 Faecal Pellet Surveys

The Australian Koala Foundation uses a survey technique that involves faecal pellet counts (Phillips 1995, Phillips and Callaghan 2000). Presence or absence of koala faecal pellets under tree species is used to ascertain preference. GIS technology and vegetation layer overlays are then used to infer habitat quality for koalas.

This technique, and other faecal pellet methods, are now being widely used to help to determine the tree usage of koalas and thus to predict koala habitat quality. This

technique certainly seems to have advantages as it is non-invasive and faecal pellets can be more readily located than the animals themselves. However, I have some concerns about the methods used by the AKF and the conclusions drawn from their data.

Ellis *et al.* (1998) found a relationship between time of day and pellet deposition for free-ranging koalas, with most pellets deposited between 1800 to 2400 hours. Nagy and Martin (1985) observed six free ranging koalas near Walkerville, Victoria, and found that there were no clear-cut activity patterns, although feeding activity may have been more frequent just before sunset (1600-1900 h) and in mid-morning (0800-1000 h).

These studies indicate that a koala's feeding behaviour and peak periods of faecal pellet deposition do not necessarily coincide, and there is now evidence koalas can use separate fodder and roost trees (Melzer 1994, Sluiter 2000, Sluiter *et al.* 2002). Thus, in faecal pellet surveys, trees that are classified as "preferred" based on faecal pellet evidence might be used for shelter, rather than for browsing.

Another concern is breakdown of faecal pellets. A moth has been documented as using koala faecal pellets (Common and Horak 1994, Allen 1995). In addition, I have observed beetle larvae (Family Cleridae) feeding upon koala faecal pellets within the Campbelltown Local Government Area (LGA). Activities of these two insects will accelerate the breakdown of the faecal pellets, but the distribution and density of these insects within a region may vary, and therefore faecal pellet breakdown rates may vary. If higher breakdown rates were associated with the distribution of a particular tree species then this would artificially lower the preference rating for this species.

Rain, or moist conditions, can increase the breakdown rate of koala faecal pellets (Achurch 1989, pers. obs.). Achurch (1989) found that pellet breakdown rates of faeces placed in the field varied with microhabitat. The fastest breakdown rate occurred in moist rainforest and the slowest in exposed dry locations. Higher activity of the beetle larvae, and fungi, in the Campbelltown area, was also observed under moist conditions (pers. obs.). This variation in breakdown rates for faecal pellets should thus be documented over more than one season.

Furthermore, there is concern about application of the AKF's methodology to populations varying in density. Harris (1999a) stated, "*it is considered that the AKF methodology and characterisation of habitat may be appropriate in determining habitat utilisation of some high-density populations. However, it cannot be ruled out that the AKF methodology may possibly lead to inappropriate conclusions with regard to low-density populations and may not have absolute compliance with the present definitions of SEPP 44*".

3.1.3.2 Asterix Method

An opportunistic survey technique (asterix method) to delineate the area used by koalas when their presence is detected has been developed by the State Forests (Ridley 1993). In summary, this method uses the tree where the koala was detected as a centre tree, and transects 120 metres long and 20-30 metres wide are placed along the cardinal compass axes. All trees within the belt transects are inspected for signs of koala use (scratches, pellets, and koalas). If other signs of koala presence are detected, these trees are used as centre trees for further transects if the tree is >20 metres from the previous centre tree. This process is continued until no further centre trees can be detected.

This technique is designed to delineate, if present, an area regularly used by koalas, and to ascertain the level of koala use. Using the asterix method to investigate koala distribution throughout my large study regions would have been extremely labour intensive, and hence this method was not used.

3.1.3.3 Pre-logging Surveys

Ridley (1993) also outlines a protocol for koala surveying before timber harvesting, which in summary consists of: (a) a transect survey using 0.5m by 0.5m quadrats to search for faecal pellets, (b) spotlight surveys on foot along main roads, access tracks and fire trails and taped koala calls played twice for 3 minutes, with a 5 minute waiting period, (c) surveys by State Forests supervisor, and (d) subsequent searches by tree fellers. As with the asterix method, this technique was not utilised in this study because the large study regions meant that applying this technique would have been extremely labour intensive.

3.1.3.4 Community Surveys

As koalas are well known, can be easily recognised and mostly enjoy a favourable public attitude they are well suited to surveys which collect information from the community. Postal surveys have been used to investigate koala distribution, obtain historical information, and to indicate overall trends in koala numbers from a local to an Australia wide level (Table 3.2). Although postal surveys are often used to gather community sighting data, some studies have used community data gathered by wildlife carer or conservation groups (Cork *et al.* 1988, Le Page 1993, Moon 1995, Clulow 1996, Nattrass and Fiedler 1996, Koosmen *et al.* 1997). Community survey data for koalas are now so well accepted that the Department of Urban Affairs and Planning recommends that postal surveys be used by councils preparing a KPOM under NSW SEPP44 (Harris 1999b).

Postal surveys to collect community sighting data have been used since 1929, but became increasingly popular in the 1990s (Table 3.2). However, this technique is biased in its coverage (Reed *et al.* 1990, Harris 1999b). When reports are collected from the public, those areas close to roads and houses are usually where human/koala encounters are likely to occur, and thus will be most effectively surveyed.

Bias in the age or sex of animals reported can also occur. Coulson (1997) found a male bias in eastern grey kangaroo (*Macropus giganteus*) and western grey kangaroo (*M. fuliginosus*) roadkills, whereas all published studies of adult population structures for these species reported significant bias towards females. Coulson (1997) concluded that this was probably due to males having larger home range sizes and greater daily movements than females.

Male koalas have larger home ranges and travel further than females (CSIRO 1997). Furthermore, male koalas bellow to advertise their presence to conspecifics and may be involved in fights with other males. These activities may attract the attention of residents or passersby, thus making it more likely that they will be spotted and reported. Koosmen *et al.* (1997) found that of koalas recovered by the Native Animal Trust Fund at Port Stephens, 254 were male, 211 female and 89 of unknown sex. This bias was significant. Nattrass and Fiedler (1996) also found a male bias in Queensland

roadkills. This indicates that differences in movement patterns can influence how often koalas will encounter humans, or in this case, vehicles driven by humans.

Table 3.2. Details of published koala postal surveys. Location, year of the survey, number of surveys distributed, response rate and percentage, or number, of respondents reporting one or more koala sightings are given for each survey. Details of references are given after the table. No. info. = no information supplied.

Year	Location	Number of surveys distributed	Response rate	Percent, or number, of respondents that reported koala sighting(s)
1929 ¹	Qld		No info.	
1949 ²	NSW	>753	Unknown	109 reports
1967 ³	Qld	No info.	584 returns	No info.
1967 ²	NSW		Data lost	
1975 ⁴	NSW	Unknown, NPWS and Forestry personnel only		353 sightings
~1975 ⁵	South Australia	Sent to unknown number of persons who had previously received koalas for release		
1977 ³	Qld	>1000	~32.9%	42.2%
1986-87 ²	NSW	43 750	5.9%	31.8%
1986-88 ⁶	Qld	No info.		2383 reports
1986-88 ⁷	Victoria	No info.	521 returns	95.4%
1989 ⁸	Barrenjoey Peninsula, NSW	14 000	32.0%	No info.
1990 ⁹	Wedderburn	210	12.4%	30.8%
1990 ¹⁰	Iluka	697	20.2%	>74%
1991 ¹¹	Eden	11 600	10.3%	8%
1992 ¹²	Port Stephens	16 500	18.2%	57%
1995 ¹³	Yengo NP and Parr State Recreation Area	823	16.9%	22.3%
	Iluka	848	11.8%	
1997 ¹⁴	Remainder of the Maclean Shire	5127	1.7%	No info.
1997 ¹⁵	Campbelltown	13 000	4.5%	16.1%
1999 ¹⁶	Lismore	22 631	4.7%	54%

1 = Anon 1929, quoted in Patterson 1996

2 = Reed *et al.* 1990

3 = Campbell *et al.* 1979

4 = Gall and Rohan-Jones 1978

5 = Robinson 1978

6 = Patterson 1996

7 = Phillips 1990 *

8 = Smith and Smith 1990

9 = Close 1993

10 = Lunney *et al.* 1996

11 = Lunney *et al.* 1997

12 = Callaghan *et al.* 1994, Lunney *et al.* 1998

13 = Curtin and Lunney 1995a, b, Curtin *et al.* 2002

14 = Lunney *et al.* 2000

15 = Callaghan *et al.* 1998

16 = Harris 1999b

* = Although some information is given for other states as a result from the 1986-87 national koala survey, greater details for NSW and Queensland are given in Reed *et al.* (1990) and Patterson (1996) respectively. Details of the postal surveys conducted in the Australian Capital Territory and South Australia were not provided, and do not appear to be published.

A bias towards detecting juvenile animals could also occur, as they can roam over large distances until establishing a stable home range (Ramsay *et al.* 1997). Because of this

roaming behaviour, juveniles may be more likely to be encountered by humans, and thus be reported.

Another concern with community surveys is that, although the koala is well known and is easily recognisable, those reporting sightings may be uncertain about details (e.g. the date or precise location), or may be mistaken about some, or all, details (pers. obs.), and such reports may be misleading. Obtaining information that is as specific as possible will help to reduce uncertainty, but will not entirely eliminate it. Therefore, some assessment of the level of uncertainty for all reports should be incorporated into an analysis of community sighting data. Community surveys, however, can complement other survey techniques and greatly increase the number of documented sightings for a region (Curtin & Lunney 1995a, 1995b). Postal surveys can also be used to gather information on sightings of other wildlife and assess the respondents' views on conservation and management issues. However, to effectively assess the attitudes of a whole community the survey forms need to be randomly distributed amongst the community, or to all members of the community, if sufficient resources are available (Hawe *et al.* 1990).

Reports of tagged koalas can also provide information about koala dispersal. Most juvenile koalas disperse away from their natal home range (Ramsay 1999) and whilst dispersing, as they are socially subordinate, they usually occupy sub-optimal habitat (Mitchell and Martin 1990). Observations indicate that koalas can travel at least 48 kilometres, although this movement occurred after translocation (Robinson 1978). Dispersal distances reported (without translocation) are 1, 4, and 11 kilometres in New South Wales (Gall 1980). Koalas will use wooded corridors whilst dispersing, but have also been reported to use open habitat and lightly wooded areas (Moon 1990).

There are also other benefits to involving the community in a research program. The main benefit is the opportunity to educate the community and to influence their attitudes towards conservation. The koala is particularly suited to influencing community attitudes, and it has already been proposed that the koala should be a conservation "flagship" (New 2000). That is, because of its popular appeal, the koala can be used to promote the conservation of other species.

The other side of the community's concern with the koala is the welfare of this animal. This is relevant to research projects, because should the public perceive that research techniques will cause harm or stress to animals, then it may oppose the research project. An example of this is Pine Creek State Forest, where the local community sought to have a research project on koalas stopped, despite the project having National Parks and Wildlife Service and Animal Care and Ethic Committee approvals (Radford pers. comm.). Importantly, it appears that the project was opposed because the public believed that the research would adversely affect the population. The significance of concerted community opposition to a research project should not be underestimated. Thus, accurate publicity about a project offers the opportunity to educate the public about the techniques used and the potential benefits resulting from the research.

3.1.4 Previous Studies of Southern and Greater Sydney Region

Koalas

A number of studies on koalas have occurred in the study regions and available information from reports and published work are reviewed below.

3.1.4.1 Southern Sydney Region

Cork *et al.* (1988) conducted a study in land at the end of Victoria Road, Wedderburn, a suburb of Campbelltown, which was a proposed development site for the company Yap Yan Pin. They conducted a vegetation survey and relied upon koala sightings recorded by the Macarthur branch of the National Parks Association (NPA), which came from walks conducted by this community group to try and locate koalas in Wedderburn and Kentlyn, both suburbs of Campbelltown. Cork *et al.* (1988) concluded that the grey gum (*E. punctata*) formed the basis for high quality koala habitat in the Sydney region. They also suggested that the population on the site was the remnant of a larger population, which once ranged over a wider area of high nutrient soils in the Wedderburn area, much of which is now cleared.

Information gathered by my supervisor, Associate Professor Robert Close, who started researching koalas in the southern and greater Sydney study regions in 1990, was also available. This included reports of koala sightings collected opportunistically and from the Wedderburn postal survey (Close 1993).

Close and associates also developed and trialed a technique which consisted of inspecting all *E. punctata* within 20m of a transect line (Close pers. comm.). The distance travelled, any koalas sighted, scratches identifiable as koala and the presence of koala faecal pellets under *E. punctata* were recorded. Recorded koala sightings allowed a crude estimation of a koala density of 0.1 koalas ha⁻¹ (Close 1993). However, as most transects were in the Wedderburn area this estimate is probably not widely applicable throughout the southern and greater Sydney regions. Still, these transects covered a considerable area, and included gully habitat (Close pers. comm.). Thus, whilst caution must be taken in applying this density estimate, the technique was useful in helping to determine the distribution of koalas and in generating a density estimate.

In 1995, AMBS Consulting and AXIS Environmental conducted a flora and fauna survey in the Holsworthy Army Range (AXIS Environmental & AMBS Consulting 1996). Koalas were recorded at two sites on the western side of the range.

The AKF produced the Wedderburn Fauna Planning Study, which examined the distribution of koalas and other species within Wedderburn (Phillips *et al.* 1996). The AKF also conducted a vegetation and faecal pellet survey in the Campbelltown Council LGA from 1994 to 1996 to develop a Koala Habitat Atlas for the shire (Phillips and Callaghan 1996). This was combined with information from a postal survey conducted by the AKF and data from UWS (University of Western Sydney) to produce a Draft Koala Plan of Management for the Campbelltown LGA (Callaghan *et al.* 1998).

3.1.4.2 Greater Sydney Region

Robinson (1985) conducted trapping and spotlighting surveys within Water Board catchment from Woronora in the north to Avon in the south, as well as noting observations by Water Board employees. Most work was completed between 1966 and 1970. Robinson considered that koalas were widespread through the southern section of the waterboard catchments, in particular the Nepean Dam catchment, which is in the greater Sydney region. Robinson also noted that a small koala population occurred at the headwaters of Goondarin Creek on the Cordeaux River prior to fires in 1968, that there was a small population in the southeast part of Cataract Dam catchment, and prior to the 1940s koalas were prevalent on Woronora (presumably near the dam), in the southern Sydney region.

Another study on water board catchment was conducted by Wollongong University's Department of Biology. This study was conducted in the Upper Nepean catchment with water board ranger Don Tilley in 1990 (Currans *et al.* 1990). They attempted a long transect approximately 7km in length at night, but were only able to cover 1.5km due to the thick undergrowth. They also shone spotlights from both sides of a vehicle whilst driving slowly along fire trails and walked along a large ridge in the study area during daylight.

Don Tilley and Keith Uebel, using their observations whilst working as water board rangers, also considered that high intensity fires were a possible threat to koalas in the Nepean and Avon Dam catchments, but that the waterboard's selective strategic hazard reduction burning reduced this risk (Tilley and Uebel 1990). They also refer to an outbreak of disease prior to 1920 that devastated the previously plentiful population in the Nepean and Avon Dams, with reports having increased since the mid 1970s.

To the north of the greater Sydney region, Curtin *et al.* (2002) surveyed the Yengo National Park and Parr State Recreation Area using community and field surveys and concluded that low density populations were present.

More recently, Close *et al.* (2000) conducted a study of the Lower Blue Mountains region for the NSW National Parks and Wildlife Service. They obtained reports of koalas which were generally close to roads and human residences, but with clusters in the Springwood and Glenbrook / Lapstone areas.

3.1.5 Techniques Used in this Study

As discussed in Chapter 2, the logistical problems of locating koalas were: koalas occurring at a low density, the koala's cryptic nature, and arduous terrain. For this reason, developing an appropriate search technique was critical to this study.

Use of a new technique using thermal infrared sensing was considered. This technique has been trialed to survey white-tailed deer (*Odocoileus virginianus*) from a light aircraft (Wiggers and Beckerman 1993). Initially the prospect of trialing a similar aerial survey system with a heat sensitive camera was investigated. The army was

approached, but rejected the proposal. Later, the usefulness of a handheld version, which provided a live image like a video camera, but based on heat, was trialed to see if it would allow koalas to be more easily spotted at night.

Two cameras were borrowed and tested for locating radiocollared koalas. However, it was found that tree foliage blocked a koala's image. An appropriate camera would have been expensive, around \$85 000, and it was deemed that the effectiveness of the camera would be low. Thus, this technique was abandoned. With improvements and reduction in cost, however, this technology may later prove useful.

A volunteer search method was also trialed, but ultimately proved ineffective and was abandoned. The data obtained did allow a crude estimation of koala density within the southern Sydney region, however. Community reports were thus employed as the main technique. Various types of publicity allowed the collection of community reports over time. Funding was also obtained from the Hacking and Georges River Catchment Management Committee small project grants to conduct a large postal survey.

UWS sightings from a variety of techniques were also collected and collated. Data from the Australian Army, NPA and NPWS (NSW National Parks and Wildlife Service) Atlas were also obtained and compiled. This then allowed the comparison of six data sources to assess their strengths and weaknesses, and to critically assess the value of community surveys.

The density estimate obtained via the volunteer searches was combined with sighting data on the distribution of females with young to produce population size estimates for the southern and greater Sydney regions.

Locating animals to allow subsequent data collection through captures and radiotracking was also a priority. Opportunistic captures from university and community reports were the main method by which this was achieved.

3.1.6 Objectives

The objectives of the search techniques used were:

1. To compare and evaluate search methods which can be applied to low-density koala populations in terrain that is difficult to traverse.
2. To locate koalas for subsequent capture, data collection, and in some cases radiotracking.
3. To investigate the distribution of koala populations in the southern and greater Sydney regions.
4. To determine the density of koalas in the southern Sydney region.
5. To estimate the size of the southern and greater Sydney koala populations.
6. To investigate relationships between koala distribution and soil fertility in the southern Sydney region.

3.2 Methods

Reports of koala sightings for the two study regions, the southern and greater Sydney regions, were collated and used for analysis. Six sources of data for koala sightings were used: Australian Army; NPA; New South Wales National Parks and Wildlife (NPWS); the general public; sightings by University staff, students and volunteers; and a postal survey I conducted in the Sutherland region. The public and university sources also included reports of koala sightings collected prior to the commencement of this study.

Three other data sources of koala sightings existed, and were not included. These were sightings documented by Water Board personnel (Currans *et al.* 1990), a community study in the lower Blue Mountains (Close *et al.* 2000), and a postal survey conducted by the Australian Koala Foundation for Campbelltown Council (Callaghan *et al.* 1998).

Following is a description of each data source and the methods used to obtain the data where appropriate.

3.2.1 Data Sources for Koala Sightings

Army

The Army's Environmental Officer for the Holsworthy Army Range facilitated the collection of koala sighting information from army personnel, with many of the reports coming from Corporal Robert Thompson. Two sightings resulted in attempted captures within the range, one of which was successful, and a further report resulted in a koala roadkill corpse being collected.

NPA

This category includes those koala sightings made during walks organised by members of the Macarthur branch of the NPA, mainly from 31st May 1986 to 4th May 1990 and sightings by David Homer, a local person with superb observational skills. These walks were often for locating koalas, and primarily occurred in bush by the suburbs of Wedderburn, St Helens Park and Kentlyn. Details were noted at the time on data sheets from the Australian Museum and passed on to Robert Close in 1990. Information noted on these sheets was: date, spotters name(s), map reference, time, weather conditions, koala's location in the tree, whether young were observed, size (adult or juvenile), whether photographs were taken, distinguishing marks, koala's behaviour, and any other comments.

Details of later sightings were passed directly to the university and were included in the public sighting category.

NPWS

The NPWS supplied details of koala sightings from their Atlas database from zone 56, 200000E to 350000E and 615000N to 6255000N. These data were supplied on 1st September 2000 and are used with the permission of the NPWS. Other reports of koala sightings from NPWS rangers, not included in the Atlas data, were also included in this category.

The NPWS Atlas data of 103 reports included details of 30 captures by Steven Ward and Robert Close, which were taken from yearly scientific licence reports to NPWS.

These data were already included in other categories, or were radiotracking observations, and hence were removed from this category.

Information supplied by NPWS and used for analysis was date, observer, observation type, number, microhabitat, zone, easting, northing and location accuracy. Breeding type was also included, but the only available entries for this field were not breeding, juvenile, pregnant and nesting. Thus, a female koala with back young would not fit into any of these categories.

Public Sightings

Publicity was employed to elicit reports of koala sightings from the community. This publicity was achieved through various media. A weekly column written by the Steven Ward and A. Prof. Close was published in the *Macarthur Advertiser*, a local Fairfax newspaper in the Campbelltown region which is delivered to all homes from Wedderburn to Glenfield (CAB circulation of 62 602 at 7th August 1996). The column's length was usually 300 - 400 words and always included a number to report koala sightings. Not all columns were on koalas; some focused on other species or ecological concepts relevant to the Campbelltown region. Approximately 245 *Macarthur Advertiser* columns were published between October 1995 and November 2000.

The *Macarthur Advertiser* also ran "Mac's koala club" (Ward and Close 1998), from October 1995, as a promotional exercise and for fundraising to support the koala research. This club had a monthly newsletter, gave talks to school groups and club members, and used a "Mac the Koala" costume. There were 1280 members in this club on 20 / 6 / 2000.

Other media used to publicise requests for details of koala sightings included: stalls and displays at fetes and shows, articles in other newspapers, talks at schools and to community groups, radio interviews, 8 roadsigns erected by Campbelltown Council (which had a traffic sign warning motorists about koalas, with a separate panel underneath with "Report koala sightings on (02) 9962 9996"), distribution of notices with the pager number (see below), and a story on Win news (Wollongong region television). A professional 19-minute video discussing the research was prepared by

UWS Educational Media Services after a \$7000 donation to meet production costs was made by a Sydney couple (Ward & Close 1999). The video has been available for purchase since August 1999 at a cost of \$20 (currently \$22 including GST). Approximately 130 videos have been sold at 15 / 6 / 2000. In 1997, a university phone-line with a recorded message and male koala bellow, provided by the AKF, was set up.

Initially the telephone numbers promoted to report koala sightings was supervisor A. Prof. Robert Close's office number and the University security number for after work hours. Later, the after hours number was changed to Robert Close's home number.

In January 1997 pagers were obtained for Steven Ward and Robert Close. The 24-hour answering service provided by Hutchinson Telecommunications allowed the promotion of one number [(02) 9662 9996] for reporting koala sightings.

Data gathered prior to this study were entered on museum data sheets (the same as used for the NPA sightings), or in field notebooks. In mid to late 1995 a standard data sheet was designed and subsequently used for recording reports of koala sightings. The data sheet included the following: date of the report, recorder of the information, name, address and phone number of the reporter, date and time the koala was seen, estimated koala's size, whether pouch or back young were present, location and activity of the cub if present, location and activity of the koala, tree species the koala was seen in, location of the koala sighting, and any other notes.

Captured koalas had a coloured ear-tag placed in each ear, and each individual could be identified by its unique colour combination. Community members were asked to look for ear-tags in any koala seen. If eartags were seen the colours were noted and the individual identified if possible. This allowed movements of individuals to be followed, sometimes over considerable distances.

Once the pagers had been purchased details of other calls to the koala hotline were also recorded. These included requests for information, reports of other animal species, and other enquiries.

University of Western Sydney

Sightings from the activities by UWS staff, students and volunteers in the field were recorded on the same sheets as for public sightings and grouped in a "UWS" category. A number of methods were used by UWS, and the techniques used are summarised below:

- (1) A postal survey was distributed prior to this study to all 210 households in Wedderburn in 1992 (Close 1993). Of the replies, six respondents reported sighting koalas but three of the sightings were of the same animal. These reports were included in the UWS category.
- (2) During a transect study, described in Close (1993), four koalas were spotted at Wedderburn and Kentlyn (Close pers. comm.).
- (3) Infrequent spotlighting with students or volunteers was conducted at Wedderburn and Kentlyn.
- (4) During radiotracking uncollared animals were occasionally spotted. These animals were identified if eartagged, and if untagged, they were caught whenever it was possible. In some instances the uncollared koala(s) were seen in the same tree as the koala being tracked. Sightings of uncollared, independent koalas were noted and included in the UWS category.
- (5) I organised volunteers to conduct five searches, with each search covering 5 hectares, to try and locate new animals. Searches were either on ridgetops or in gullies. Many potential gully sites were rejected because of significant risk of injury to volunteers.

Prior to the search volunteers were given instructions in the methodology to be used, and if necessary instructions were given on the use of a compass. Volunteers were then organised into a straight line, and spaced 10m apart. The volunteers on either end of the line had compasses, which they used to obtain a bearing on a given heading, which was at a 90° angle to the search line. Where possible volunteers in the middle of the line were also given compasses. If volunteers in the middle of the line did not have a compass they were instructed to walk parallel to adjacent volunteers, whilst trying to keep the spacing at 10m.

Volunteers were instructed to try to remain in a straight line, walking at the pace of the slowest member in the line. Volunteers were asked to visually search all trees where the trunk of the tree was between themselves and the next person. Thus the volunteers on the end of the line only searched in one direction whilst those in the middle searched in two. All trees, regardless of species (including stags), were searched from the base up and throughout the canopy. Volunteers were encouraged to look back to rescan trees already searched.

The distance traversed was measured with a 100m measuring tape and every 100m the group was halted and the length of the search line measured and noted. Volunteers were again spaced out at 10m and the search then continued. If impassable terrain was encountered, the search line was restarted with a new bearing, or in a new location. The search continued until approximately 5ha had been covered.

The volunteers on the end of the line were asked to make notes on provided data sheets about the tree species present, average tree height, whether or not the bush had been burnt recently, approximate locations of large rock outcrops, ridges and streams.

Two test searches were conducted and I was not part of the search line for either test. One of these test searches had a radiocollared koala within the search area. For this search I arrived prior to the volunteers, located a radiocollared koala, and placed the search area so as to include this animal. The volunteers were told that a koala was present, but were not told its location.

As there were insufficient radiocollared koalas to test how well the volunteers were detecting the koalas, without doing many test searches, another test search was conducted using six toy koalas. A search area was measured and one side of the transect was marked with flagging tape. Six random locations within the search area were generated using a die. The closest tree to the random location was determined and a toy stuffed koala placed in the tree by a volunteer climber.

The toy koalas were 32cm high, and a medium grey in colour over most of the head and body, with white patches on the front of the ears, chest, and soles of the hind feet, and were a similar size to an adult female koala (Fig. 2-toy-koala). The chest and feet

white patches were mostly hidden because they faced the trunk or branch. Although similar in size and shape to a koala, the fur of the toy koalas, being synthetic, was more reflective than that of real animal.

The locations that the toy koalas were placed in were restricted to places within reach of locations that would bear the climber's weight. As these were usually more exposed than those observed to be used by local koalas, the most camouflaged forks possible were chosen, and the toy koalas were tied on in a manner so that they resembled, as much as possible, the posture and position that a real koala might adopt (Fig. 3.2). The percentage of toy koalas detected, and the average density, from the searches performed, was calculated.



Figure 3.2. Photographs of toy koalas. A) a toy koala being put into place by volunteer climber Brett Tyler. B) a toy koala in place amongst *E. punctata* foliage.

Postal Survey

A constraint on those areas that could be targeted with a postal survey was funding. Letters were sent to Liverpool, Sutherland, Wollondilly and Wingecarribee councils proposing that a survey within their council area be conducted, and that they pay for the printing and postage costs and that my labour to conduct the survey would be provided free of charge. No councils chose to fund a postal survey themselves, but grant funding from the Hacking River (\$2968.20) and Georges River (\$4982.00) Catchment Management Committees allowed this to go ahead.

Approval to conduct the survey was given by the University of Western Sydney Macarthur Human Ethics Committee (HEC No. 98/77). A total of 25 925 surveys were hand delivered in October and early November 1999 to all households in the following suburbs: Alfords Point, Bangor, Bundeena, Darkes Forest, Engadine, Grays Point, Kirrawee, Heathcote, Helensburgh, Illawong, Lucas Heights, Maianbar, Menai, Otford, Sandy Point, Stanwell Park, Stanwell Tops, Waterfall, Woronora, Woronora Heights and Yarrawarra (Fig. 3.3).

Image unavailable due to copyright restrictions.

Please refer to print copy

The survey questions and design were based on a koala postal survey conducted in Port Stephens (Callaghan *et al.* 1994). The survey was printed on both sides of an A2 sheet, and folded to standard letter size. Once filled out by the respondent the survey could be folded up and returned via reply paid mail without an envelope.

Soon after distribution of the survey, publicity was obtained in the *Sutherland Shire Leader*, a local Fairfax newspaper, announcing the survey and explaining the reasons for it. Another article in the same newspaper, which encouraged people to send in completed surveys, was published approximately two weeks after the requested return date of 5th November 1999.

Respondents were asked to answer 13 questions and to mark the location of koala and other selected species sightings on maps provided (Appendix 1). Separate maps were provided to mark koala sightings and those for other species. Black and white drawings and a short description of species other than the koala were included to increase the accuracy of non-koala sightings (Appendix 1).

3.2.2 Estimating Koala Population Numbers

Two estimates of koala population densities for the southern Sydney region were made in this study: counts on a modified bounded transect and using MCP home range size. Sufficient fixes to estimate home range size were available for only three adult female koalas (section 5.2.4). As stable home range size estimates were not available for males, the proportion of females (section 4.3.1) was used to estimate the density of independent koalas. The home range size estimate was calculated by: $1 / \text{average adult female MCP} / \text{proportion females}$.

No density estimates were available for the greater Sydney region, and in this absence, the estimate obtained in this study for the southern Sydney region was also used for the greater Sydney region.

The distribution of sightings of female koalas with young gathered during this study was used to estimate the area of habitat utilised by breeding koalas in the southern Sydney region. Few sightings of females with young were available for the greater

Sydney region, so the area covered by the dense cluster of sightings immediately to the southwest of the southern Sydney region was estimated. These area estimates were then multiplied by the density estimates from this study (section 3.3.12). Upper and lower values around these numbers were then subjectively estimated.

3.2.3 Data Management

Two Microsoft Access 97 databases were constructed to make data analysis practical: one for the postal survey response data, and another for all community sighting data, (including reports of koala sightings from the postal survey), radiotracking and capture data. MapInfo v5.5, a GIS program, was used to map sightings.

3.2.3.1 Postal Survey Data

Where possible, those respondents that reported sighting a koala, and that gave permission to be contacted, were telephoned to clarify the details provided in the survey response. The date and location quality categories for reports from respondents who did not give permission to be contacted, or did not provide contact details were classed as “unreliable” (see section 3.2.3.2).

Question 9 of the survey asked the respondent “*Would you support any of the following actions to help koalas in southern Sydney (circle those you support)*”. Five actions were listed, (i) traffic restrictions, (ii) restrictions of dogs, (iii) tree planting programs, (iv) environmental protection zones, and (v) using public money to buy land for koala reserves. For all, unless the respondent clearly indicated that they supported the proposed action, their response was put down as a “no”.

3.2.3.2 Koala Sighting Data

In the design of the koala sighting database, fields were added, described below, to allow sightings to be classified according to their reliability under different parameters. I hereafter refer, in general, to these fields as data filters, as they allow a specific subset of data to be extracted, or filtered out from the complete database, depending on the settings of the various parameters.

- Hoax, false alarm, and unreliable reports. Deciding that a sighting qualified for one of these categories was a subjective assessment based on the information available. These categories were defined as:
 - Hoax: a deliberately misleading report of a koala sighting.
 - False Alarm: where the reporter felt that they had seen a koala, but where the “koala” was later identified as something else.
 - Unreliable: where the person appeared to be reporting a genuine koala sighting, but where there was some uncertainty about the veracity of the report. For example, koala roadkills were classed as unreliable unless it was clear that the reporter had stopped and checked the corpse. Also included as unreliable were those reports where there was a lack of information, or where details were contradictory.
- Multiple reports. Reports of sightings were checked, as much as possible, against others to see if they were sightings of the same animal. All reports that were thought to be a sighting of the same animal within a week of the first report were classed as a multiple report and were not used for data analysis, except where specified. Unless reported sightings of koalas in the same locality at the same time differed in their description (e.g. koala with back young and large solitary koala), it was assumed that these were multiple reports.
 - The period of 7 days is arbitrary, but was selected to minimise the possibility of an animal choosing a highly visible location and creating bias by generating many reports.
- The accuracy of the location of koala sightings, based upon the description of the location from the reporter, was subjectively assessed and placed into one of four categories (see below). For most NPA records and Army records, the location ordinates had been determined by the reporter at the time of the sighting. It was decided to place all reports with a pre-determined location into the “Fair” category. For NPWS Atlas records the location accuracy had been determined to within 10m, 100m, 1km, 10km or 100km and this information was used to determine the appropriate category. Note that for some reports of koala sightings a location could not be estimated and these reports were not used in the analyses. For other records the following definitions were used:
 - "Good" = location known to within 100m,

- "Fair" = location known to within 500m,
- "Poor" = location known to within 1km,
- "Unreliable" = location not known to within 1km.
- The accuracy of date of the koala sighting was also assessed from the description given from the respondent, and the following definitions used:
 - "Good" = date known within a week,
 - "Fair" = date known to within a two month period,
 - "Poor" = date known to within a two year period,
 - "Unreliable" = date not known to within a two year period.
- A number of types of reports were loosely termed "historical" sightings. This category included:
 - Sightings where persons reported having seen more than one koala, excluding females with young, but could not describe the date and location of individual koala sightings. For example, six koalas seen in the same locality over a one-year period. These were called "lumped" sightings. The estimated number of koalas seen and the period of time were also recorded for these sightings.
 - Recollection of statements about koala sightings by family or friends, either about single or lumped sightings. That is where the person reporting the sighting had not actually seen the koalas themselves and the person who had sighted the koala could not be contacted.
 - Personal sightings where the date or location was classed as unreliable.
- Koala sightings that were not classed as historical, were not a multiple report and were not classed as a hoax, false alarm or unreliable report were called "credible reports".
- Where possible reports were placed into an age category. This was based on the reporter's description of the koala's size. Animals with a head-body length of <25cm were classed as juvenile, 25 – 35cm head-body length as juvenile to adult, and >35cm head-body length as an adult. However, descriptions of the koala's size were frequently vague, for example a koala might be described as "large". Thus, in many instances a subjective judgement as to the most appropriate age category was made based on the reporter's description.
- Other fields used were:
 - Whether the koala was dead, injured or sick.

- If back or pouch young were sighted, and if so the size, location and activity of the young.
- If eartags were sighted the colours were entered, along with the probable identity of the koala and whether this identity had been confirmed.
- Non-koala sightings were also entered, with a special field to separate these from the koala sightings. Information on whether these reports were about koala faecal pellets or bellows, or the reason for the inquiry, was also recorded.

3.3 Results

3.3.1 Number of Reports

The number of reports collected from the southern Sydney region was considerably larger than the number from the greater Sydney region, for both credible and historical reports (Table 3.3). This reflects the greater effort placed on collecting reports from the southern Sydney region.

For both the southern and greater Sydney regions, credible sightings (88.7% and 68.6% respectively of total sightings) were more numerous than historical sightings.

Table 3.3. Credible, historical and total number of reports of koala sightings for the southern and greater Sydney study regions.

Source	Southern Sydney			Greater Sydney		
	Credible Sightings	Historical Sightings	Total	Credible Sightings	Historical Sightings	Total
Army	8	1	9	0	0	0
NPA	69	1	70	0	0	0
NPWS	20	8	28	31	2	33
Public	263	18	281	37	31	68
UWS	67	0	67	4	0	4
Postal Survey	68	35	103	0	0	0
Total	495	63	558	72	33	105

A total of 663 reports of koala sightings for the two study regions were compiled. The public category of reports was the largest source of sightings for both the southern and greater Sydney regions (Table 3.3). However, for the greater Sydney region, sightings came from only three sources: Public, NPWS and UWS (Table 3.3). For the southern Sydney region, sightings came from all six data sources, with the postal survey being

the second highest source of sightings (Table 3.3). The number of historical reports was high for the postal survey source, because there were many replies where details could not be clarified. The number of historical reports in the greater Sydney region from the public data source were also comparatively high, because the location accuracy of many sightings was classified as unreliable as it was difficult to determine accurate location for most reports from this region.

An assessment of data to June 1996 showed that the number of koala sightings reported per year increased three-fold after publication of the *Macarthur Advertiser* newspaper columns (Ward and Close 1998: Appendix 2). A further increase in sightings occurred from 1996 to 1997, for both the southern and greater Sydney regions (Table 3.4). This increase was tested with a Wilcoxon ranked sum test, and was significant for both the greater and southern Sydney regions [for both: $W_s=38$, $p = 0.006$]. These increases coincide with the purchase and promotion of the pagers in January 1997.

Table 3.4. Number of public reports of credible and historical koala sightings by the year they were reported, for the southern Sydney and greater Sydney regions.

Year	Southern Sydney	Greater Sydney
1990	6	1
1991	11	1
1992	23	5
1993	10	3
1994	8	1
1995	17	1
1996	20	5
1997	53	16
1998	55	12
1999	26	13
2000	52	10
Total	281	68

3.3.2 Sighting Quality and Reliability

The quality of information received for the date when koala(s) were observed was generally high, with the date quality field rated as good for 61.4% of all sightings. There was significant variation between the data sources in date quality ($\chi^2_{[8]} = 315.66$, $p < 0.005$). The greatest contribution to the χ^2 test statistic came from the comparatively large number of poor and unreliable postal survey reports. These low quality

classifications arose because many respondents only gave the year of the sighting, despite instruction to provide the month and year (Table 3.5).

Table 3.5. Sighting date quality by data source for the southern and greater Sydney regions combined.

Source	Date Quality			
	Good	Fair	Poor*	Unreliable*
Army [†]	7	2	0	0
NPA	53	13	4	0
NPWS	32	14	14	1
Public	246	59	36	8
UWS	68	3	0	0
Postal Survey	1	27	54	21
Total	407	118	108	30

*=Poor and Unreliable date classifications were combined to avoid having χ^2 expected cell values of < 5.

[†] = The Army data source was excluded from the χ^2 analysis as it had few reports, thus some of its cells would have had an expected value < 5.

There was significant variation between public, UWS and postal survey data sources in their location quality ($\chi^2_{[6]} = 104.84$, $p < 0.005$). Again, the postal survey category contributed most to the χ^2 test statistic, with 50.5% of all reports from this category classed as having either a poor or unreliable location quality. All sources had a low number of locations classed as unreliable, and the UWS, NPWS and public sources all had over 47% of their sightings classed as good (Table 3.6). The Army and NPA records were mainly classified as fair (Table 3.6), as this was the default classification for these categories, without further information.

In the southern Sydney region the distribution of location and date quality classifications for credible sightings was examined (Fig. 3.4). The distribution of good, fair and poor classifications for both date and location reflect the distribution of the different sources of sightings. Sightings in Kentlyn, St Helens Park and Wedderburn often have a high degree of confidence for both date and location, whereas sightings from Sandy Point south to Darkes Forest, and within the Royal National Park, are generally of a lower quality classification (Fig. 3.4).

Table 3.6. Sighting location quality by data source for the southern and greater Sydney regions combined.

Source	Location Quality			
	Good	Fair	Poor	Unreliable
Army*	1	6	1	1
NPA*	5	62	2	1
NPWS*	30	5	19	7
Public	167	104	49	29
UWS	51	20	0	0
Postal Survey	7	44	42	10
Total	261	241	113	48

* = These data sources were excluded from the χ^2 analysis as all predetermined Army and NPA sightings were classified as "Fair". NPWS data were excluded because the NPWS location quality system did not match the categories used in this study, thus excluding most reports from being classed as "Fair" quality.

Including credible and historical sightings, false alarms, hoaxes, unreliable and multiple reports, as well as reports of koala bellows or scratches, there were a total of 904 koala-related reports from all data sources (Table 3.7). There were also many non-koala reports or inquiries documented for the public and postal survey sources (Table 3.7). Some of the non-koala related inquiries were: 7 reported sightings of water rats (*Hydromys chrysogaster*), 2 platypus sightings (*Ornithorhynchus anatinus*), 3 giant burrowing frog sightings (*Heleioporus australiacus*), requests for information about koalas, requests to do talks, and questions about what to do with injured fauna.

Table 3.7. Number of non-koala and koala reports by source, for both the southern and greater Sydney study regions. Non-koala reports are reports of sightings of animal species other than koalas, and requests for information and displays or talks. Koala related reports are subdivided into: false alarm, hoaxes, unreliable reports, multiple reports, other (reports of koala bellows, scats or scratches), credible and historical reports, and a total of all koala-related reports.

Source	Non-Koala related reports	False Alarm	Hoaxes	Koala related reports			Credible + Historical	Total
				Unreliable Reports	Multiple Reports	Other		
Army*	0	1	0	0	0	1	9	11
NPA	3	0	0	0	4	8	70	82
NPWS	1	0	0	0	7	14	61	82
Public	114	5	2	30	58	30	349	474
UWS	0	0	0	0	2	3	71	76
Postal Survey	Not available	0	2	47	25	2	103	179
Total	>118	6	4	77	96	58	663	904

* = The Army data source was excluded from χ^2 analyses as it had cells with an expected value < 5.

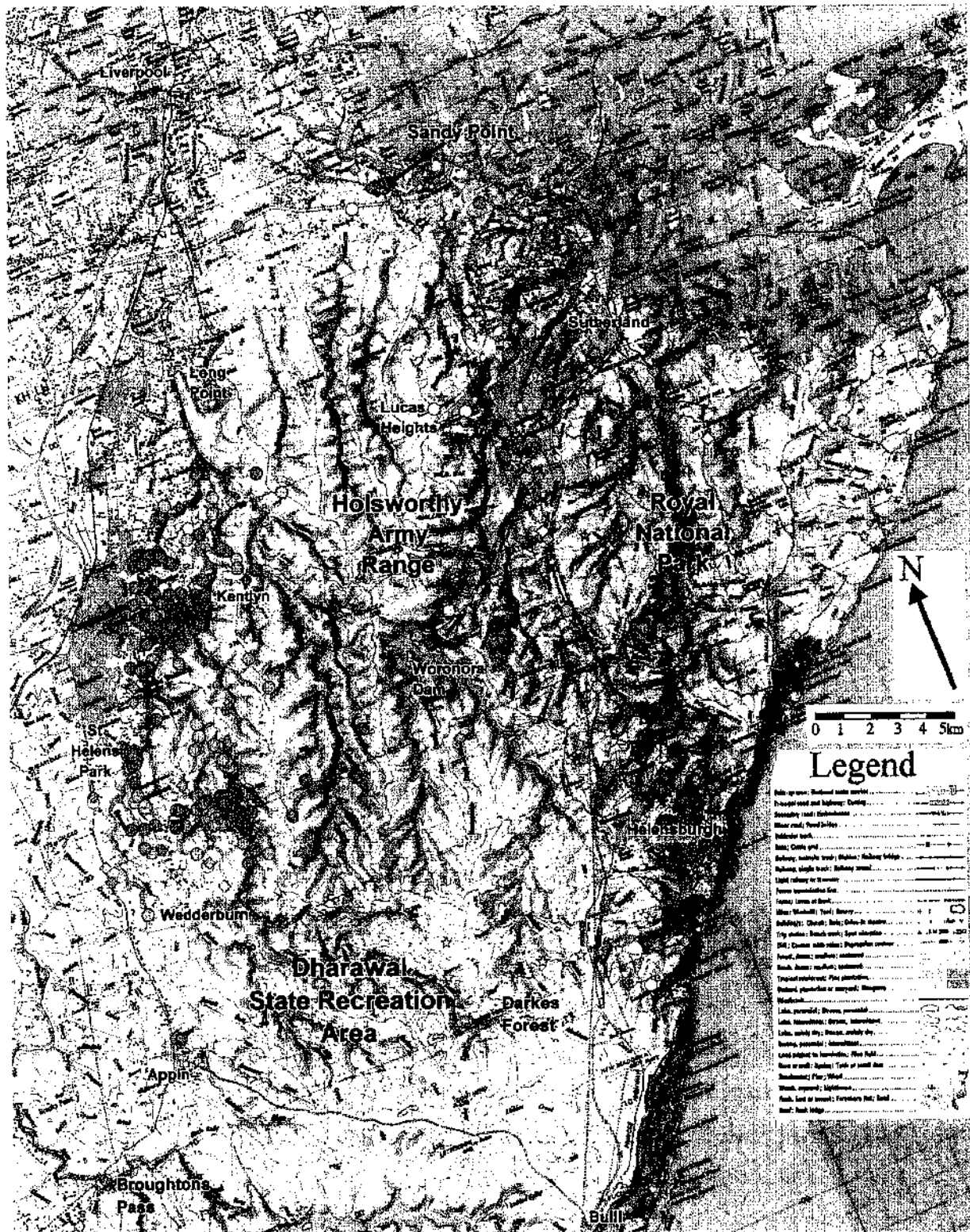


Figure 3.4. The location accuracy represented by colour, and date accuracy represented by symbol type, for credible reports of koala sightings in the southern Sydney region. The following colours represent location quality classifications: red = “good”, orange = “fair”, and yellow = “poor”. The following symbols represent date quality classifications: circle = “good”, diamond = “fair”, and star = “poor”. See methods for definitions of date and location accuracy categories. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

Few false alarms and hoaxes were detected (1.1% of all koala-related reports), and these came from the army, public and postal survey sources (Table 3.7). There was significant variation between the data sources, excluding the army, in the number of unreliable reports compared against an expected number based on the total of credible and historical reports ($\chi^2_{[4]} = 127.06$, $p < 0.005$). The number of reports classified as unreliable was particularly high for the postal survey source (26.3% of all koala-related reports, Table 3.7). Many of these unreliable reports came from reports of dead koalas, where unless the respondents were successfully contacted, and they stated that they had checked the identity of the corpse, the sightings were classed as unreliable. For all sources combined unreliable reports comprised 8.5% of all koala-related reports (Table 3.7).

There was significant variation between the data sources, excluding the army, in the number of multiple reports (Table 3.7), compared against an expected number based on the total of credible and historical reports ($\chi^2_{[4]} = 18.42$, $p < 0.005$). The UWS and postal survey sources both had large contributions to the χ^2 test statistic, with fewer UWS multiple reports than expected, and more multiple reports for the postal survey source than expected. For the postal survey, it seems likely that a few animals generated many reports when they appeared in highly visible locations. For all sources combined, multiple reports comprised 10.6% of all koala-related reports (Table 3.7).

Other signs of koalas being present (bellows, scats or scratches), were reported in low numbers from all source categories (Table 3.7). However, there was significant variation between the data sources, excluding the army, in the number of these reports, compared against the expected number based on the total of credible and historical reports ($\chi^2_{[4]} = 23.01$, $p < 0.005$). The NPWS category accounted for most of the χ^2 test statistic with many more reports of bellows, scats or scratches than expected. This probably reflects the emphasis for all other data sources on the collection of reports of koala sightings, rather than bellows, scats or scratches.

3.3.3 Distribution of Southern Sydney Sightings

There are clearly different patterns to the location of sightings from different sources (Fig. 3.5). Sightings reported by members of the public, although widely distributed,

are at their highest concentration around the Campbelltown suburbs of Kentlyn, Wedderburn, and St Helens Park (Fig. 3.5). The NPA sightings are heavily concentrated in the east of Wedderburn, in the catchments of O'Hares and Pheasants Creeks. The UWS sightings are concentrated in Wedderburn and Kentlyn; the areas where radiotracking and koala searches were conducted. Both NPWS and army sightings are widely distributed with most sightings within the Holsworthy Army Range. Sightings from the UWS postal survey mainly occur in the eastern portion of the southern Sydney region, from Sandy Point in the north, to Darkes Forest in the south (Fig. 3.5).

The overall picture formed by the 495 credible koala sightings (Fig. 3.5) is that the bulk of sightings have come from the Campbelltown suburbs of Wedderburn, St Helens Park and Kentlyn. There are also many sightings from Sandy Point through to the Royal National Park. A loose conglomerate of sightings also occurs in Darkes Forest and to the south of Helensburgh, small groups at Appin and Broughton's Pass, and scattered sightings in the Holsworthy Army Range.

Historical sightings generally occurred in the same areas as the credible southern Sydney sightings, with some exceptions. Five sightings occurred between Bulli and Appin, where no credible sightings were recorded (Fig. 3.6). Historical sightings also occurred within suburban development in the Sutherland area, and one to the north of the Georges River (Fig. 3.6, see section 3.3.8 for notable information from historical reports).

It is striking that reports of koala sightings are almost completely absent, bar two credible sightings, from Long Point north to Glenfield and Holsworthy (Fig. 3.5 and 3.6). Also, there are only a few historical sightings along the well-used road from Bulli to Appin, and 2 credible sightings at Appin itself (Fig. 3.5 and 3.6). As many people frequent these areas, it seems reasonable to expect that people would encounter koalas more often if breeding groups occurred in these areas (see section 3.4.10 for further discussion).

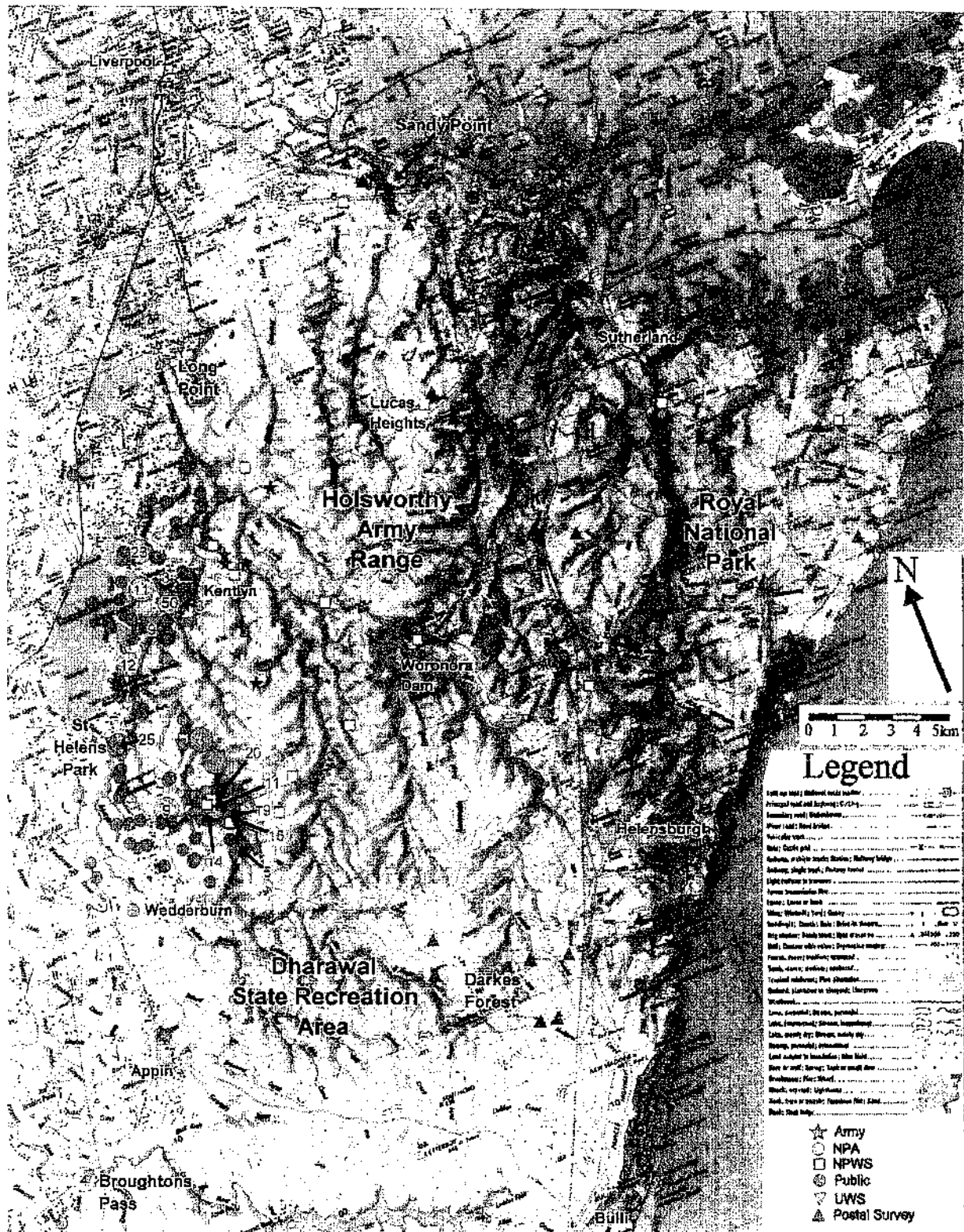


Figure 3.5. Locations of credible koala sightings by the source of the sighting in the southern Sydney region. Small symbols represent one sighting whilst larger symbols represent multiple reports. Numbers with the larger symbols indicate the number of sightings for that source in that locality. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

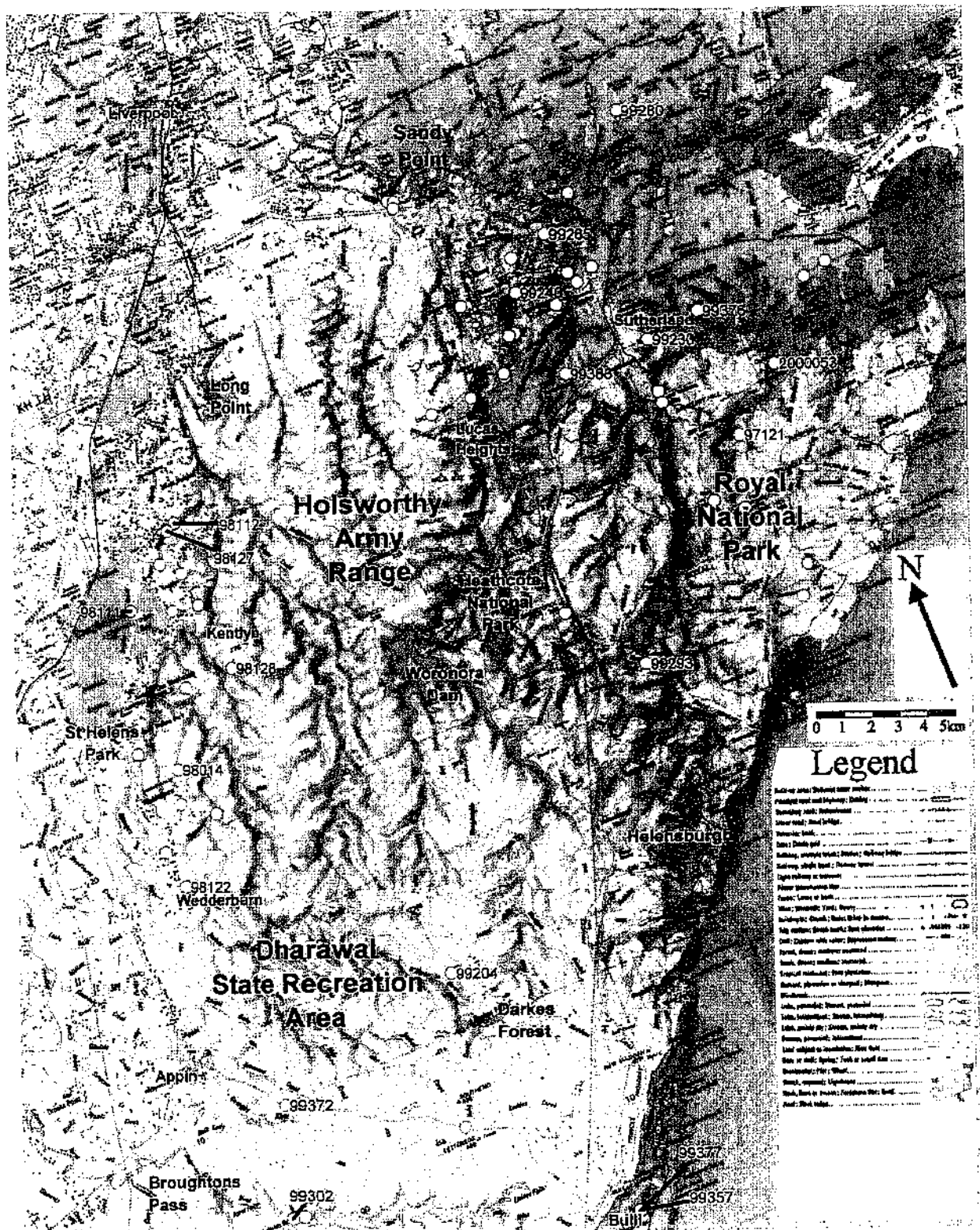


Figure 3.6. Locations of historical sightings in the southern Sydney region. See methods for a definition of historical sightings. Numbers next to sightings represent the unique identification number for the sighting and where necessary these are linked to the sighting location by a line. See Table 3.10 for information on selected reports from this figure. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

Few sightings came from within the Holsworthy Army Range, Heathcote National Park, Woronora Dam and Dharawal State Recreation Area. This result is consistent with the expectation that these areas would be utilised by relatively few people compared to the number of people found within suburban areas, thus resulting in few reports of koala sightings.

In general, koala sightings tended to occur in, or close to, valleys. This is particularly noticeable for four locations: Broughtons Pass, the Georges River (between St Helens Park and Wedderburn), Peter Meadows Creek, and at Deadmans Creek near Sandy Point. In each instance, a stretch of well-used road crosses a creek or river, and the sightings are concentrated around the creek or river valley.

3.3.4 Distribution of Greater Sydney Sightings

Scattered sightings, mainly public and NPWS, occur through the greater Sydney region (Fig. 3.7). NPWS sightings are more common than public sightings in the Cordeaux, Cataract, Nepean and Avon dam catchment areas to the west and south of Wollongong (Fig. 3.7).

Another cluster of koala sightings occurred where the remnant vegetation in the Nepean Dam catchment and Nattai National Park meet (Fig. 3.7). That is, a koala could travel from Campbelltown, through the water catchment and into the large expanse of vegetation in the Nattai and Blue Mountains National Parks.

The distribution of historical sightings in the greater Sydney region appears to be similar to the distribution of credible sightings: scattered sightings with a cluster in the remnant vegetation between, or in, the Nepean Dam catchment and Nattai National Park (Fig. 3.8).

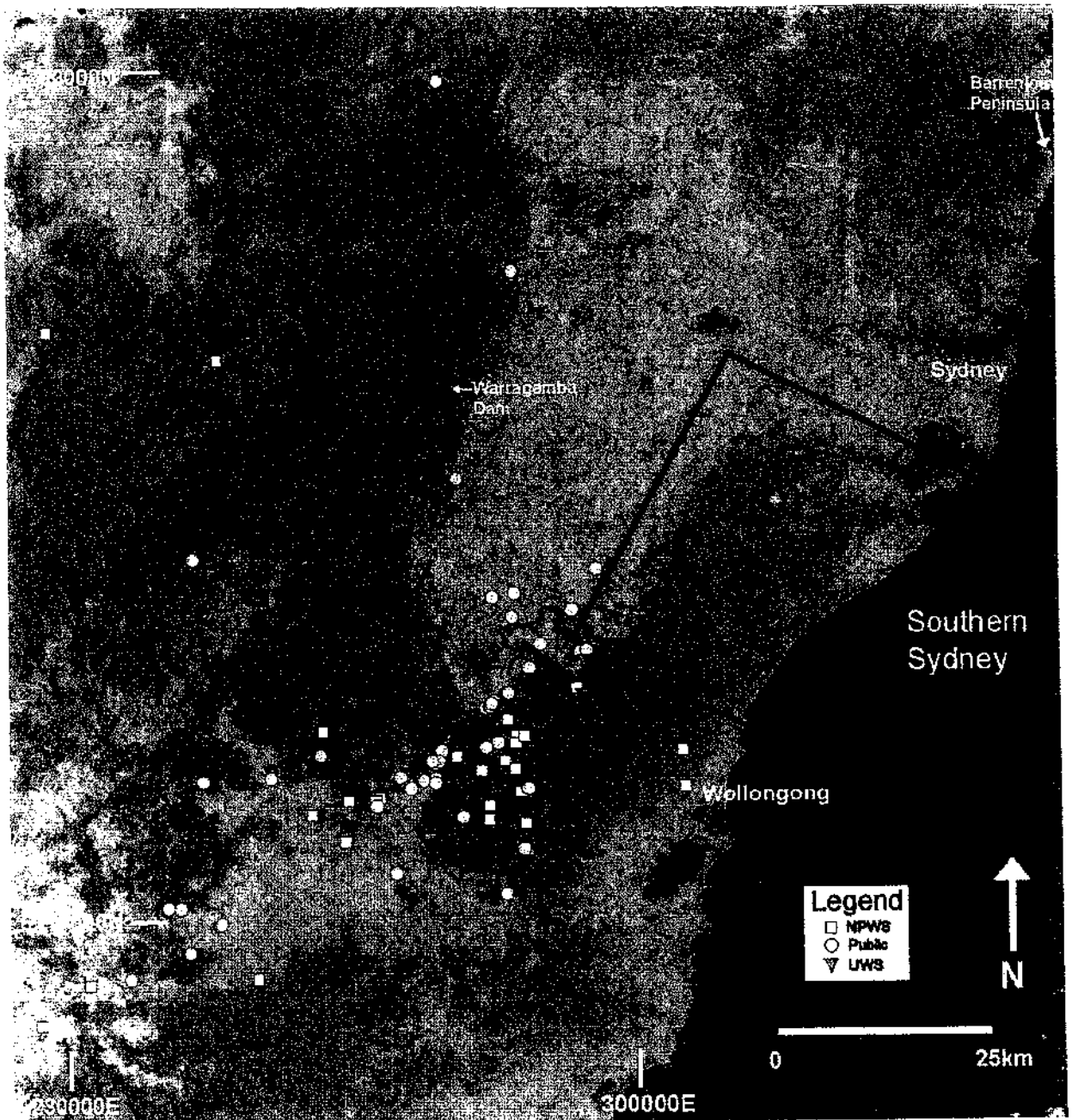


Figure 3.7. Locations of credible koala sightings by the source of the sighting in the greater Sydney region. Note that some symbols may be superimposed on each other.

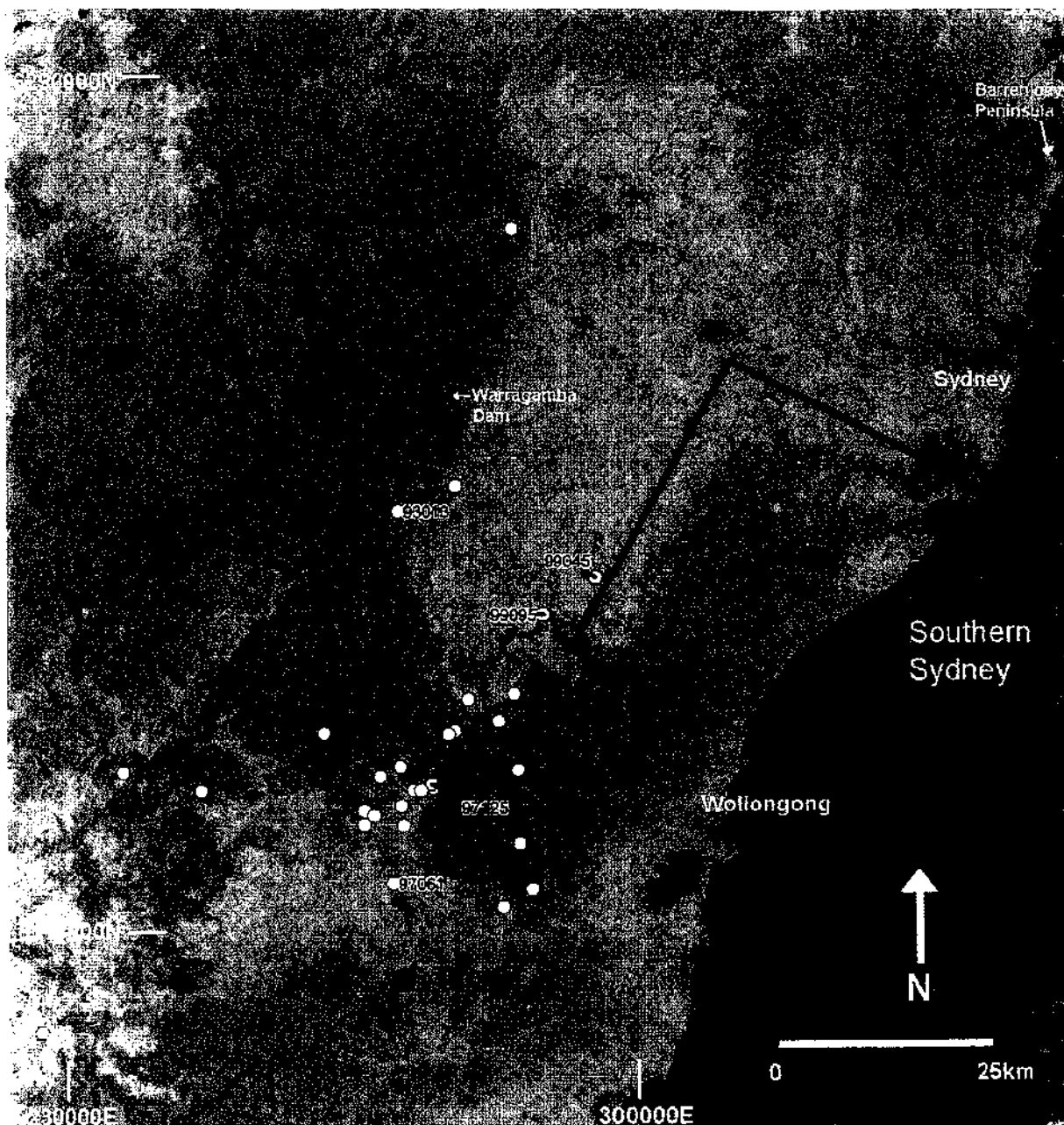


Figure 3.8. Locations of historical koala sightings in the greater Sydney region. Numbers next to sightings, or where necessary linked to the sighting by a line, represent the unique identification number for selected reports. See Table 3.11 for information on selected reports from this figure.

3.3.5 Koala Ages

NPA, Public and UWS source credible reports were compared where the reports could be placed into an age category, and there was no significant difference in age between sources ($\chi^2_{[2]} = 2.65, p > 0.05$). The other data sources were excluded because some of their expected cell values were less than five.

Data for all sources were then pooled and the age categories for the southern and greater Sydney regions compared (Table 3.8). There was no significant difference in age between the two areas; however, the expected value was less than five for two cells ($\chi^2_{[2]} = 1.74$, $p > 0.05$). For the combined southern and greater Sydney regions from 339 reports that could be classified (59.8% of the total reports), 18.3% of the reports were of juveniles, 12.1% of juveniles to adults, and 69.6% of adults.

Table 3.8. Number of credible reports in one of three age categories based on the reporter's description of the size of the koala.

Age category	Southern Sydney	Greater Sydney
Adult	217	19
Adult to juvenile	38	3
Juvenile	60	2
Total	315	24

3.3.6 Females with Young

For credible and historical reports of koalas with young (Table 3.9) there was significant variation between the observed and expected number of reports based on the total number of credible and historical reports for each data source ($\chi^2_{[4]} = 20.84$, $p < 0.005$).

Table 3.9. Number of credible and historical reports of koalas with young for both the southern and greater Sydney regions. Percentage of the total number of credible and historical reports for each category is also given.

Source	Number of reports of koalas with young	Percent of total
Army*	0	0%
NPA	15	21.4%
NPWS	1	1.6%
Public	27	7.7%
UWS	14	19.7%
Postal Survey	12	11.6%
Total	69	10.4%

* = The Army data source was excluded from the χ^2 analysis as it had an expected value < 5 .

The highest detection rates for breeding females were for NPA and UWS sightings, at 21.4 and 19.7% respectively (Table 3.9). To qualify for inclusion in the "koala with young" category required that there be a cub on the female's stomach or back. Koala cubs spend approximately 6 months on their mother's stomach or back (Lee & Martin

1988). Thus, for the other 6 months of the year breeding females that were seen would not be classified as such. If the percent of reports is doubled to account for the period when young are in the pouch, 42.8% of NPA, and 39.6% of UWS sightings, were of breeding female koalas. This would be conservative, as stomach young would be hard to spot in many situations.

For the army, NPWS, public and postal survey data sources, the percentages of females, with young were much lower than the NPA and UWS sources (Table 3.9). There were few army reports so no reports of koalas with young could simply be due to chance. For NPWS sightings, the Atlas database sightings did not record whether the animal sighted was a female with young. There appears to be two possible explanations for the low number of females with young for the public and postal survey sources: a low number of breeding female koalas within the population(s), or, a low detection rate of koalas with young by these data sources (Table 3.9).

The percentage of public sightings of females with young is lower than the postal survey source (Table 3.9). This may be because all reports for the public category come from different persons, whereas for the postal survey, one respondent reported four, and another two sightings of females with young. That is, these two respondents accounted for half of the reports of koalas with young from the postal survey, and may have increased the percentage of koalas with young reports for this data source.

The distribution of sightings of koalas with young in the southern Sydney region is mainly clustered around the Wedderburn, St Helens Park and Kentlyn areas (Fig. 3.9). All reports for these areas, however, are quite recent, with the earliest from 1986 in Wedderburn, 2000 in St Helens Park, and 1990 in Kentlyn. There is also a sighting from 1999 in the eastern part of Minto Heights (directly to the north of Kentlyn), and scattered sightings in the Sutherland region (from 1939 to 1990), Royal National Park (1973 to 1996), Heathcote (1998), Helensburgh (1998) and Darkes Forest areas (two, both 1998), (Fig. 3.9).

For the greater Sydney region, there are only 6 reports of koalas with young, all widely scattered and sighted from 1991 to 1998 (Fig. 3.10).

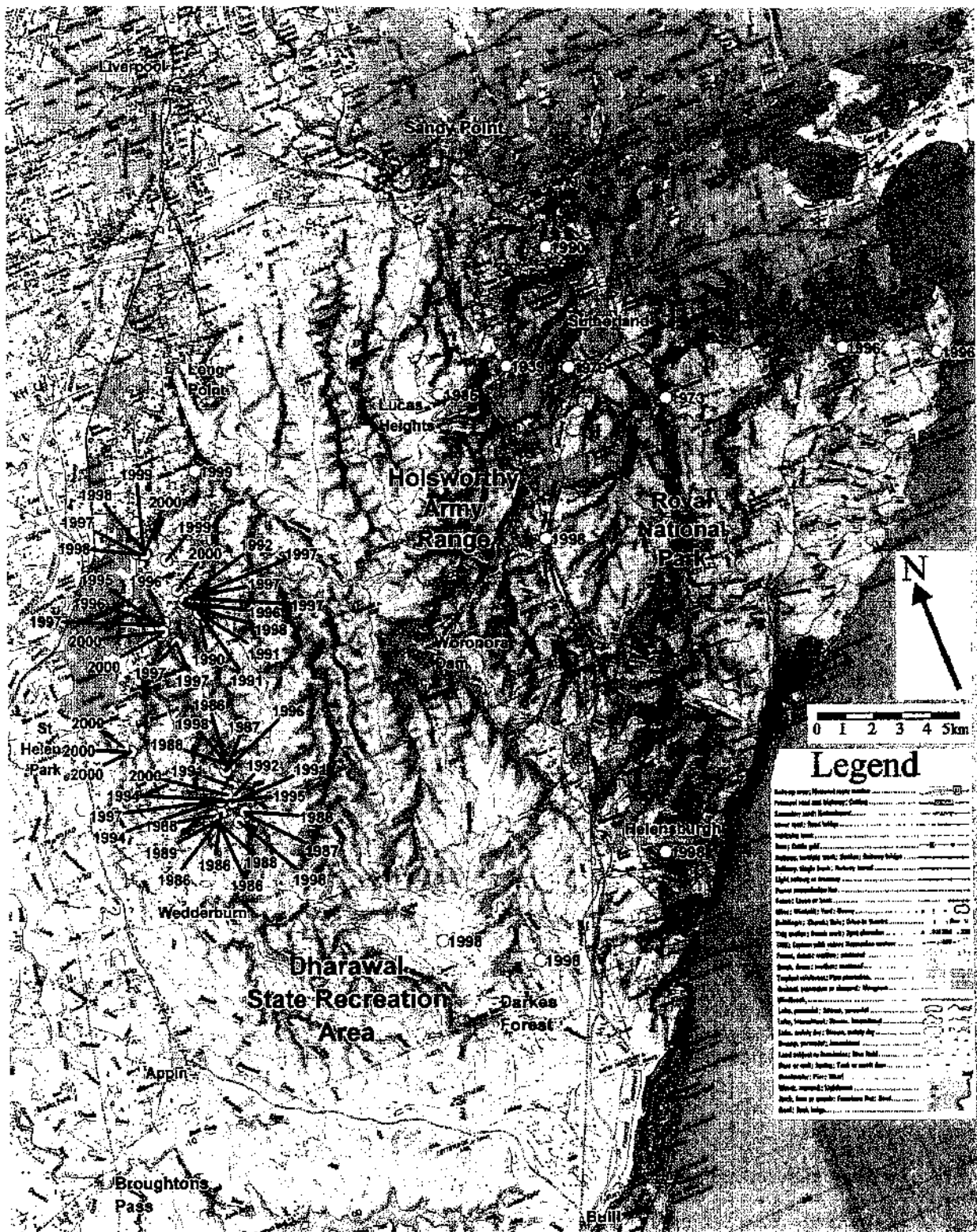


Figure 3.9. Locations of sightings of koalas with young, both credible and historical, in the southern Sydney region. The year is shown and is linked to the sighting location by a line where necessary. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

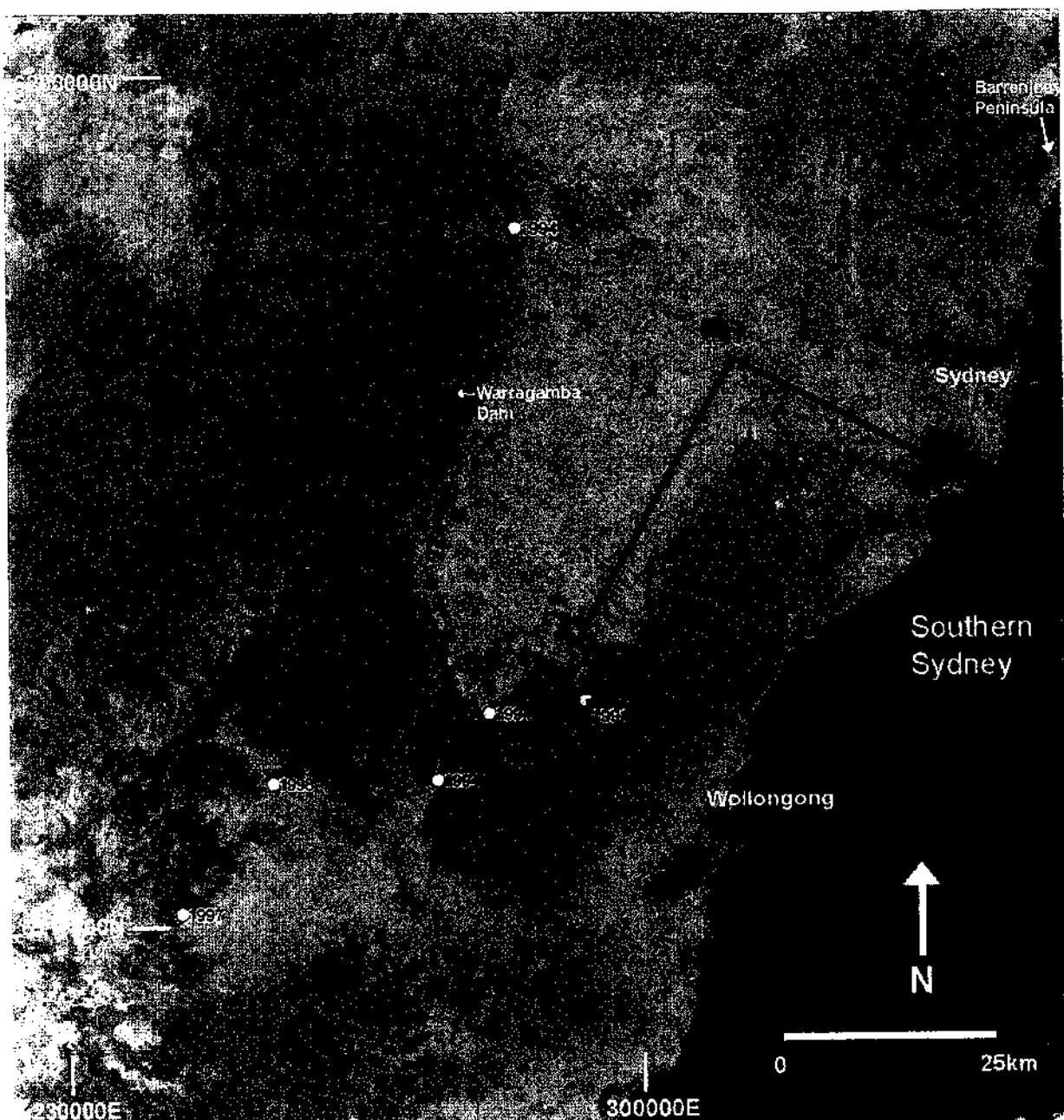


Figure 3.10. Locations of sightings of koalas with young, both credible and historical, in the greater Sydney region. The year is shown and is linked to the sighting location by a line where necessary.

3.3.7 Dead or Injured Koalas

The number of reports of dead or injured koalas varied depending on the data source, from 0 to 32.2% (Fig. 3.11). There was significant variation in the total number of reports of dead or injured koalas compared against the expected number of reports based on the total number of credible and historical reports ($\chi^2_{[4]} = 97.27$, $p < 0.005$). Note that the Army data source was excluded from the χ^2 analysis because expected value were less than 5. As for the sightings of koalas with young, the total number of army koala sightings was low; therefore, the rate of 20% may not be representative.

The number of dead or injured koala reports for the postal survey (32.2%) is particularly high, with many of these reports being classed as unreliable (Fig. 3.11). Many of these reports of dead koalas were placed in the unreliable category because the respondent could not be contacted to find out whether the respondent had checked the corpse's identity. For both public and postal survey reports, a number of people stated that they saw the corpse whilst they were driving, and these reports were classed as unreliable. Often the public reports were made soon after the corpse had been sighted, however, and in many cases the corpse's identity was clarified when a member of the koala research group drove out to collect it. In two cases reported corpses were identified as dead grey cats, and these reports were classified as false alarms instead of unreliable reports.

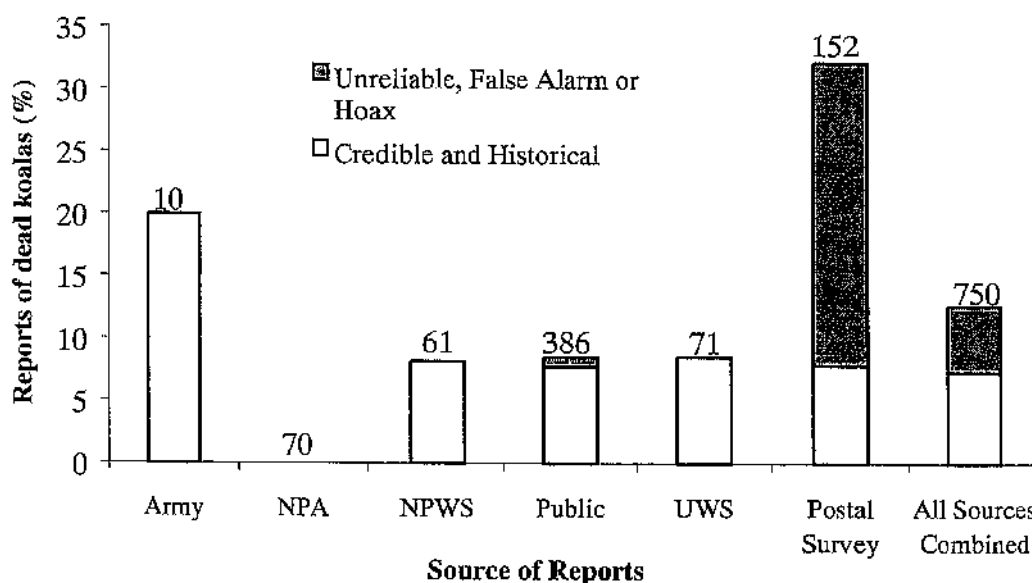


Figure 3.11. Graph of the percentage of reports, by data source, of dead or injured koalas for both the southern and greater Sydney regions. Reports are separated into combined credible and historical reports, and unreliable, false alarm or hoax reports (see section 3.2.3.2 for definitions of these terms). The total number of reports used to calculate percentages was the sum of all credible, historical, unreliable, false alarm and hoax reports for each data source, and is shown above each column.

Many of the reports of dead or injured koalas occur in the north and eastern part of the southern Sydney region, and many of these reports have been classed as unreliable (Fig. 3.12). However, there is a high concentration of credible sightings where Heathcote Road crosses Deadmans Creek at Sandy Point, and a cluster of unreliable reports where Heathcote Road crosses the Woronora River, at Lucas Heights (Fig. 3.12). Three koala male corpses were also collected from Heathcote Road, all

apparently killed by vehicle impact. All three corpses were collected within a one kilometre stretch of Heathcote Road where it crosses Deadmans Creek. Given that Heathcote Road passes through bushland habitat for approximately 13 kilometres, these corpses appear to be concentrated around Deadmans Creek.

A group of reliable reports of dead or injured koala reports occurs around the area of radiotracking activity at O'Hares Creek, Wedderburn. There are also clusters of reports where Wedderburn Road crosses the Georges River between St Helens Park and Wedderburn, on Georges River Road in Kentlyn, and where Peter Meadows Road crosses Peter Meadows Creek, also in Kentlyn (Fig. 3.12).

Most reports of dead or injured koalas for the greater Sydney region occurred in a rough line from the southwest corner of the southern Sydney region (Fig. 3.13). Most of these reports occurred on, or close to, the southwest freeway. However, a few of these reports come from koalas being hit by trains, such as at Yerrinbool.

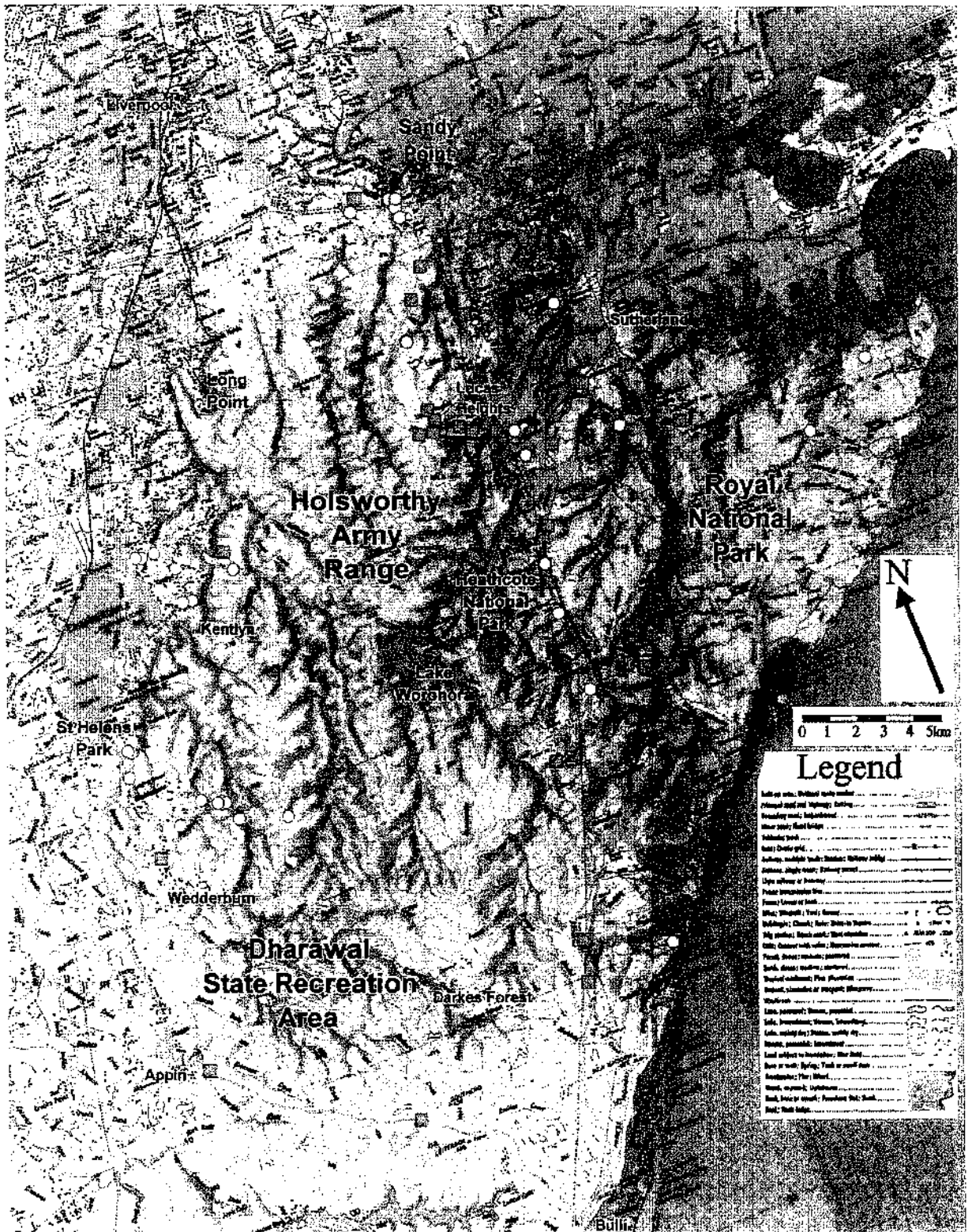


Figure 3.12. Locations of sightings of dead or injured koalas in the southern Sydney region. Reports classed as reliable are represented by yellow circles and those classed as unreliable by red squares. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

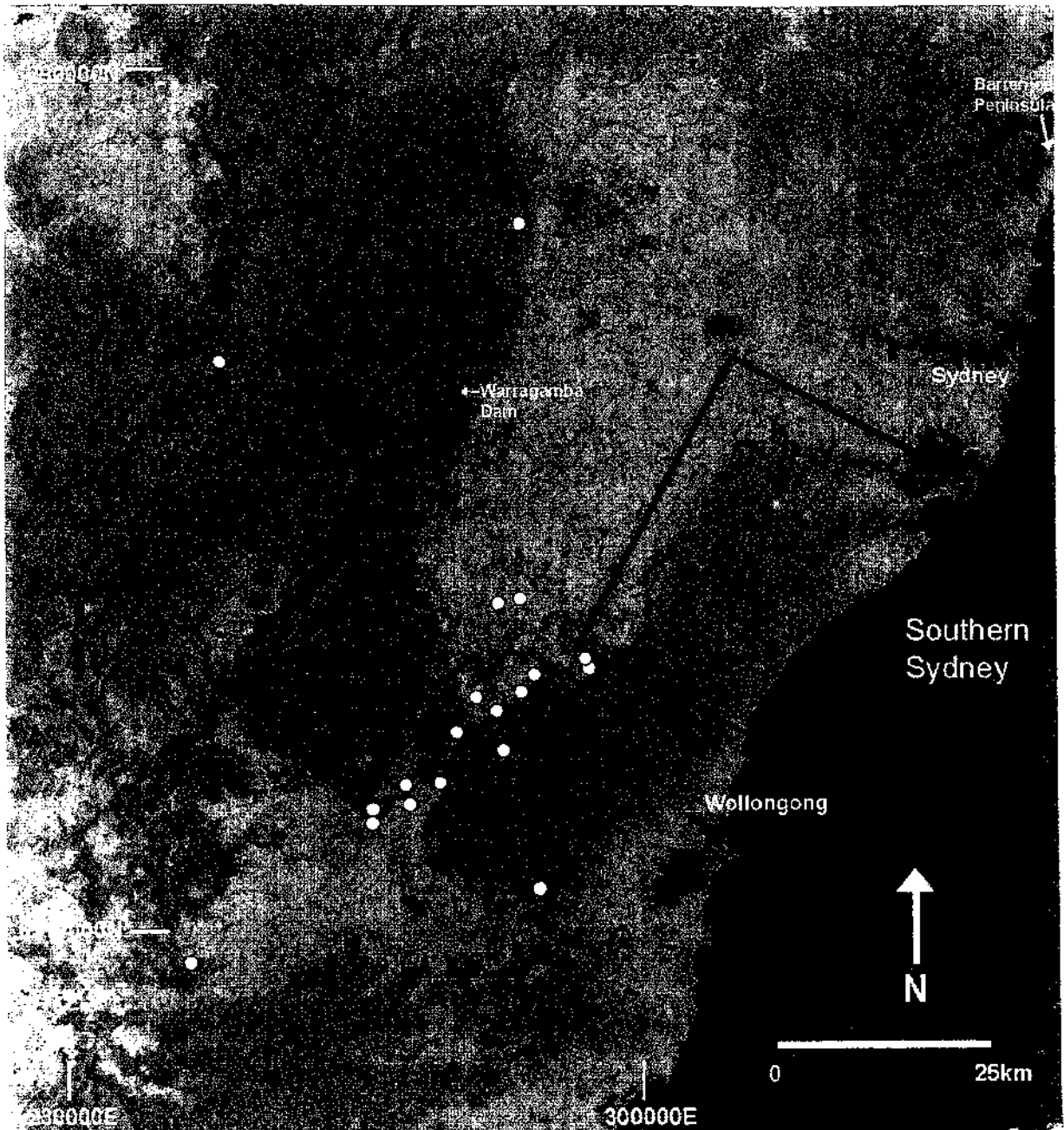


Figure 3.13. Locations of sightings of dead or injured koalas in the greater Sydney region. All reports are classed as reliable.

3.3.8 Temporal Changes

At least 75% of sightings of koalas received from all sources, for both the southern and greater Sydney regions, have occurred within the last 10 years, that is, from 1991 to 2000 (Fig. 3.14). In comparison, relatively few sightings have been reported for the much longer pre-1981 period, although the percentage is higher for the greater Sydney region (Fig. 3.14).

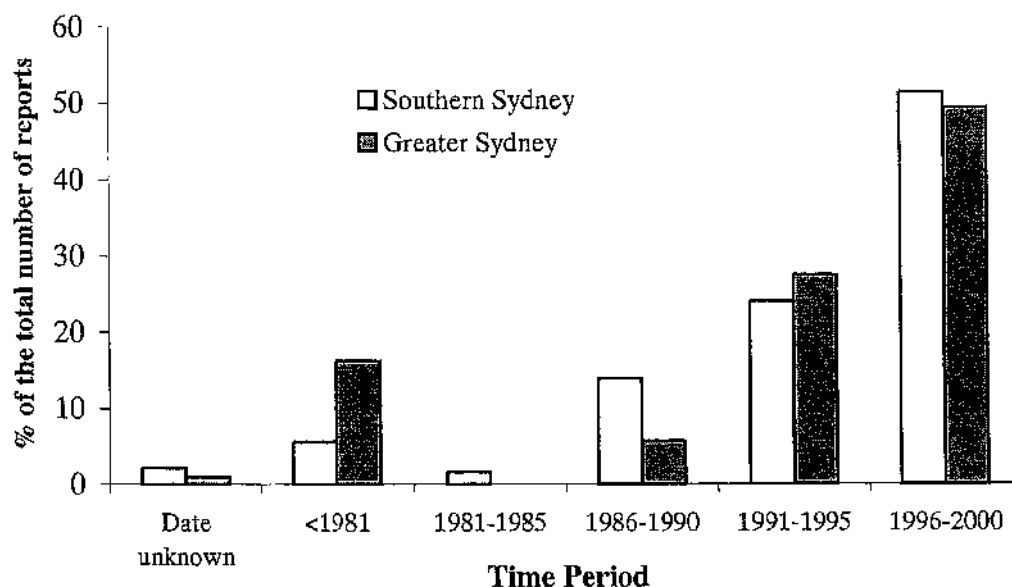


Figure 3.14. Graph of the percentage of the total number of koala sightings (both credible and historical) within given time periods, for both in the southern and greater Sydney regions.

Sightings from the periods 1996-2000 and 1991 to 1995 are widely distributed, with no discernible distribution changes (Fig. 3.15). For the period 1986-1990, the majority of sightings are from the Campbelltown region. This focus coincides with the uproar in 1986 over the proposed Wedderburn development and the walks conducted by the NPA to locate koalas (Fig. 3.16). The distribution of sightings during the period 1981-1985 is quite restricted, with the majority in the Sutherland region (Fig. 3.16).

Many of the pre-1981 sightings occur just to the south of Sydney in the Sutherland Shire region, with the earliest report from this region occurring in 1920, but also with a number of 1960 and 1970 sightings (Fig. 3.17). Pre-1981 sightings, the earliest in 1912, are also scattered through the Cataract, Cordeaux, Nepean and Avon dam catchments (Fig. 3.17).

In the Campbelltown area there are three pre-1981 reports from 1900 (all these reports are from the one person), and other sightings in the 1960s and 1970s, some in areas cleared in the present day (Fig. 3.17).

The Campbelltown postal survey by Callaghan *et al.* (1998) recorded three pre-1981 sightings, not recorded in this study. A sighting in the 1970s by G. Wilson at Wedderburn, one by Thomas Moorland in 1976 at Myrtle Creek (to the north of Minto

Heights), and by Ian and Peggy Rodden in 1978 at Ingleburn and Myrtle Creek (Callaghan *et al.* 1998).

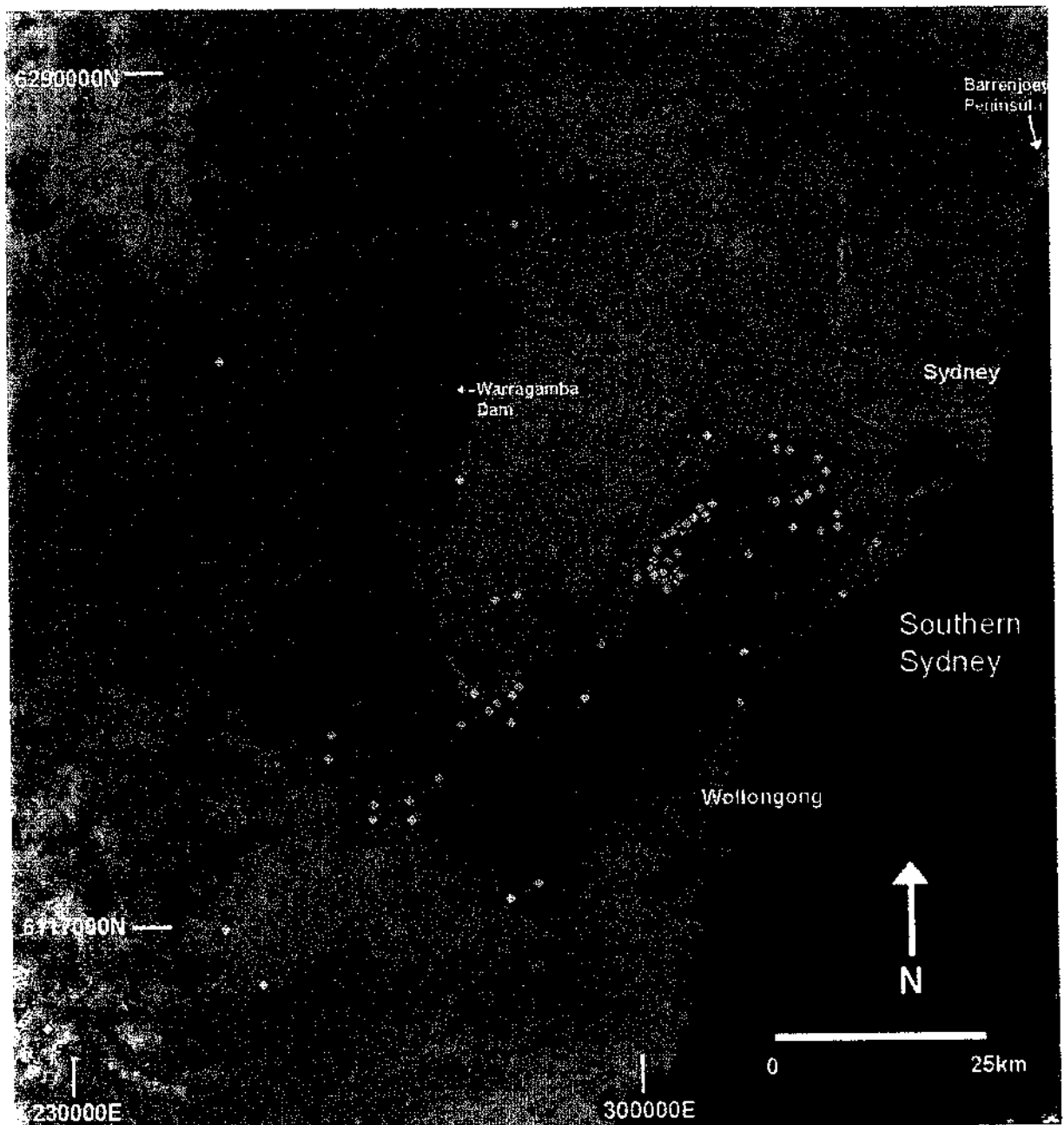


Figure 3.15. Locations of koala sightings, both credible and historical, that occurred from 1991 to 2000. Orange diamonds represent sightings from 1991 to 1995, and blue triangles represent sightings from 1996 to 2000.

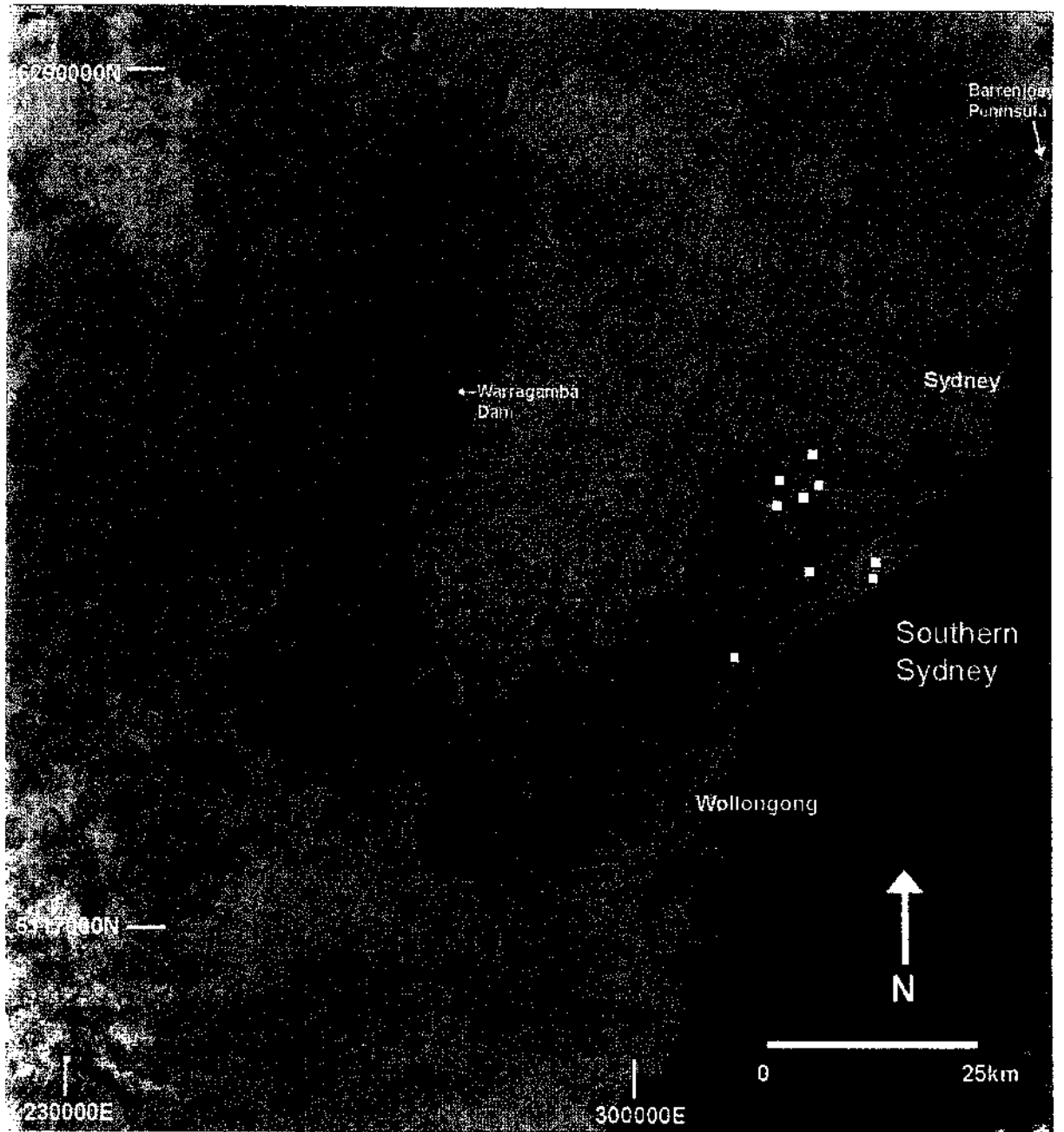


Figure 3.16. Locations of koala sightings, both credible and historical, that occurred from 1981 to 1990. Yellow squares represent sightings from 1981 to 1985, and red circles represent sightings from 1986 to 1990.

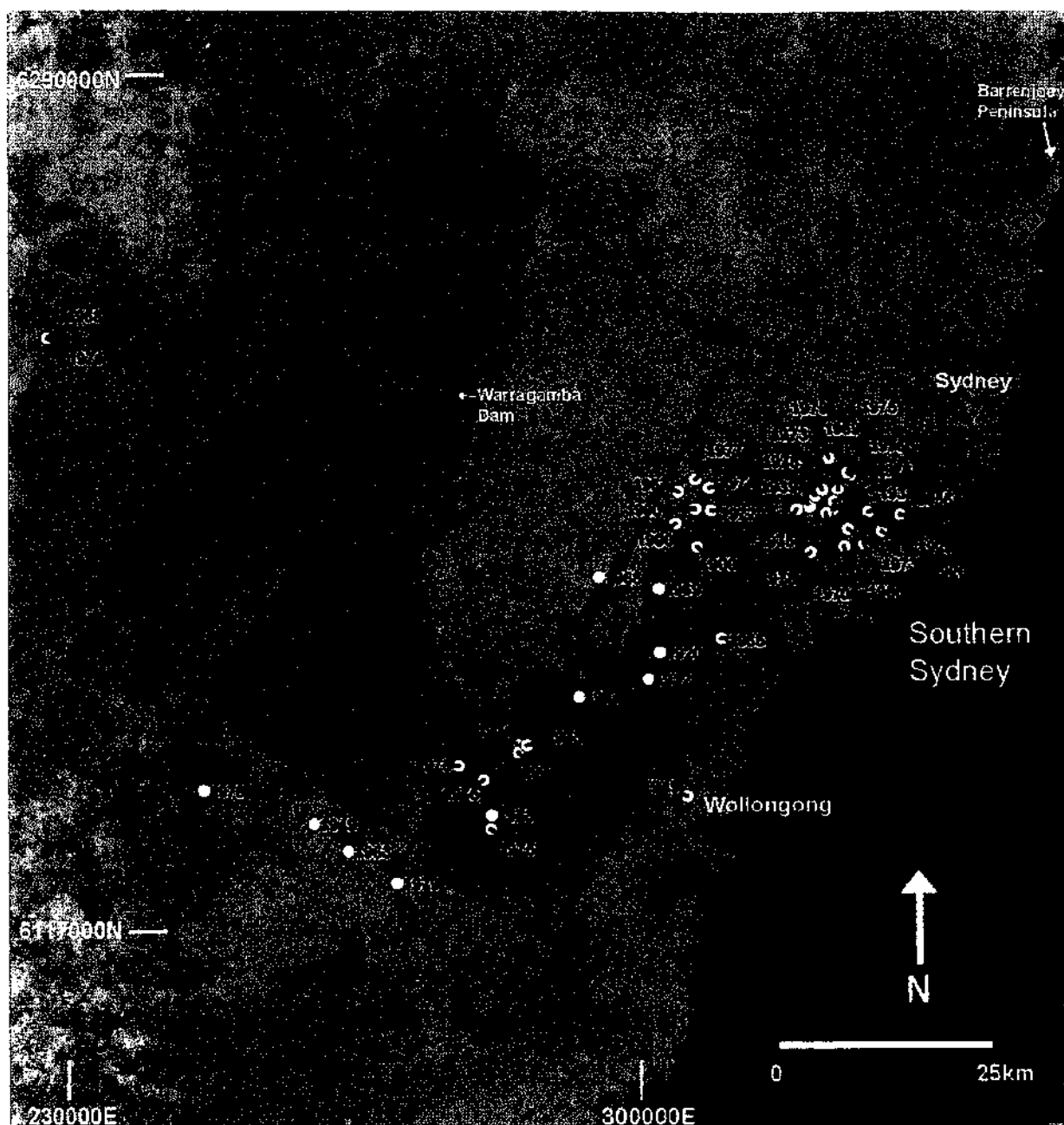


Figure 3.17. Locations of koala sightings, both credible and historical, that occurred prior to 1981. The year is shown and is linked to the sighting location by a line where necessary.

In the southern Sydney region, there were a number of historical sightings of note (Table 3.10). Report numbers 97121, 98014, 98112, 98122, 99265, 99291, 99293, 99357, 99363, 99377, 99376, and 2000053 are all reports where individual sightings cannot be separated (Table 3.10). Report numbers 99204, 99265, 99302 and 99372 provide evidence that breeding female koalas were present at the following locations: Darkes Forest, along the Woronora River from Barden Ridge to Woronora/Yarrowarra, and within the Royal National Park (Table 3.10). Most of these areas, except Darkes Forest, have now been heavily developed, or there are barriers to

movement caused by roads and railways. Thus, it is difficult to ascertain whether these breeding groups still remain. It seems probable, however, that breeding koalas are still present at Darkes Forest, and that there may be scattered breeding females in the other areas.

Report numbers 98111, 98127, and 98128 provide evidence that Campbelltown residents hunted koalas in the 1900s for their pelts. Close (1993) also recorded that Aub and Mick Rixon hunted koalas in Wedderburn around the turn of the century and that *“With his 60 to 80 hounds, Mick would venture out to the second creek over (presumably O’Hares Creek) to hunt”* (Close 1993).

The comments in report 99280 about a “Mr Hicks” breeding koalas in the Oatley area in the 1970s, is of particular interest because it is unclear what was the origin, and what became of, these animals. Despite enquiries to see if these koalas may have gone to a koala park and requests for further information from the public, it has not been possible to clarify this report.

Five reports, by four people are particularly noteworthy for the greater Sydney region (Table 3.11). The report of 12 koalas seen at Oakdale (report number 93013) is significant because it is the only report from that region; however, the large number of sightings suggests that there may be a breeding colony there. The female with young hit by the train (report number 97125) indicates, together with other sightings from this region, that koalas are breeding in the Yerrinbool area. The 10 sightings in the Nepean Dam catchment (report number 97061) helps to confirm that koalas are breeding in this area. The report of koala colonies at Didicollum and between Douglas Park and Menangle (report numbers 99045 and 99095) is vague, but suggests that koala populations may previously have been more widespread than is the case today (assuming these colonies are no longer present).

A number of people reporting koala sightings have commented that they felt particular koala colonies had been destroyed by bushfires (Tables 3.10 and 3.11). Whether these perceptions are accurate is impossible to determine, especially as koalas are sighted infrequently. However, it certainly suggests that intense fires have at least reduced koala populations.

Table 3.10. Details for historical sightings of note for the southern Sydney region, together with the number assigned to the records. See Fig. 3.6 for locations of these reports.

Record Number	Description
97121	Reporter used to canoe up Southwest Arm Creek, Royal National Park, when he was 13 - 15 years old. He would canoe up the creek as far as possible (to around Winifred falls), and then walk upstream. He saw 3 - 4 koalas between 1964 and 1966. All koalas were on their own and were within 50 to 100m of Southwest Arm Creek in a 400 to 500m stretch from where he left his canoe. The koalas were seen on the seaward side of the creek.
98014 and 98122	About a half dozen koalas seen on fire trail at the north end of Aberfoyle Rd, Wedderburn, whilst bush walking. Has also seen "a few" koalas while bushwalking, picking fruit, about 100m south of Rice's orchard on eastern side of Wedderburn Road. All sightings occurred from 1988 to 1990.
98111, 98127 and 98128	Approximately the 1900s. Reporter's father and grandfather used to hunt koalas in the Campbelltown area. They used to go out when there was a full moon to spot koalas by their silhouette against the sky. They found koalas at a number of locations from Wedderburn (around the Woolwash) to Ingleburn (possibly in Myrtle Creek or Georges River). Koalas also lived on Smith Creek where there were grey gums (<i>E. punctata</i>) and in Peter Meadows Creek, anywhere along the length of the creek.
98112	Reporter has seen about nine koalas along Peters Meadow Creek from Minto Heights to Kentlyn, dates unknown.
99204	Statement given by respondent to postal survey: " <i>Hearsay only. My father was very familiar with the map area in the 1930-40. He said he knew of a koala colony west of Darkes Forest.</i> "
99240	Reporter used to work for Western Earthmoving (a construction company now in liquidation). Several construction workers reported two separate koala sightings (probably both adults) in 1973 at the top of the escarpment, at the south end of Anzac Rd in Menai.
99265	Response to postal survey: " <i>A friend reported to me he had sighted 5 koalas pre 1994 bushfires in the Still Creek- Woranora River intersection area. No longer there now since bushfires.</i> "
99280	Date given as 1990. Respondent's sister lived in Kitchener St, Oatley and it was well known that a "Mr Hicks" had a captive group of koalas in his backyard.
99291 and 99293	Reporter stated that she saw about five koalas sightings every month (a total of around 20 sightings) from 1994 to 1999, whilst driving along Sir Bertram Stevens Drive, Royal National Park, probably near Southwest Arm Creek. Was always going too fast to see if there were any koalas with young. Also saw koalas on about 30 occasions between 1996 and 1999, off McKell Av, Royal National Park, just past Waterfall, going towards Sir Bertram Stevens Drive.
99302 and 99372	Reporter passed on information about observations of koalas by her parents (both are now dead). Her father was in charge of Cataract and Cordeaux Dams and he saw koalas around the Cataract Dam (her parents lived at the dam) from about 1910 to 1915. Her mother sighted koalas along the Appin-Bulli Road in the 1920s, and said that there had been many changes since then. Location along the road estimated only.
99357, 99363 and 99377	Koalas seen two to three separate times in 1993, around the Christmas period, in a reserve on the escarpment of Austinmer or Thirroul, possibly Lady Fuller Park. The largest koala had a head-body length of about 45cm. Also a small koala, about 30cm head-body length, seen in a back yard of a house, possibly 21 Hill St, Austinmer, also around Christmas 1993. Also, when the reporter was a child in 1970, her family would visit 118 Old Bush Rd, Yarrawarra, and she would go with other children to look for koalas. They probably went into the Loftus Creek area and they saw an unknown number of koalas, but these animals included females with young.
99376	Response to postal survey: the reporter saw an unknown number of koalas. They grew up in Gynea Bay and "often" saw koalas in the bush in the 1950s and 1960s. No contact details given.
2000053	NPWS ranger John Andrew referred to koalas at Warrumbul, at "Hilltop" house in the Royal National Park in the 1920s (Andrew 2001). Mr John Andrew has now died. Number of sightings unknown.

Table 3.11. Details for historical sightings of note for the greater Sydney region, together with the number assigned to the records. See Fig. 3.8 for locations of these reports.

Record Number	Description
93013	12 koalas seen off Steveys Forest Rd, Oakdale, dates unknown.
97125	Adult female with young hit, and presumably killed, by train in 1994 on Yerrinbool side of Yerrinbool tunnel 125.
97061	Was helping to fight fires in 1979 on Nepean Dam catchment, and saw about 10 koalas in a two-week period. Also heard that there were koalas at the old coalmines in 1800s. Unclear as to which coalmines are referred to.
99045 and 99095	Two locations with an unknown number of koala sightings. Colony halfway between Douglas Park and Maldon "a long time ago". Also on a property called Didicollum, on Morton Park Rd between Douglas Park and Menangle. According to the reporter bushfires destroyed both colonies, the one at Didicollum in 1968 fires.

3.3.9 Seasonal Variation in Koala Reports

October and September are the most prolific months for koala sightings, and are notably higher than all other months (Fig. 3.18).

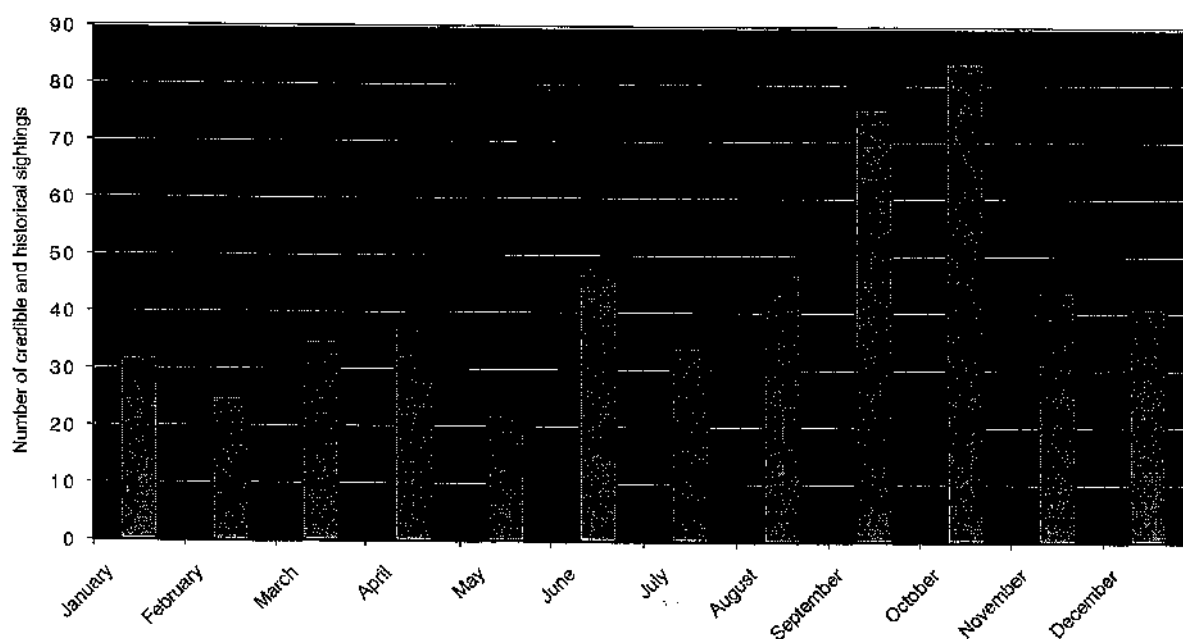


Figure 3.18. Graph of the total number of credible and historical koala sightings per month for all data sources. Only reports of koala sightings where the date was classed as good or fair were used.

3.3.10 Koala Movements

Large movements of nine koalas could be traced because of reports where the eartag colours were described accurately or confirmed by a member of the UWS koala research team (Figs 3.19 and 3.20). Only one animal, Wilhelmina, was female, and the remaining eight were male. Young animals made the three longest recorded movements: Dan 19.7km, Bill 19km, and Wilhelmina 12.9km, (Figs 3.19 and 3.20).

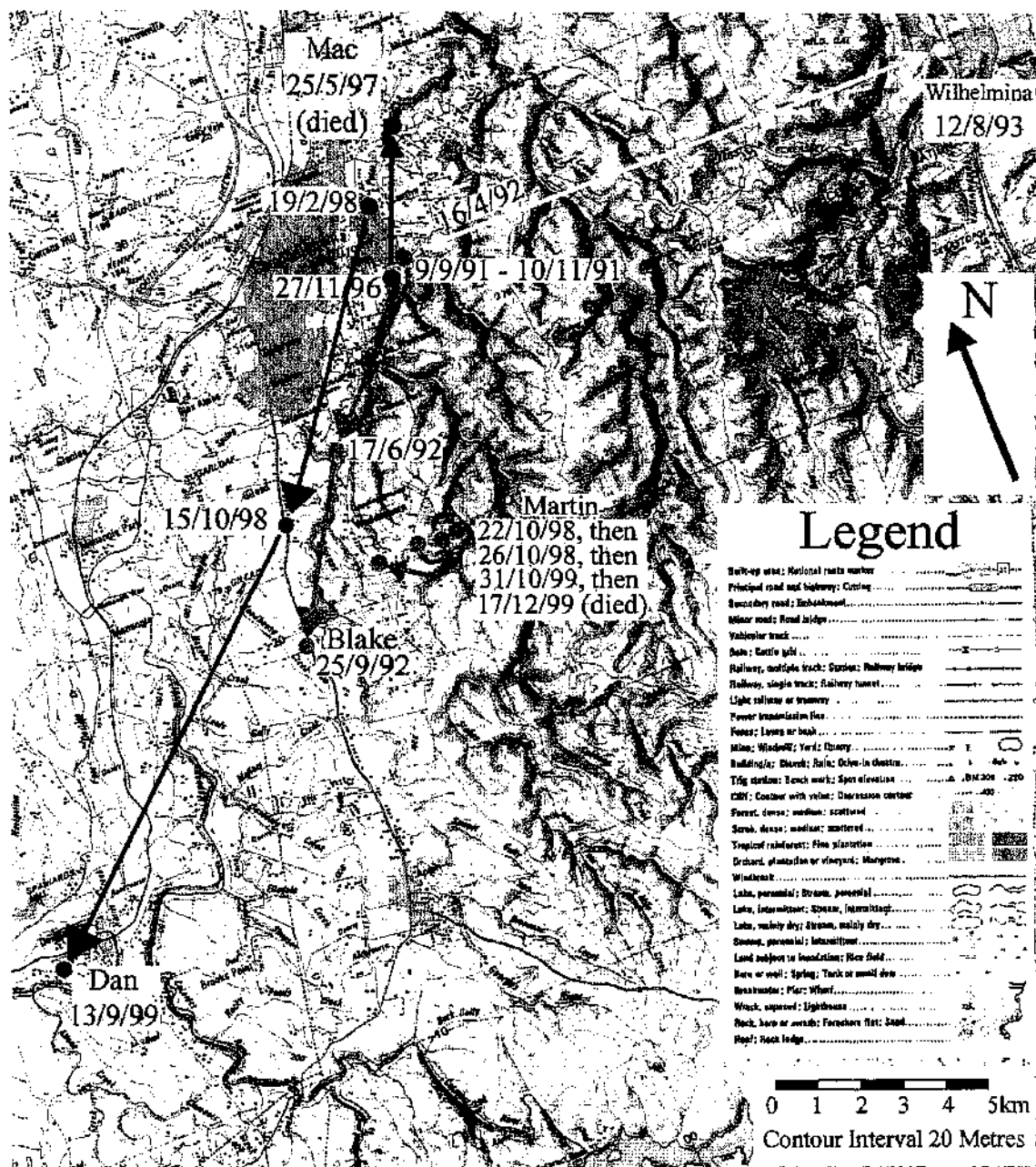


Figure 3.19. Map 1 of selected koala movements greater than 2km. Dates of sightings are indicated for each point. A range of dates means that the koala was radiotracked in that area over the period indicated. Five koalas are shown: Mac in dark blue, Blake in light blue, Dan in dark green, Wilhelmina in yellow, Martin in light green. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

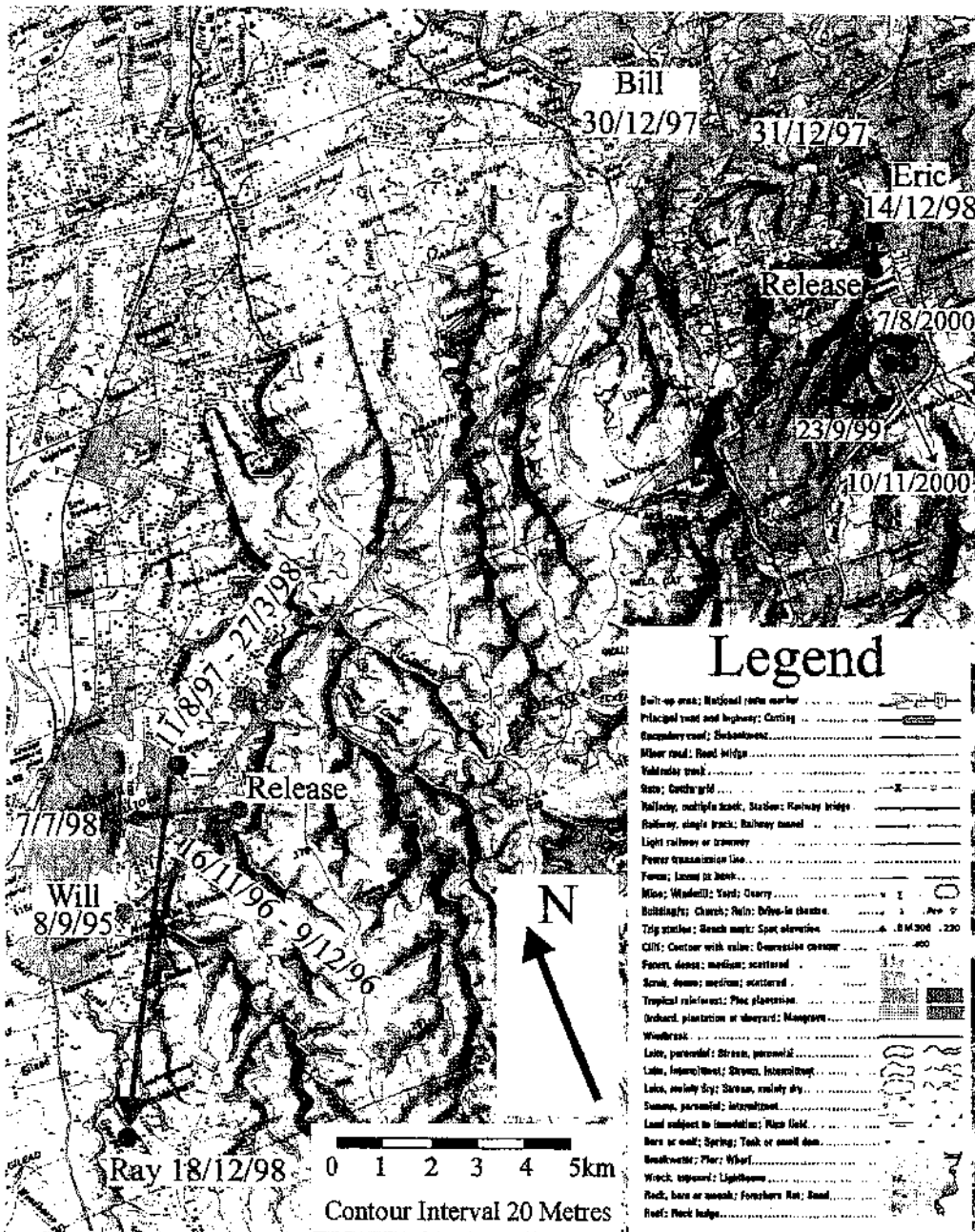


Figure 3.20. Map 2 of selected koala movements greater than 2km. Dates of sightings are indicated for each point. A range of dates means that the koala was radiotracked in that area over the period indicated. Four koalas are shown: Ray in purple, Bill in light blue, Eric in navy blue, and Will in light green. The points marked "Release" is where koalas Eric and Will were released after being captured. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

These movement records clearly indicate that koalas are moving within the Holsworthy Army Range. These movements also mean that it is feasible that present day sightings of koalas in the northern and eastern parts of the southern Sydney region could all be derived from the known Campbelltown breeding population.

Furthermore, the movements of koala Dan are particularly noteworthy as he managed to cross from the Georges River catchment into remnant bushland within the Nepean River catchment. This clearly demonstrates that gene flow between the southern Sydney, and greater Sydney region, is possible, at least at a low level. However, the low number of sightings along the Appin to Bulli road should be noted. Interspersed woodland and heathland occur in this area and this habitat, which appears to be unsuitable for koalas, may hinder koala movements.

3.3.11 Soil Fertility

Much clearing of habitat in the southern Sydney region has occurred since the 1800s, particularly in the more fertile soils (see section 2.5), and this clouds the assessment of koala sightings in relation to soil fertility. However, three points should be noted.

First, the reports of sightings from Kentlyn, St Helens Park and to the west of Wedderburn were located on, or close to Wianamatta group shales (Fig. 3.21). However, the sightings to the east of Wedderburn, which is where most Wedderburn animals were radiotracked, occur on Hawkesbury Sandstone (Fig. 3.21). This is important, because soil derived from the Wianamatta group shales are more fertile than those derived from Hawkesbury Sandstone.

Second, remnant Narrabeen group shale vegetation exists in the south of the Royal National Park and in the Helensburgh area, but there are few koala sightings in these areas (Fig. 3.21).

Third, between Appin and Bulli, where only two historical reports of koala sightings have been received, there are many patches described as "*Clayey Quartz sand with humic matter*" (Fig. 3.21). This results in low fertility, poorly drained, soils and the vegetation in the area is heathland interspersed with low open woodland. This habitat may be unsuitable for supporting koalas.

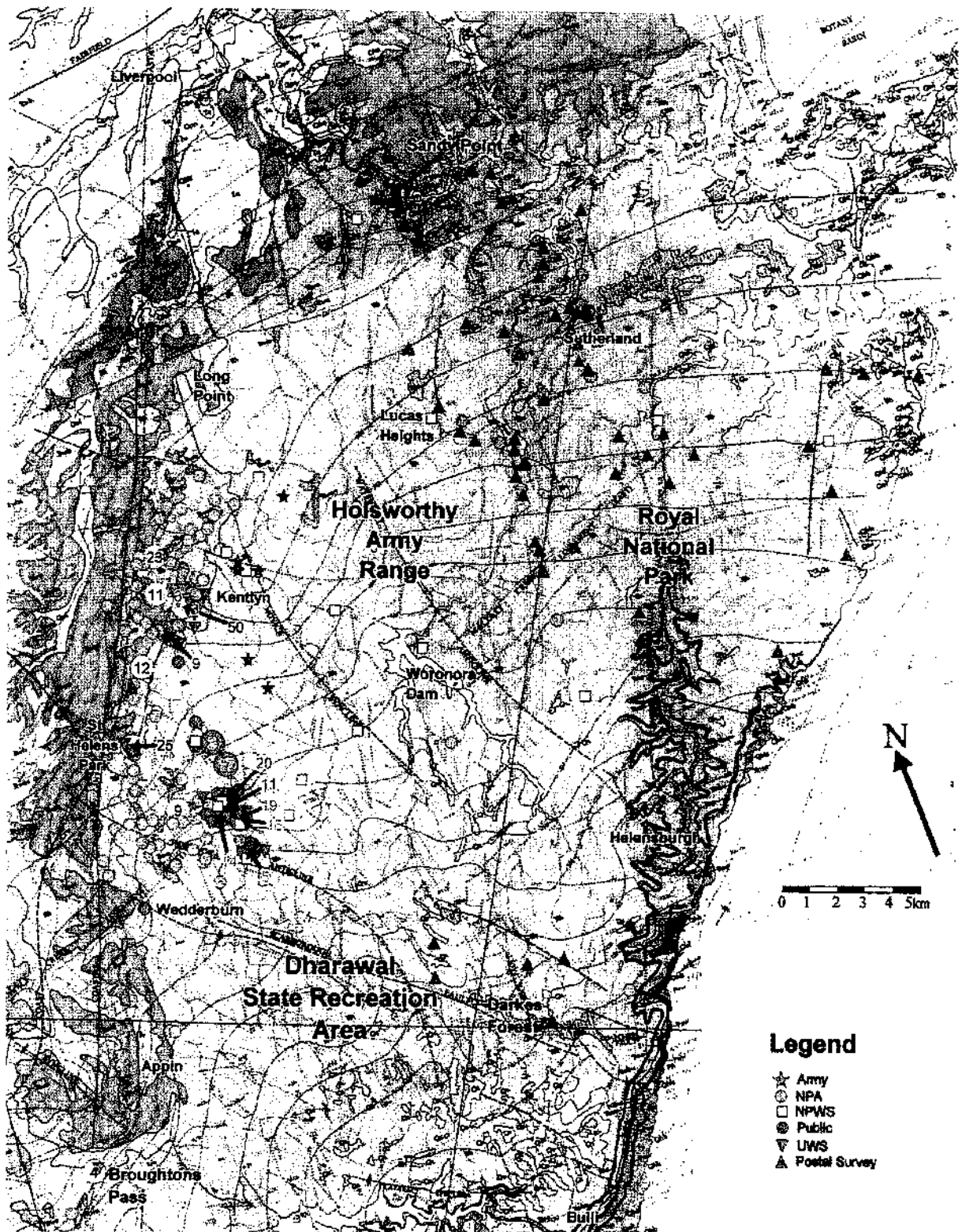


Figure 3.21. Locations of credible koala sightings separated by the source of the sighting, plotted over the geology of the southern Sydney region. Small symbols represent one sighting whilst larger symbols represent multiple reports. Numbers with the larger symbols indicate the number of sightings for that source in that locality. See Figure 2.2 for legend to geological features. Acknowledgment: Map courtesy of Department of Mine and Mineral Resources. Crown copyright ©. All rights reserved.

3.3.12 Density Estimates

3.3.12.1 Volunteer Searches

The volunteer search method was abandoned after two trials, two tests and five normal searches (with a “normal” search being a search of either ridgetop or gully habitat as described under *University of Western Sydney*, in section 3.2.1), with a total of 63 person days of search effort. These searches were mainly conducted on ridges (Table 3.12). From this effort one new koala, a juvenile male, was found and captured, and the remains of a previously collared animal were discovered.

Table 3.12. Details for all volunteer searches conducted.

Search type	Area searched (ha)	Location	Gully or Ridgetop	Koalas Found
Collared Koala Test*	5.0	Wedderburn	Ridge	Collared female with back young and koala remains found.
Toy Koala Test†	4.7	Wedderburn	Ridge	Collared female‡ and 5 of 6 toy koalas found.
Trial	1.1	Wedderburn	Ridge	No
Trial	1.3	Kentlyn	Ridge	No
Normal	5.0	Kentlyn	Ridge	No
Normal	5.1	Wedderburn	Gully	No
Normal	5.4	Wedderburn	Ridge	Juvenile male found, but not in search area.
Normal	5.1	Wedderburn	Ridge	No
Normal	5.4	Wedderburn	Ridge	No
Total	33.1	-	-	1 female

* = This row not included in totals at the bottom of the table.

† = For this test, six toy koalas were tied into place in randomly selected trees in a pre-defined search area.

‡ = The collared female's presence in the search area was unknown prior to the search being conducted.

The test searches detected a collared female during both tests. The female's presence during the second test was incidental, as the objective was to see how many of the randomly placed toy koalas in a predetermined search area would be detected by the volunteers. Five of the 6 toy koalas, or 83% were detected (Table 3.12).

Excluding the search that specifically included the collared female koala and young within the search area, the remaining eight searches covered 33.1ha, with one animal

spotted within the search areas (Table 3.12). This gives a density estimate of 0.035 koalas ha⁻¹ with a standard deviation of 0.087.

3.3.12.2 Home Range Estimate

The average adult female MCP home range size (section 5.3.1) was 45.94ha and the proportion of females 0.44 (section 4.3.1). This gave an density estimate of 0.049 koalas ha⁻¹, excluding dependent young.

3.3.13 Estimates of Koala Numbers

The sizes of the areas used by breeding animals were estimated to be 3600ha for the southern Sydney region (Fig. 3.22), and 9750ha for the greater Sydney region (Fig. 3.23).

Multiplying the estimate of the area used by breeding animals by the density estimate of 0.035 koalas ha⁻¹ for the volunteer search method, gave population size estimates, excluding dependent young, of 126 individuals for the southern Sydney region, and 341 individuals for the greater Sydney region. Using the home range density gave estimates, also excluding dependent young, of 178 individuals for the southern Sydney region, and 482 individuals for the greater Sydney region. Upper and lower values, within which the true population size is thought to lie, were estimated to be 90-200 individuals for the southern Sydney region, and 170-700+ individuals for the greater Sydney region (excluding the southern Sydney population).

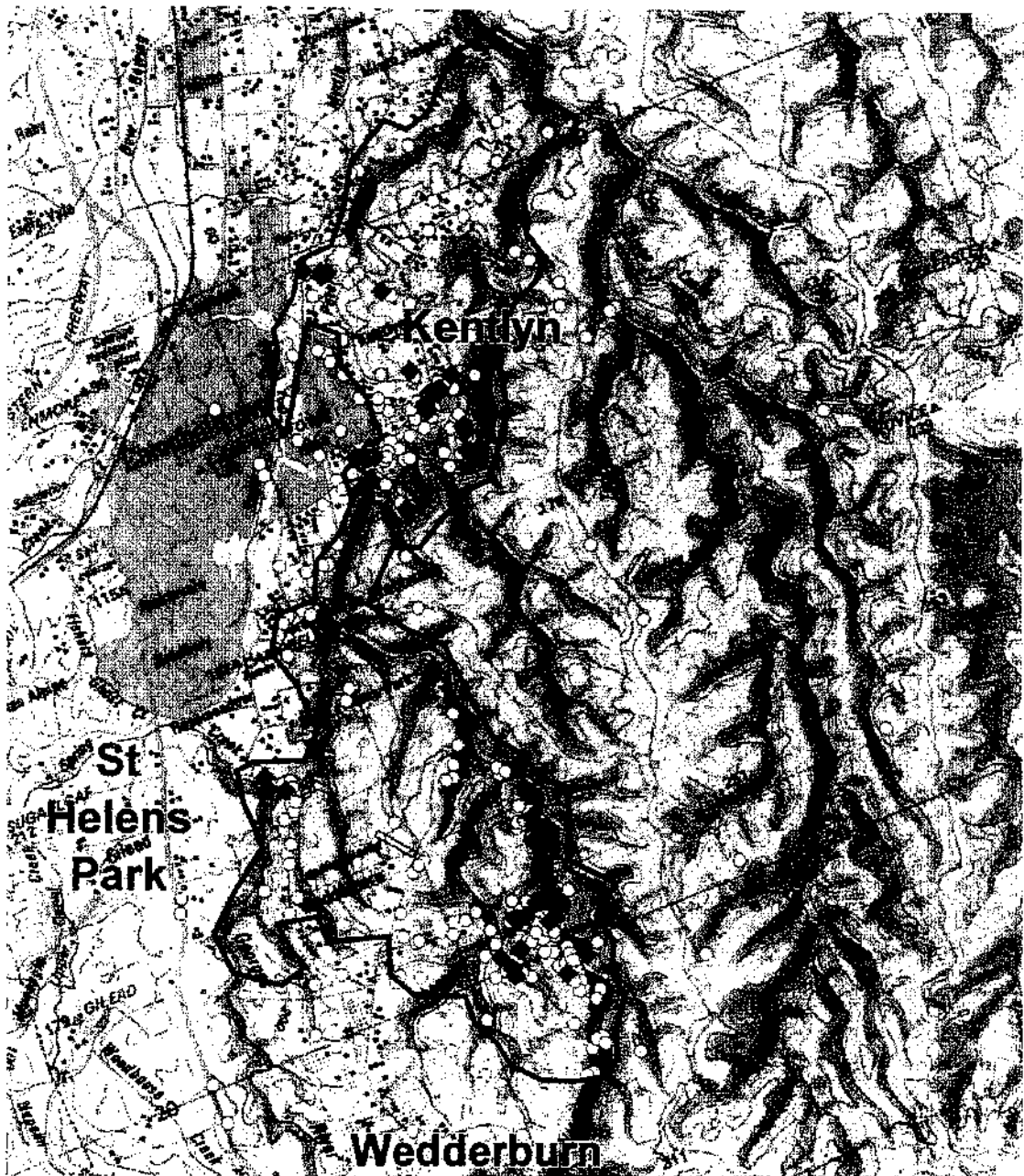


Figure 3.22. The estimated area used by breeding female koalas in the southern Sydney region. White dots represent locations of credible and historical koala sightings, and diamonds represent reports of females with young. The black line encompasses the estimated area used by breeding female koalas (3600ha). Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

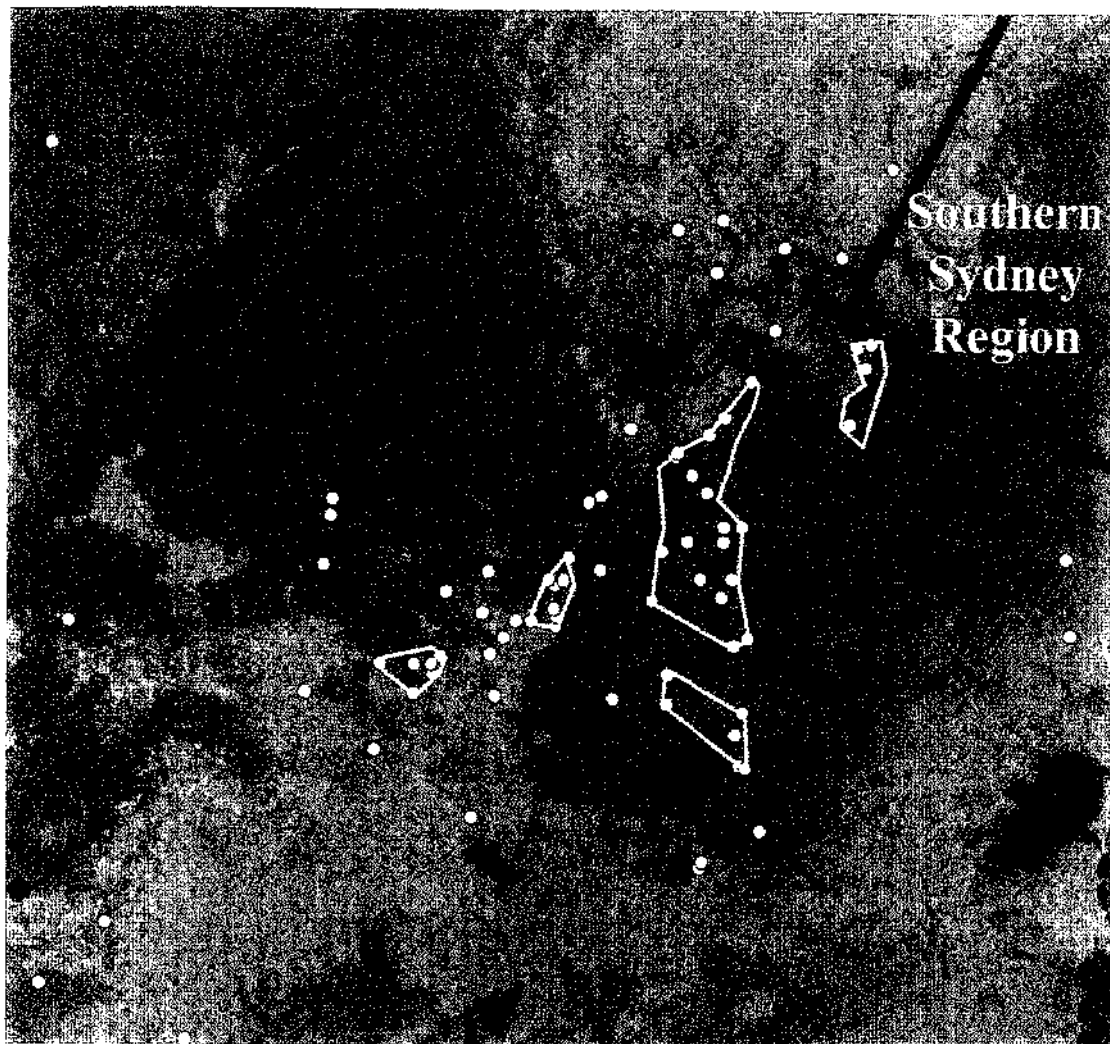


Figure 3.23. The estimated area used by breeding female koalas in the greater Sydney region. White dots represent locations of credible and historical koala sightings, and diamonds represent reports of females with young. The white line encompasses the estimated area used by breeding female koalas (9750ha).

3.3.14 Sutherland Postal Survey

A total of 2676 returns were received by 1st March 2000, a response rate of 10.3%. Respondents to the survey varied widely in their ages (although 1368 respondents did not answer this optional question), ranging from 10 to 90 years old, with the average being 47.05 years. All except 27 respondents supplied information on how long they had lived in southern Sydney, with the average time being 22.41 years, which is much lower than the average age. Eighty-two years was the longest reported time living in southern Sydney.

A total of 158 respondents, or 5.9% reported having sighted a living or dead koala. Some respondents indicated that they had never seen a koala at question 3, but yet indicated that they had seen a dead koala in question 6.

Unfortunately, some respondents indicated sighting a koala at question 3 or 6 but did not provide location(s), or contact details, and therefore could not be contacted for clarification. These survey responses were entered in the survey database, but were omitted from the koala sighting database.

Eight respondents indicated that they believed that the number of koalas had increased and 33 that they believed that the number of koalas had decreased. Many of these persons did not give a year when they had noticed this change and no consistent trends were evident for those who did give a year. The majority of respondents either did not answer this question or answered that they didn't know. This result is not surprising given the low number of koala sightings.

The greatest support from respondents was for tree planting programs (2301, or 86.0%), then environment protection zones (2255, 84.3%), restrictions on dogs (2209, 82.6%), traffic restriction in koala blackspots (1897, 70.9%) and using public money from rates or taxes to buy land for koala reserves (1754, 65.6%).

Many respondents made additional comments in the space provided. The most common were that they (the respondents) supported the survey, that they would support controls on cats, that they walked a lot in the area (often with the comment that they had never seen a koala despite lots of walking) and that they would like to see more koalas or other wildlife. Some respondents also expressed concern about overdevelopment in their area. A number of respondents requested further information or offered their help as volunteers. Some also commented that they believed that koalas should be released in the area and others that the rusa deer (*Cervus timoriensis*) should be removed from the area, and in particular from the Royal and Heathcote National Parks.

3.4 Discussion

A central problem for this study was the difficulty in locating animals. Indirect study techniques, for example faecal pellets counts, can provide useful information. However, a crucial advantage to this study from ongoing collection of public sightings was that these sightings allowed many opportunistic captures and subsequent data

collection. An advantage of constructing the database for data analysis is that it has made the koala sighting data accessible, and this information will be useful to councils, consultants, community groups and the Land and Environment Court.

I also utilised the opportunity to review community sighting data by comparing the six koala sightings data sources. Key outcomes from the comparison and review of the data sources were:

- Ongoing collection of sightings from the public provided the greatest number of reports of koala sightings.
- Greater publicity and the use of pagers to provide a simpler and speedier method for those reporting sightings greatly increased the number of reports received.
- The postal survey conducted in the Sutherland region resulted in many new koala sightings, but also included many unreliable and multiple reports.
- Various data “filters” were used, namely whether a sighting was a false alarm, hoax, unreliable, or multiple report, data and location quality, and separation of “historical” sightings.
- Credible reports comprised 62.7%, and historical reports 10.6%, of all koala-related reports from the combined data sources, with the remaining 26.7% classed as a false alarm, hoax, unreliable or multiple reports, or a report of a koala bellowing, scratches or scats. Thus, use of the data “filters” removed many misleading reports from the data used for analysis.
- This systematic approach of data filtering has not previously been used for assessing community reports of koala sightings, but this technique should improve this increasingly popular survey method.

3.4.1 Sutherland Postal Survey

The response rate to this survey (10.3%) was approximately in the middle of rates achieved by other postal surveys (see section 3.1.3.4). The higher return rate for the Port Stephens survey can probably be attributed to more effort, particularly through schools to encourage returns and the greater koala population in the area (i.e. members of the public would be more likely to have sighted a koala, and because they had something to report, more likely to return the survey). Publicity for the Sutherland

region survey in the *Sutherland Shire Leader* would have helped to inform the community about the purpose of the survey, and to encourage replies.

Respondents varied widely in their age, and length of time living in the shire, which indicates that koalas attract attention from many different groups in the community. Conversations with respondents indicated that the quality of information reported about koala sightings appeared independent of the respondent's age. That is, some respondents, both young and old, could supply quite specific information, whereas others were vague.

For the Sutherland region survey only 5.9% of respondents reported sighting a koala in the southern Sydney region, which is even lower than the 8% for the Eden survey (see section 3.1.3.4). The Eden area has a low koala density (Allen 2000), and the fact that fewer respondents to this survey reported sighting koalas than for the Eden survey is consistent with koalas occurring at low densities within the Sutherland region. The lower number of respondents reporting koala sightings for the Sutherland survey may be due to fewer people spending time in, or passing through, the bushland areas in the Sutherland region than at Eden.

No trends in changes of koala populations over time were discernible from the responses to the postal survey. Again, the response to this question emphasises that koalas occur at a low-density in the area surveyed. In hindsight, given the low-density of the koala population, this question was not useful.

Support amongst respondents for conservation actions was high, although lower than support for similar actions proposed in the Port Stephens survey where support ranged from 75-98%. There was particularly high support for tree planting programs, environment protection zones, and restrictions on dogs, despite a low percentage of respondents reporting having personally sighted koalas in the area. Probably these three actions were seen as having other benefits, even if respondents did not believe koalas to be present in their local area.

Thus, the Sutherland postal survey has many similarities with other surveys that have been conducted. The respondents reported few koala sightings, which is consistent with

koalas occurring at a low-density in the region. The low number of reports of koala sightings from the respondents, and the high number of reports of koala roadkills, may account for why a high percentage (41.3%) of these reports of koala sightings were classified as either being hoaxes, unreliable or a multiple report. Further, the postal survey had the worst date and location quality for koala reports of the six data sources used, despite attempts to contact as many respondents reporting koala sightings as possible.

The high number of hoaxes, unreliable and multiple reports for the postal survey sound a warning for the use of these types of data, as not all reports are reliable. Where there are many reports in a location this is unlikely to matter, as at least some of the reports should be reliable, thus indicating that the location is indeed utilised by koalas. As a note of caution, however, one roaming, juvenile male koala, Bill, generated 12 reports (in both the public and postal survey categories) by choosing extremely visible locations within suburbs in the Menai area, over a period of only two days. Eleven of these sightings were classed as multiple reports, thus avoiding the erroneous conclusion that this location is particularly important to koalas.

Where there are few reports of koala sightings for a location, unreliable reports could lead to a false conclusion that koalas are present at that location, and for many locations within both the southern and greater Sydney regions there were few koala sightings. Thus, the use of data filters in this study has improved the reliability of the conclusions.

I believe that the postal survey design was sound, but I found that question four, which asked whether koala numbers had changed, did not provide useful information. The problem with this question was even those respondents who had seen koalas more than once, and these were few, had seen koalas too infrequently to observe changes in population numbers. Also, in retrospect, question three, which asked how often koala were seen, could have reflected the low population density better, by changing it to:

How often have you seen koalas in southern Sydney?

- a) *never* b) *once* c) *twice* d) *more than twice.*

3.4.2 Comparison of Data Sources

Next, I review the strengths and weaknesses of the six data sources used in this study (compiled in Table 3.13).

The data sources varied in the areas they surveyed effectively. The Army and NPWS data sources covered the Holsworthy Army Range, but this region was poorly covered by other data sources. However, there were few Army reports. For the postal survey, the distribution area was selected to provide more information about the Sutherland region, about which little was previously known (Ward and Close 1998, 2000).

Table 3.13. Strengths and weaknesses of the data sources used.

Source	Strengths	Weaknesses
Army	<ul style="list-style-type: none"> • Most sightings came from locations poorly covered by other data sources • Some reports resulted in capture attempts or retrieval of corpses 	<ul style="list-style-type: none"> • Few reports
NPA	<ul style="list-style-type: none"> • High detection rate of females with young 	<ul style="list-style-type: none"> • Covered a small area
NPWS	<ul style="list-style-type: none"> • Covered a large area, including locations poorly covered by other data sources • Included location quality assessment 	<ul style="list-style-type: none"> • Female koalas with young not recorded
Public	<ul style="list-style-type: none"> • Many reports • Koala sightings continue to be reported • Some reports resulted in capture attempts or retrieval of corpses • Eartag colours could be recorded • Can collect reports of other animal species • Offers the opportunity to educate and inform the community 	<ul style="list-style-type: none"> • The area covered is limited • Low detection rate of females with young • Required publicity to obtain reports • Included reports classified as false alarms, hoaxes or unreliable • Many multiple reports of koala sightings
UWS	<ul style="list-style-type: none"> • High detection rate of females with young • Sightings could result in a capture attempt or retrieval of corpses • Eartag colours could be recorded • High degree of confidence in these reports 	<ul style="list-style-type: none"> • Covered a small area
Volunteer Search Method	<ul style="list-style-type: none"> • Provided a density estimate 	<ul style="list-style-type: none"> • Large work effort • Few new koalas located • Difficult to utilise in gully habitat
Postal Survey	<ul style="list-style-type: none"> • Many reports • Can ask for respondents' opinions about management issues • Can collect reports of other wildlife sightings 	<ul style="list-style-type: none"> • The area covered is limited • Low detection rate of females with young • Had the highest percentage of reports classified as a false alarm, hoax or unreliable • Many multiple reports of koala sightings • High workload to design and distribute the survey, and to collate and enter the replies

The NPWS Atlas provided widely distributed sightings from a large area and inclusion of the location accuracy field for these data was advantageous. However, the lack of information about the breeding status of animals sighted was a deficit. Moreover, although the name of the person who sighted the koala helped to identify duplicate records, contact details for those persons who reported NPWS Atlas sightings were not available, so reports could not be clarified.

NPA and UWS sightings were more numerous than NPWS sightings, and detected more koalas with young than other data sources. However, these sightings mainly occurred in the suburbs of Kentlyn and Wedderburn where the NPA conducted walks to locate koalas and the UWS radiotracking occurred.

Public sightings provided the largest number of reports of koala sightings and the sightings were widely dispersed. However, the areas which the sightings came from were biased towards those where human-koala encounters were most likely to occur. Also, the reporting of koala sightings is ongoing, and will continue to provide information. Public reports allowed opportunistic captures of koalas, and an avenue for the education of the public about the research, the techniques employed, and general ecological issues.

The education of the public has also lead to a generally high level of support, for the research program, amongst the local community. This contrasts with some other areas where the community is opposed to koala research (Radford pers. comm.). Because the koala is such a well known, and loved, animal amongst the general community the importance of community support to allow *any* research to proceed should not be underestimated.

Support from the local community can also assist koala research. For example, this project received financial support from the community through donations, Mac's Koala Club membership fees, and through sales of a video (Ward and Close 1999). Furthermore, promotion of the science of ecology itself is considered worthwhile (Hobbs 1998, Recher 1998).

Whilst publicity helped to increase the reporting of sightings, what is not readily apparent from the statistics is the need, sometimes, to “break-in” to a community to start receiving reports from that area. An example is Airds, a suburb to the east of Campbelltown between Kentlyn and St Helens Park, where only two reports of koala sightings had been received prior to 2000. However, approximately 10 reports were received in 2000 (some of them multiple reports). It is unlikely that koalas have suddenly colonised this area, and it seems that once a few people had reported sightings, and talked to others members of the community about it, that this was a particularly effective form of publicity. Not “breaking-in” to these local communities may explain why few reports of koala sightings have been received from Long Point to Glenfield; despite Callaghan *et al.* (1998) predicting that there is suitable koala habitat present in this area.

3.4.3 Southern Sydney Distribution

Close (1993) mapped 23 sightings from Wedderburn to Kentlyn and describes sightings from some other locations. My study has greatly increased the number of koala sightings gathered by the University of Western Sydney (public, UWS and postal survey categories) to 439, and 84, credible reports, respectively, for the southern and greater Sydney regions (Table 3.3).

The reports collated from the six data sources clearly show that in the southern Sydney region, koalas occur in the Campbelltown area from Wedderburn, through St Helens Park, to Kentlyn and Minto Heights, and that they are breeding in these areas.

The wide distribution and scattered sightings of koalas with young in the rest of the southern Sydney region make the data hard to interpret. Some historical reports indicate that koalas used to breed along the Woronora River, from Lucas Heights to Woronora, and in the Royal National Park. Some koalas may still be breeding in these areas. Koalas may also be breeding at Darkes Forest.

It appears that female koalas may be breeding in some scattered locations in the Sutherland region. This fragmentation may be because suburban development, particularly the extensive clearing of shale soils, has left little habitat that will support

females with young. Undetected breeding groups may also be present in the Holsworthy Army Range.

The report of a “Mr Hicks” who was apparently breeding koalas in the Oatley area is particularly interesting. It is unclear what activities Mr Hicks was undertaking and what happened to the animals that he dealt with. Some respondents indicated that they believed that he was releasing koalas back into the wild. If true, this could impact upon the genetic makeup of koala populations in the area, especially if the koalas came from other areas.

3.4.4 Greater Sydney Distribution

There were few reports of koalas with young from the southern Sydney region, and these were scattered. However, the evidence gathered in this study, and from Currans *et al.* (1990) and Tilley and Uebel (1990), shows that koalas are present within the Nepean and Avon Dam catchments. It is unknown if the populations in the Cordeaux River catchment have recovered from the 1968 fires (Robinson 1985). It also appears likely that populations are present to the west and south of these catchment areas.

The western Sydney and Blue Mountains regions were not targeted by this study, although a few sightings from these areas were still received. However, in these regions Curtin *et al.* (2002) and Close *et al.* (2000) have gathered evidence that shows that koalas occur at low densities in Yengo National Park, Parr State Recreation Area and Lower Blue Mountains. The ability of koalas to travel long distances (see sections 3.1.3.4 and 3.3.10), may mean that genes are being exchanged between the greater and southern Sydney populations, and those in the Blue Mountains and to the north of Sydney. This study gathered koala tissue samples for genetic analysis by other researchers, but as the majority of samples came from the southern Sydney region, it was not possible to ascertain whether southern and greater Sydney region populations are genetically isolated. Further research to clarify this issue would be useful for koala management in the southern and greater Sydney regions (see chapter 7).

3.4.5 Estimates of Koala Numbers

The estimated population sizes of 90-200 individuals for the southern Sydney region, and 170-700+ individuals for the greater Sydney region, are small. Confidence in these estimates, however, is low, and I acknowledge that these population estimates are essentially educated guesses. The density estimate from the modified bounded transect (volunteer searches) is based upon finding one koala. The density estimate using the home range size assumed that use of home ranges by koalas is exclusive (ie. that there is no overlap between animals), that the MCP home range was an appropriate estimate, and that the 0.44 proportion of females found in this study reflects the true status within the population. Furthermore, the estimates of the areas used by the breeding koalas were highly subjective and relied upon reports of koala sightings, and this technique has bias in the areas from which reports are likely to be received.

I have more confidence in the estimate for the southern Sydney region than for the greater Sydney region, because significantly more information was available for the southern Sydney region. Furthermore, at the end of the year 2000, fifty-five tagged koalas in the southern Sydney region may still have been alive, with untagged animals frequently being reported, and thirty of the tagged animals were seen during, or after, the year 2000. Thus, I believe it extremely unlikely that the true population sizes could be less than two-thirds of the lower population estimates. However, the upper population size estimates are considered conservative given the large tracts of remnant vegetation, particularly for the greater Sydney region. That is, these population estimates apply to the areas where koalas are known to be breeding, and some areas where koalas are breeding may not have been detected and hence it is more likely that I have underestimated, rather than overestimated the population sizes.

3.4.6 Population age structure

The similarity of koalas' ages for reports from the southern and greater Sydney regions indicates that populations in both areas have similar proportion of juveniles within their populations. The fact that at least 69.6% of reports were of adult animals (some adults may have been included in the 12.1% of reports placed in the juveniles to adult category), despite an expected bias towards detected dispersing juveniles, indicates that a high proportion of animals in these populations are adults.

3.4.7 Koala Movements

The ear-tags used were often not readily visible unless a koala was seen close up (crossing a road for example). People often also did not think to note down the colours of ear-tags if they were seen. Nevertheless, the ear-tags were sufficient to identify a number of animals that had moved long distances. These movements clearly showed that gene mixing is possible within the southern Sydney region, and Dan's movement from Kentlyn to Douglas Park shows that koalas can travel between the southern and greater Sydney regions and between the Georges and Nepean catchment systems, which link the entire Sydney basin. This contrasts with statements by Phillips and Callaghan (2000), who argue that the Campbelltown region is isolated from other koala populations. However, the low number of koala sightings between Appin and Bulli indicates that the heathland habitat, the low soil fertility, or the lack in the woodlands, of suitable food-trees species, may act as an obstacle to koala movements.

3.4.8 Dead / Injured Koalas

Many unreliable reports of dead or injured koalas occurred in the eastern part of the southern Sydney region, and most of these reports came from the postal survey.

The cluster of dead or injured reports to the east of Wedderburn appears to be associated with the radiotracking work that has occurred in this area. That is, this is the area where most UWS work has occurred, and this led to koala corpses being found.

Most reports of dead or injured koalas appear to be due to trains or road vehicles, and are particularly prevalent in some areas. The road and rail locations, roughly in descending risk of koala fatalities, are:

- Much of the southwest freeway from Campbelltown to Mittagong.
- Heathcote road crossing Deadmans Creek at Sandy Point.
- The railway line at Yerrinbool.
- Wedderburn road, particularly where it crosses the Georges River.
- Peter Meadows road crossing Peter Meadows Creek, in Kentlyn.
- Appin road, from Kellerman Drive, St Helens Park, to Rixon Road, Appin. Note there have not been any koala fatalities at this location, but vehicles have caused injuries.

Callaghan *et al.* (1998) identified four high-risk areas within the Campbelltown LGA, which include the latter three locations listed above. Callaghan *et al.* (1998) also identified Georges River Rd in Kentlyn as a high-risk area, but whilst I believe it does pose a threat, I have no data on deaths or injuries on this road and therefore believe it is a low-risk area. It should also be noted that in three of these six locations (Heathcote Road, Wedderburn Road, and Peter Meadows Road), a well used road crosses a gully used by koalas. This appears to be a particularly high-risk situation, and I believe these three areas are “blackspots”; a short length of road with a high risk of koala mortality.

There is also no evidence that there are female koalas in Deadmans Creek, yet all three male corpses collected from Heathcote Road came from locations close to this creek. There was also a cluster of sightings where Heathcote Road crossed the Woronora River gully. These results suggest that either gully habitat is preferred by male koalas, or alternatively, if these males were dispersing, that gullies are often used by dispersing koalas. Whatever the reason, these data suggest that koalas will be more likely to move along gullies, or between closely spaced gullies.

Management strategies to minimise fatalities, whilst allowing the movement of koalas, would be particularly beneficial for the six areas where koala fatalities or injuries are particularly prevalent. Signage has already been erected in a number of areas in Campbelltown, and along Heathcote Road (see section 7.2.4.1). I also feel that if built, the proposed Georges River Parkway, to the east of Campbelltown, would be likely to cause koala fatalities (see section 7.2.4.1).

3.4.9 Temporal Changes

An important question to ask about the koala populations in both the southern and greater Sydney regions is whether there been large population fluctuations, and if so, what was the cause of these fluctuations?

Undoubtedly clearing has impacted upon the koala populations by reducing the habitat available, particularly in the areas with more fertile soils (Callaghan *et al.* 1998). However, 75% of reports for both the southern and greater Sydney regions occurred within the last 10 years. This suggests that the populations have increased recently.

However, the increase in publicity would have increased the chance of koala sightings being reported, so this does not necessarily indicate that the koala population has increased within the last 10 years.

It also appears that breeding populations of koalas are present in the Sutherland shire area, but it is likely that these populations have been reduced by the housing development. Maintaining movement corridors into the Royal National Park and Woronora River, where suitable habitat and some breeding animals may remain, should be a priority for management in this area.

The only evidence I encountered that disease has been a problem for southern and greater Sydney populations comes from Tilley and Uebel (1990), who refer to a devastating disease outbreak in the Nepean and Avon dam populations prior to 1920.

Bushfires, particularly intense ones, may reduce koala populations, or possibly even lead to local extinctions, based on comments from a number of people that they felt colonies had been destroyed by fires, and the findings of Tilley and Uebel (1990) and Robinson (1985). The possibility of local extinctions also emphasises the need for movement corridors to allow reestablishment of populations if needed.

Tilley and Uebel (1990) found a trend towards a greater number of sightings from November to February, but noted that their finding may be due to the frequency of inspection. This contrasts with the finding from this study that September and October had notably higher number of reports than other months. However, both Moon (1995) and Clulow (1996), using, respectively, the Coffs Harbour Wildlife Information and Rescue Service (WIRES) and Port Stephens Hunter Koala Preservation Society databases, found that October was the peak month for reports, with higher numbers from around August to December-January. Thus koala activity appears to be highest from spring to early summer, peaking from September to October, presumably due to activity related to the breeding season and dispersal of young.

3.4.10 Soil Fertility

The literature review in Chapter 1 led to the expectation that koala densities and therefore sightings would be higher on shale soils. The bias in areas from which koalas were detected, and the clearing of much of the shale-based vegetation in the southern Sydney region, made it difficult to assess if koalas were associated with the shale substrates, but many koala sightings did occur on, or close to shale, consistent with the findings of Phillips and Callaghan (2000). The notable exception is the group of sightings on sandstone to the east of Wedderburn, but this is probably due to the concentration of NPA walks and UWS work in this region. Moreover, the patches of low fertility clayey quartz sand between Appin and Bulli and the interspersed heathland and low open woodland appear to be unsuitable koala habitat, and may deter koala movements.

3.4.11 Volunteer Searches

The volunteer search technique was intended to utilise volunteers to help locate koalas and for intense searches applicable to both gully, and ridgetop, habitat. The volunteer searches were also intended to derive a density estimate more applicable to the whole of the southern Sydney region. Unfortunately, the technique was inefficient, despite good detection rates of both collared animals and toy koalas. However, the estimate of 0.035 ± 0.087 koalas ha^{-1} must be used with caution, because the technique was abandoned. Thus, it was not possible to fulfil the fifth aim of this chapter: to determine (accurately) the density of koalas in the southern Sydney region.

The primary reason the technique was abandoned was that only one new koala was detected from five trial searches. Thus, a larger search area was required, to increase the probability of detecting animals within the search area. However, the intensity of the search method meant it took approximately five hours to search 5ha of ridgetop habitat, and six hours to search accessible gully habitat. Around 5 to 6 hours appeared to be the maximum amount of time most volunteers could contribute, and the less accessible gully habitat would have taken considerably longer to search. This meant that it would have been difficult to greatly increase the search area.

There were also other problems with the technique. All volunteers were instructed prior to the start of the search on the methodology to be used. However, I was the only supervisor, and as the line was spaced out over some distance, it was impossible to directly supervise all volunteers at all times. Periodically this caused problems when some volunteers failed to follow instructions. In the initial trial, one volunteer even disappeared for approximately two hours to locate koalas by herself!

3.4.12 Conclusions about Search Techniques

An outcome of this study has been the development of a systematic method of dealing with reports of koala sightings, and a database to allow this information to be used effectively. These techniques are applicable to other studies gathering community information about koala populations.

The technique of continuous collection of community sightings requires a long-term sustained effort to obtain sufficient publicity and to educate the community. The benefit of this technique, however, is that the information gathered is of a higher quality compared to that collected from postal surveys because if details are unclear, the person reporting the sighting can be asked for clarification. This technique can also allow opportunistic captures, which are particularly useful when studying low-density populations. Appropriate education of the community about the research program is also likely to increase the community's support for the research.

A rigorous density estimate for the southern Sydney region was not possible for this study. The most promising technique for future work is the use of distance sampling (section 3.1.2). Difficulties that would need to be resolved with this technique are that the detection rate of koalas close to the transect line would not be 100%, and that separate detection curves would probably need to be developed for different habitat types. In addition, use of this technique in gullies, as for most techniques, would be difficult.

4 Population Parameters.

4.1 Introduction

A number of basic population parameters provide information useful for management decisions. These include: age, sex ratio, causes of death, the impact of disease and parasites, condition of animals, and female fertility rates (Caughley 1977).

Knowledge of female fertility rates, which are affected by their age, and sex ratio, combined with knowledge of the death rate, allow the population rate of increase (r) to be established. Continued negative values of r indicate that a population is declining, whilst continued positive values may bring about problems due to overpopulation. Koalas have been documented as experiencing both population declines (Gordon *et al.* 1988, Phillips 1990, Smith and Smith 1990), and overpopulation (Martin 1985a, b). Even if the population rate of increase cannot be calculated, knowledge about these factors provides useful insights into a population.

Prior to this study, little was known about the population parameters of koalas in the study regions. Furthermore, the resource-availability hypothesis (section 1.6.1), predicts that koalas using vegetation on shale soils, which are more fertile than sandstone soils, will encounter lower levels of plant defences. If true, and if the difference is significant enough, koalas using the shale soil vegetation would be expected to be in better condition than animals using only sandstone soil vegetation, and may also affect other population parameters such as female fertility. Thus, conserving remnant shale soil could be crucial, and for this reason, the effect of soil fertility on weight, condition, and female fertility rate is investigated in this chapter. First, however, I review techniques used to gather information on population parameters. Furthermore, it is also only possible to gather information on population parameters once an animal is "in hand". Much information about individual behaviour can also be gathered via radiotracking (Chapters 5 and 6), but clearly, animals must first be captured to permit the fitting of radiocollars. Thus, I also review techniques used to capture koalas.

4.1.1 Aging Koalas

Some population attributes, such as fertility rate, are age dependent (Caughley 1977), and thus aging animals is important. Tooth wear, generally on the premolar and the first two molars, has been used to estimate the age of adult koalas in other studies (Gall 1980, Martin 1981, 1985b, Mitchell *et al.* 1988, Gordon *et al.* 1988, Mitchell and Martin 1990, Young *et al.* 1996). However, there is a problem in comparing the age structure of populations using this method, as the plant species consumed may differ, and if these leaves have different levels of abrasiveness, different rates of tooth wear may result (Martin 1981). As koalas were not anaesthetised in this study, it was found that accurately determining tooth wear for captured koalas was not possible without causing considerable stress. Thus, data from female koalas of known age were used to construct weight and head length growth curves for estimating the age of female koalas less than 4 years.

A number of curves have been used to describe growth rates, but when examining the growth of mammals, the Gompertz curve appears to be the most accurate (Lee and Cockburn 1985). The Gompertz curve has been used in studies to describe koala growth rates (Martin and Lee 1984, Martin and Handasyde 1990a). It is assumed for the Gompertz curve that there is a relationship between the relative growth rate, and the animal's size (Kaufmann 1981). However, the crucial requirement for a growth curve, of whatever type, is that it should accurately reflect the animal's growth over the time scale examined. Martin (1985a) used 2nd-order polynomial curves to examine koala weight and headlength growth, rather than the Gompertz curve.

4.1.2 Sex ratio

Martin (1985b) and Martin and Handasyde (1990a) found female biased sex ratios amongst adults in established Victorian populations. This bias appears to be due to the social structure where large, dominant males overlap the home ranges of a number of females, and exclude subdominant males (Mitchell 1990a, b). I expected that animals located via community sightings would be biased towards males and dispersing juveniles because these animals have greater movements (Mitchell 1990b, Gordon *et al.* 1990a, see section 1.7), and are thus more likely to be seen by the community.

4.1.3 Death, Disease, and Parasites

Causes of mortality and reduced condition are important from a conservation perspective, as they provide information about threats to a population. Large-scale disturbance events, as discussed in Chapter 1, may cause population crashes. Humans can cause koala mortalities through road fatalities and attacks by dogs. Predators and disease, particularly bacterial pathogens from the genus *Chlamydia*, can also cause koala deaths.

4.1.3.1 Natural Predators

The koala has few natural enemies apart from humans, but the powerful owl (*Ninox strenua*), wedge-tailed eagles (*Aquila audax*), and dingoes (*Canis lupus dingo*) can all prey on koalas (White and Kunst 1988). Dingoes may still occur in the greater Sydney region, but are uncommon (Robinson 1985). The powerful owl and wedge-tailed eagle occur in both the southern and greater Sydney regions, but in low numbers (Close pers. comm.). Predation from these sources, in both the southern and greater Sydney regions, was thus expected to be low.

4.1.3.2 Car and Dog Mortalities

In koala populations close to urban areas, vehicle impacts and dog attacks are the most common cause of death (Backhouse and Crouch 1990, Le Page 1993, Moon 1995, Natrass and Fiedler 1996, Koosmen *et al.* 1997). However, these findings are based on reports from the public about sick or injured animals, often to carer groups. Thus, it seems reasonable that vehicle impact and dog attack are more likely to be detected than other causes of death as these trauma incidents are associated with humans. I also expected a bias towards detecting deaths or injuries caused by human-associated trauma, as most animals in this study came from community reports. Deaths in the bushland, away from roads, would therefore be rarely noticed.

Natrass and Fiedler (1996) found a male bias in koala roadkills, but no sex bias in dog attacks. Canfield (1987) performed a mortality survey of free-range koalas from the north coast of NSW and found that koalas hit by cars were generally in good condition and free of underlying disease, but that animals in poor, debilitated condition were more prone to dog attack. Harassment by dogs may also disrupt movements, because

animals may be prevented from descending until the dogs leave, and this may cause stress in itself (Prevett 1991).

The location of koala mortalities caused by vehicle impact is not random, and road mortality 'blackspots' often occur (Prevett 1993). The location of these blackspots is influenced by traffic speed and volume, presence of koala habitat (i.e. trees), and visibility for drivers (Prevett 1993, Natrass and Fiedler 1996).

4.1.3.3 Disease

Several diseases have been documented as affecting the koala. Of these, chlamydial disease has received the most attention and is reviewed separately below. Other diseases include respiratory infections (rhinitis / pneumonia complex), leukaemia, cryptococcosis, and septicaemia (Blanshard 1994). However, none of these diseases was detected in the southern or greater Sydney regions, and thus they are not reviewed here.

Canfield (1990) reviewed the causes of death for 162 free-ranging koalas in NSW and found that urogenital disease was the second most common cause of death behind trauma, although whether all deaths were attributable to chlamydial infections was not clear. Canfield (1987) noted that 12% of koalas examined had kidney disease; thus this also appears to be a significant disease.

Chlamydia

Chlamydial bacteria can reduce a koala's condition, and in some cases cause death. Initially it was believed that the koala was affected by one chlamydial species: *Chlamydia psittaci* (Brown *et al.* 1987). Girjes *et al.* (1988), based on gene probe data, first suggested that there might be two distinct strains. Since then, the phylogenetic relationships within both the order *Chlamydiales* (Everett *et al.* 1999) and the genus *Chlamydia* (Pettersson *et al.* 1997, Pudjiamoko *et al.* 1997) have been reviewed. It is now recognised that two chlamydial species affect koalas: *C. pecorum* and *C. pneumoniae* (Glassick *et al.* 1995, 1996, Wardrop *et al.* 1999). Furthermore, multiple strains of *C. pecorum* have been found to affect koalas, probably due to infections from other species (Jackson *et al.* 1997), whilst only one unique strain of *C. pneumoniae* has been found to affect the koala (Wardrop *et al.* 1999).

C. pneumoniae usually infects ocular sites, whereas *C. pecorum* infects both ocular and urogenital sites (Martin and Handasyde 1999). Clinical symptoms of ocular infection are corneal conjunctivitis or 'red eye', which can impede vision, or cause blindness. Urinary tract infection can cause leaking of urine from the bladder, which stains the fur on the rump and is commonly referred to as 'wet bottom'. Reproductive tract infection can cause females to become infertile through enlargement of the fallopian tubes, cervixes and uteri (Obendorf and Handasyde 1990).

Detecting Chlamydial Infection

Detecting chlamydial infection can be difficult, as clinical symptoms often only occur in a small proportion of those infected. Wood and Timms (1992), in an investigation of the incidence of chlamydial infection amongst a Queensland population, found that 62.5% of the population studied were infected, but that only 11% displayed clinical symptoms.

Wood and Timms (1992) also assessed the effectiveness of nine antigen detection kits in detecting urogenital chlamydial infection. They found that specimen collection and storage and laboratory conditions could affect the sensitivity of cell culture methods, that immunofluorescence tests of smears of swabbed cells on a slide were hampered by low sensitivity, whilst solid-phase enzyme-linked immunosorbent assay (ELISA) kits were more accurate. However, Osawa *et al.* (1996) noted that changing to using ELISA techniques could be costly and complicated.

Another test that has been used is the complement fixation test, which is based on the amount of complement-fixing chlamydial antibodies present in blood serum. Blanshard (1994) notes that the major limitations for this test are:

- (1) *Chlamydia-naive koalas may take at least 3-4 months to develop detectable complement fixing antibody levels after infection*
- (2) *Some infected koalas without clinical signs of disease may not develop detectable complement fixing antibody levels.*

The detection techniques used in this study were limited by cost and availability. Hence, despite sensitivity problems, a complement fixation test and an

immunofluorescence test kit (IMAGEN), which were available at a local veterinary laboratory, were used.

4.1.3.4 Parasites

Stone and Carrick (1996) examined 259 koalas at EPRAPAH, a koala care centre at Victoria Point, Queensland, and found that 3% had ticks. However, due to the koala's dense fur, and because ticks could have dropped off after feeding and thus not been detected, they considered 3% to be an underestimate.

Certain species of tick can cause toxicosis, or tick paralysis, and this can cause death or serious health effects, particularly for naive animals. Anaemia caused by tick exsanguination has also been observed to affect koala haematology and heavy tick burdens can lead to poor condition (Spencer and Canfield 1993). Stone and Carrick (1996) also noted that ticks could help to transmit chlamydial infection, as well as other diseases such as Lyme borreliosis.

The koala is also a specific host for the tapeworm *Bertiella obesa*, which resides in the lower intestine, and tends to be more commonly encountered in debilitated koalas (Blanshard 1994). A number of nematode species have also been noted as affecting koalas (Blanshard 1994).

4.1.4 Fertility

The rate of increase (r) can be established when fertility rate is combined with knowledge of the death rate (section 4.1). Death rate data could have been obtained by monitoring animals of known age. Radiotracking allows animals to be monitored, but this technique was labour intensive, and hence only 5 females and 3 males were monitored for more than two years (see section 5.3). Furthermore, monitoring of these animals was also not possible when collars came off, or when radiocollar batteries failed. Gathering death rate data was thus beyond the scope of this study, and therefore r could not be established, but future research may be able to determine koala death rates for the study populations.

Mitchell (1990a) proposed that a bimodal male population structure exists within socially stable breeding habitat. That is older, dominant males exclude other sexually mature males through aggressive encounters and advertisement by scent marking and bellowing, but share their territory with young, immature animals and adult females. Mitchell also proposed that females use male behaviours to make sure they mate with the dominant males. Ellis *et al.* (2002), however, in a study at Blair Athol in Queensland, tested the parentage of koala offspring using microsatellite DNA analysis, and found that 'resident', presumably dominant males, did not have any advantage over 'transient' males in siring offspring. This finding of Ellis *et al.* (2002), is not consistent with dominant male koalas having a greater chance of mating with females, as proposed by Mitchell (1990a), and thus the role of male territoriality will need to be reviewed.

It has long been recognised that female vertebrates' production of young varies with age (Caughley 1977). To allow for this variation, both White and Kunst (1988) and Martin and Handasyde (1990a) present age specific fecundity data, based on tooth wear estimates, for Queensland and Victorian koala populations respectively.

Martin and Handasyde (1990a) found that four known age females from French Island gave birth at 665, 720, 745 and 780 days old. Thus, they found that female koalas could be sexually mature by 2 years old. However, they also suggest that body weight is a better indicator of sexual maturity than age, and that females were usually 6kg or more before they had their first young.

Martin and Handasyde (1990a) also gave the 'fertility rate' for the koala populations studied. Their definition of 'fertility rate' is the percentage of females with young from the total number of females, and is hereafter referred as a 'population fertility rate'. Thus, Martin and Handasyde (1990a) define the 'infertile' component as including immature females, females that have failed to breed, and females that have become permanently infertile (usually due to chlamydial infection).

Another definition of 'fertility rate' has been used, however, and I will refer to it as 'adult fertility rate'. The adult fertility rate is the proportion, or percentage, of tagged *adult* females known to have given birth to young (Gordon *et al.* 1990b).

White and Kunst (1988) defined adult female koalas as those >2.9kg in weight, and >105mm head-length, which appears to be those animals two years of age or greater. Gall (1980) also appears to consider females two years of age to be sexually mature. Unfortunately, Gordon *et al.* (1990b), and Martin and Handasyde (1990a) for French Island, Sandy Point and Kangaroo Island data (Table 4.1), do not define how old they considered an 'adult' female koala to be.

The results from these fertility studies show that chlamydial infections can cause a marked decrease in the fertility rate for a population (Table 4.1). A decrease in fertility rate will, at the very least, slow population growth. However, it is possible for a population affected by *C. pecorum* to continue to increase, such as on Phillip Island where overpopulation is a management problem (Martin and Handasyde 1999). A decrease in fertility rate can also mean a population decline, such as at Inverness, Queensland, where the population density decreased from 1980 to 1985, although it appears that chlamydial infection both reduced fertility and caused increased mortality in this population (Gordon *et al.* 1990b). Thus, fertility rate is an important population attribute, which can be affected by chlamydial infection.

Table 4.1. Published information on koala fertility rates, and the incidence of chlamydial infection (if available). Koala populations are separated into those where information on the incidence of chlamydial infection is not available, populations which appear to be relatively free of chlamydial infection, and those with a comparatively high incidence of chlamydial infection.

Location	Adult Fertility Rate	Population Fertility Rate	Incidence of Chlamydial infection	Reference
Lismore, NSW	71%		No information	Gall 1980
Brisbane Ranges National Park, Vic		61%	No information	Hindell 1984
Springsure, Qld	84%		2% animals had cystitis	Gordon <i>et al.</i> 1990b
French Island, Vic.	97%	78%	'Chlamydia-free'	Martin and Handasyde 1990a
Sandy Point, Vic.	67%	56%	'Chlamydia-free'	Martin and Handasyde 1990a, b
Kangaroo Island, S.A.	74%	59%	'Chlamydia-free'	Martin and Handasyde 1990a, b
Sheldon, Qld	41%		5% animals had cystitis	Gordon <i>et al.</i> 1990b
Bremmer River, Qld	66%		12% clinical symptoms	White and Kunst 1988
Stony Rises, Vic.	38%	36%	'Chlamydia-infected'	Martin and Handasyde 1990a, b
Grampians, Vic.	0%	0%	'Chlamydia-infected'	Martin and Handasyde 1990a, b
South Gippsland, Vic.	62%	56%	'Chlamydia-infected'	Martin and Handasyde 1990a, b
Brisbane Ranges, Vic.	52%	45%	'Chlamydia-infected'	Martin and Handasyde 1990a, b
Phillip Island, Vic.		17%	'Chlamydia-infected'	Martin and Handasyde 1990a
Raymond Island, Vic.	42%	40%	'Chlamydia-infected'	Martin and Handasyde 1990a, b

4.1.5 Condition

Using the resource-availability hypothesis, I predicted that koalas using shale soil vegetation would have access to more nutritious foliage than animals using only sandstone soil vegetation, and would, therefore, be in better condition. Techniques to compare animal condition were therefore required, and are reviewed below.

A technique for estimating koala condition, a subjective 4-point scale, was developed by Wood (1978). This scale assesses the amount of muscle mass present, caudal and cranial to the spine of the scapula: more muscle indicates better condition. Ellis and Carrick (1992) used this same technique, except that a 10-point scale was used for the condition assessment. They compared this 10-point scapula scale against the percentage of body fat for euthanased koalas and concluded that there was a significant relationship between the scapula scale and the percentage of body fat, measured using the tritium dilution method. Scapula scale condition ratings have now been used by a number of other koala researchers (White and Kunst 1990, Krockenberger 1993a, White 1994, Hasegawa 1995, Harris 1999b, Ramsay 1999).

Another technique is to use an animal's weight as an indicator. However, individuals may vary in body size, and accordingly in weight, so size is a confounding variable in this assessment. Thus, it is necessary to control for size variations, and a skeletal measurement is a common way of doing this (Bakker and Main 1980, Lidicker and Ostfeld 1991, Ward 1994). Both of the techniques described here, to measure condition, were used in this study.

4.1.6 Capture Methods

Capturing koalas is difficult due to the koala's arboreal nature, and there are often risks to both the animals themselves, and to the capture personnel. A number of capture methods have been used and include: drop and catch, noose and flag, flag-only, mechanical lift, and trap (Bali and Delaney 1996).

The drop and catch technique, where a koala is forced off its branch to captors waiting with a tarpaulin or blanket below, is no longer considered acceptable because of the high death and injury rate (Bali And Delaney 1996). The noose and flag technique

involves slipping a noose on a rope over the koala's head, and applying pressure on the rope to stop the animal from climbing higher. A flag is then used to persuade the koala to move to a location from which it can be caught. The main drawback with this method is that it is difficult to abort a capture attempt once the koala is noosed. The flag-only technique does not suffer from this problem, although the captures may be less likely to succeed. Mechanical lifts, such as a cherry picker approach the koala at the same height in the tree and catch it immediately. Access to the machinery is needed, and capture locations are limited to flat open terrain accessible by vehicle. The trap method, as described by Hasegawa and Carrick (1995), involves constructing a fence around the trunk of the koala's tree, and placing a metal sheath around the tree trunk to prevent the koala climbing back up, once it descends. The main advantage is that no climbing is required but the trap needs to be regularly monitored, and ideally requires flat ground and trees without overlapping canopies.

In this study, the trap method was trialed on a few occasions, but it was found that sloping and rocky terrain usually made this technique impractical. Mechanical lifts were not available, the noose and flag technique used only where necessary, and when there were few interfering branches. Thus, the commonly used capture method during this study was flag-only.

Subsequent to this study, however, an adaptation of the trap technique has been developed, with a portable fence which is useable in rocky and sloping terrain, and which does not require a sheath around the koala's tree trunk, but which has a cage trap incorporated into the fence (Close pers. comm.).

4.1.7 Objectives

The objectives of capturing koalas were:

1. To collect age, sex, condition and morphological data and establish age and sex ratios and breeding success.
2. To investigate the effect of soil fertility on koala size, weight, condition, and female fertility rates.
3. To test for chlamydial infection.
4. To collect koala corpses and ascertain the cause of death whenever possible.

5. To effect captures with a minimum of risk to both koalas, and the capture personnel.
6. To eartag previously uncaught animals, to allow koalas to be identified if sighted later.
7. To allow the fitting of radiocollars to selected animals.

4.2 Methods

Previously uncaught koalas were captured opportunistically whenever possible and radiocollared animals were captured if new batteries were required. Capture techniques varied depending on the location, situation of the koala, type and height of the tree, which were up to 30m tall, and the availability of personnel and other resources. Occasionally, after assessing these factors, it was decided that proceeding would place the koala, or capture personnel, at too great a risk, or would have a low likelihood of success, and therefore no capture attempt was made.

Furthermore, if during a capture attempt the koala showed signs of stress by making a 'crying' sound the capture was aborted unless the capture could be finished quickly (within 3 minutes). Captures were also terminated if the koala could not be reached with the pole and flag, or if the koala would not descend.

The technique most commonly used during a koala catch consisted of the following:

1. Communication. This study relied heavily on community support; therefore, good community relations were considered essential. It was found that if a koala capture was performed close to the public that a crowd of onlookers would quickly form. After an aborted capture in 1996 where onlookers objected halfway through the attempted capture, it was concluded that communication with onlookers needed to be improved. Before subsequent captures, the audience was told the reason for the capture attempt, what would happen to the koala, and how the koala was expected to react. People were also asked to restrain any dogs, to keep as quiet as possible during the capture to minimise stress to the koala and keep well away from the capture tree.

2. **Flagging.** A 'flag' on the end of an extendable 8m aluminium pole was waved above the koala's head. Alternatively, the pole was used to shake branches, to create a disturbance to persuade the koala to descend. On a few occasions koalas that had partially descended the tree trunk, but not low enough to be grasped from the ground, were noosed.
3. **Capture.** Ideally, the koala was grasped around the shoulder blades, but sometimes by a hind limb or foot if the shoulders couldn't initially be reached, and was then placed into a large hessian sack. Welding Gloves were worn to provide protection from bites and scratches. Measurements were taken with the koala in the sack to make handling easier. No sedatives or anaesthetics were used. If taken for a veterinary inspection, the koala was transported in the sack, with the bag held up by tying the opening and securing it to a hook in the vehicle, or held by a passenger. Those animals which were injured or in very poor condition were examined by vets and either euthanased or passed on to Gaylene Parker from WIRES for care if necessary.

Animals were released as soon as possible after capture and as close to the capture site as possible. If threats at the capture site from roads and dogs were deemed to be too high the koala was moved as short a distance as possible into suitable habitat prior to release.

4.2.1 Measurements

Koalas were weighed in the sack using 15kg Salter clockface scales. Size and development of pouch young were recorded.

Head length measurements were taken with callipers from the tip of the snout to the rear of the occipital crest. Two measurements were taken for each animal and if discrepancies between measurements were greater than 5mm, then the measurements were taken again. Where discrepancies between successive measurements were <5mm, the lower of the two measurements was recorded.

Wear on the premolar and first molar was assessed and noted where possible. However, as animals were not sedated, assessing tooth wear was often difficult, and was abandoned where it was felt that the assessment was causing the koala too much stress.

For female koalas the length, estimated age and development of any pouch young were noted. If possible, the sex of the pouch young was determined. For back young, measurements were taken as for adult koalas.

A leather punch was used to take a tissue sample from one ear, for genetic analysis, after it was sterilised with 70% alcohol (see Houlden *et al.* 1999, Montgomery *et al.* in prep., for analysis of genetic data). One coloured, numbered sheep swivel tag from Leader Products was fitted in koalas that had emerged from the pouch, through the hole created by the earpunch for genetic material. Another tag was inserted in the other ear with the tag applicator.

Gompertz specific growth rates using the methods given in Kaufmann (1981) were calculated for female koalas, and a birth weight of 0.5g and headlength of 8mm (Martin and Handasyde 1999) were used to determine predicted weights and headlengths for 2, 3 and 4 year old females. These predictions, however, did not fit with measurements from three female koalas, two from sandstone habitat and one from shale and sandstone, whose age classes were known. The weights and headlengths of these three females were then plotted over time against their estimated age, and second-order polynomial curves fitted to these data as they gave the highest r^2 values. Weights and headlengths for 2, 3, and 4 year old females were then determined using the fitted curves and used to estimate female's ages.

Data from koalas of known age were not available for male koalas. Age estimates were therefore based on subjective estimates of ages based on the wear for the cutting tooth and first molar, animal's weight and head size. Subsequently, based on these estimates, a minimum weight of 6.2kg and minimum headlength of 129mm was set for "adult" males, which may have included animals as young as 2 years old. However, these minimum values were used because some older males, based on tooth wear, had low body weights.

From July 1996, condition was estimated using the 4-point scale developed by Wood (1978). The index was based on the bulk of the muscularis trapezius muscle both caudal and cranial to the spine of the scapula. The ratings used were: 1 = concave muscle mass, bone prominent, 2 = little muscle, tone bad, bones still prominent, 3 = muscle starting to bulge, bones covered, 4 = large convex muscle mass. Notes were also made about the pelage and general condition of the animal.

When practicable, veterinary inspections were obtained. Blood samples were taken from the forearm for complement fixation testing for chlamydial antigen. Conjunctiva and urogenital swabs were taken with sterile cotton buds; the cells smeared on to labelled positions on slides and examined using the immunofluorescence IMAGEN test kit. All chlamydial tests were performed by Elizabeth Macarthur Agricultural Institute laboratories.

Koalas taken into care by WIRES and euthanased, and remains found in the field, or reported by the public, were collected whenever possible and a cause of death determined if possible.

4.2.2 Data Handling

The effect of soil fertility on the size, weight, condition and fertility of animals was investigated by grouping animals by their location (Fig. 4.1). Data for adult females were separated based on whether the females had access to vegetation on shale soil, which was determined by examining geological maps (see Fig 2.2).

Adult male koalas were captured in a greater range of locations than females. The data on males were split into those coming from known breeding areas, and those from areas where groups of breeding females were not known to occur, based on the results from Chapter 3. Those from the known breeding areas were further subdivided into animals coming from the Kentlyn region, and separate groups for Wedderburn areas with and without shale (Fig. 4.1). Those males from the areas where sightings of female koalas with young were few were also subdivided into animals coming from the southern and greater Sydney study regions.

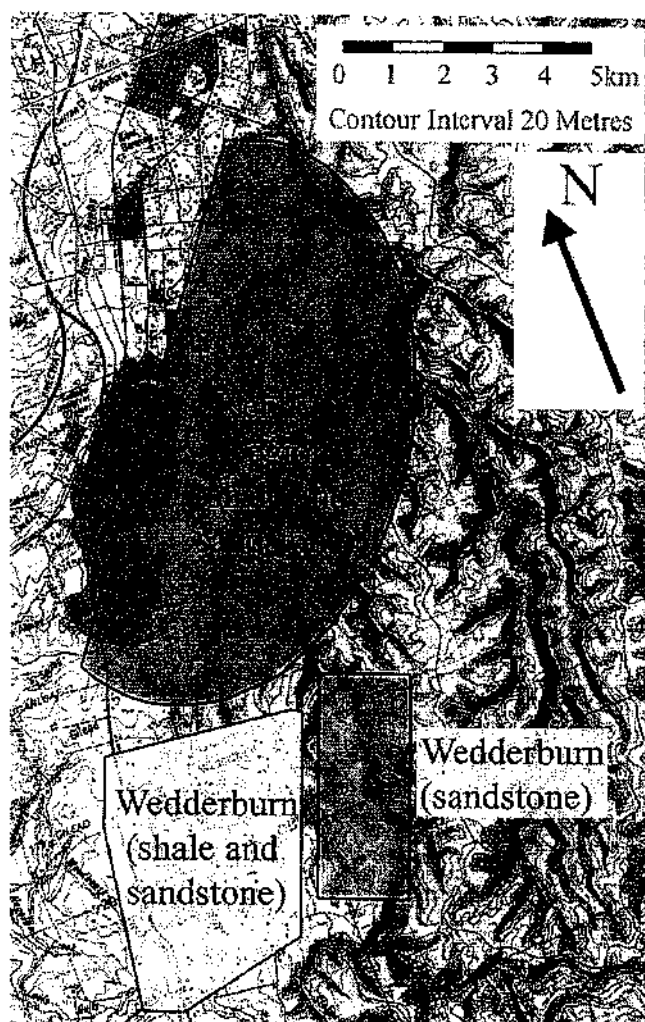


Figure 4.1. Map of the area subgroupings used for comparisons of koala weight, headlength and female fertility. Female captures came from the Kentlyn and Wedderburn regions shaded dark grey. Male captures were widely distributed within the southern Sydney region; those from the shaded regions were considered to have come from breeding habitat, whilst those from all other areas in the southern Sydney region to have come from areas where sightings of female koalas with young are few (ie. there is little no evidence of koalas breeding in these areas). Three subgroupings for breeding males following the shaded regions were also examined: Wedderburn sandstone only, Wedderburn shale and sandstone, and Kentlyn shale and sandstone. Note that these regions do not accurately delineate the boundary of known breeding habitat. Only crude boundaries are shown for placing capture data into subgroupings. Acknowledgment: Map courtesy Australian Surveying and Land Information Group, Canberra, Australia. Crown Copyright ©. All rights reserved. www.auslig.gov.au.

4.3 Results

4.3.1 Sex Ratio

Prior to 1996, unsuccessful capture attempts were not recorded. Since 1996 there has been a success rate of 85% out of 112 attempts, with back young included as separate captures.

The sex ratios of dependent young and independent animals (Table 4.2) appeared male biased, but neither differed significantly from a 1:1 sex ratio ($\chi^2_{[1]} = 0.22$ and $\chi^2_{[1]} =$

0.89 respectively, $p > 0.05$ for both). The sex ratio of dead animals was significantly male biased ($\chi^2_{[1]} = 9.00$, $p < 0.005$).

Table 4.2. Sex ratios within three categories for all koalas captured from 1990 to 2000. Dependent young includes all pouch and back young where the sex of the offspring could be determined. Independent animals were those that were not in the same tree as their mother when caught and tagged. Animals caught and tagged as dependent young were excluded from the independent animal category. The dead category includes all corpses collected and animals that died or had to be euthanased after capture. The number of tagged animals within this category is given in brackets.

Sex	Dependent Young	Independent	Dead (tagged koalas in brackets)*
Male	10	31	20 (7)
Female	8	24	5 (2)
Proportion of Females	0.44	0.44	0.20

*Ratio of males to females significantly different to a 1:1 ratio ($p < 0.005$).

4.3.2 Deaths

Koala deaths due to being hit by a vehicle accounted for 42.3% of all known fatalities and, as expected, were male biased (Table 4.3). Two other deaths were directly due to interactions with humans: one was due to the injuries sustained when a koala jumped to the ground during a catch (prior to my study) and another due to a veterinarian using the wrong anaesthetic. A further three deaths were due to dog attacks.

Table 4.3. Causes of known koala deaths.

Cause	Male	Female	Sex Unknown
Hit by vehicle	10	1	
Stress and renal failure or stress and dehydration	1	2	
Dog attack	3		
Unknown	2		
Vet mistake	1		
Koala euthanased due to broken, infected humerus probably caused by a bite from another male koala	1		
Lung tumour	1		
Euthanased due to old age & poor condition (injuries also present due to impact from vehicle)	1		
Old age, starvation and internal parasites		1	
One female, prior to this study, died from injuries received when she jumped to the ground during a capture		1	
Pouch young ejected in captivity by female in poor condition and with eye cataracts			1
Total	20	5	1

Stress and renal failure, or stress and dehydration, were the second most common causes of death. All of these animals came from the eastern area of Wedderburn where Sydney sandstone soils occur (Table 4.3).

4.3.3 Chlamydia

Thirty-one complement fixation blood tests were performed on 21 koalas and all returned levels less than 8, which is considered to be negative. However, as discussed in the introduction, this test often does not detect chlamydial infection.

Thirty-six immunofluorescence tests were performed on 27 koalas. Of these 30 were negative, and 3 were positive, and 4 were 'suspect' positive (Table 4.4). Three of these 'positives' were for eye smears only (Table 4.4). Two koalas that returned positive, or suspect positive results, had been tested on other occasions and returned negative results (Table 4.4). The animals with possibly positive chlamydial infection results were both male and female from varied locations within the southern Sydney region and none was considered to be in poor condition (Table 4.4). Three other koalas were observed to have cloudy corneas, which may have been an indication of chlamydial infection, but unfortunately, none of these animals was tested. Two other koalas were noticed to have eye cataracts, and another had corneal damage from a scratch or wound.

Table 4.4. Details for koalas that returned positive, or 'suspect' positive results, for the IMAGEN slide immunofluorescence test.

Location	Slide Smear Results	Other Test Results	Sex	Condition Rating
Kentlyn	One eye smear 'suspected' positive	3 subsequent inspections all negative	F	Not Taken
Kentlyn	One eye smear 'suspected' positive	No other tests	F	4
Kentlyn	Smears 'suspected' positive	No other tests	F	3
Kentlyn	Smears positive	No other tests	M	3
Sandy Point	Cloaca and eye smears 'suspected' positive	No other tests	M	3
Wedderburn	One eye smear positive	One previous and one subsequent test both negative	F	3
Wedderburn	Cloaca and eye smears positive	No other tests	M	Not Taken

Seventeen animals from the Kentlyn region were tested, and 15 from Wedderburn (both shale and sandstone, and sandstone alone). As there were 4 'positive' results for Kentlyn (23.5% infection rate), compared to 2 'positives' from Wedderburn (13.3% infection rate), Kentlyn appeared to have a higher rate of chlamydial infection. However, due to the limitations of the test techniques used, definitive conclusions about chlamydial infection within the study regions are not possible. Furthermore, as no clinical symptoms of chlamydial infection were observed, it appears that the impact of both *C. pecorum* and *C. pneumoniae* upon this population is relatively low compared to some other populations.

4.3.4 Parasites

Ticks (*Ixodes tasmani*) were found on two male koalas, both of which came from locations close to Waterfall, in the eastern part of the southern Sydney region. One female koala from Bargo in the greater Sydney region was found to have a high tapeworm load, which appears to have contributed to this koala's death (Table 4.3).

4.3.5 Growth Curves

Female growth curves were fitted for both weight and head length (Fig. 4.2). Two of these koalas came from Wedderburn and one from Kentlyn. The curves were used to calculate cut off points to determine the age of female koalas less than 4 years old (Table 4.5). As an older animal in poor condition could have a low body weight, headlength was primarily used in determining female ages. Insufficient data were available from males of known ages to construct growth curves.

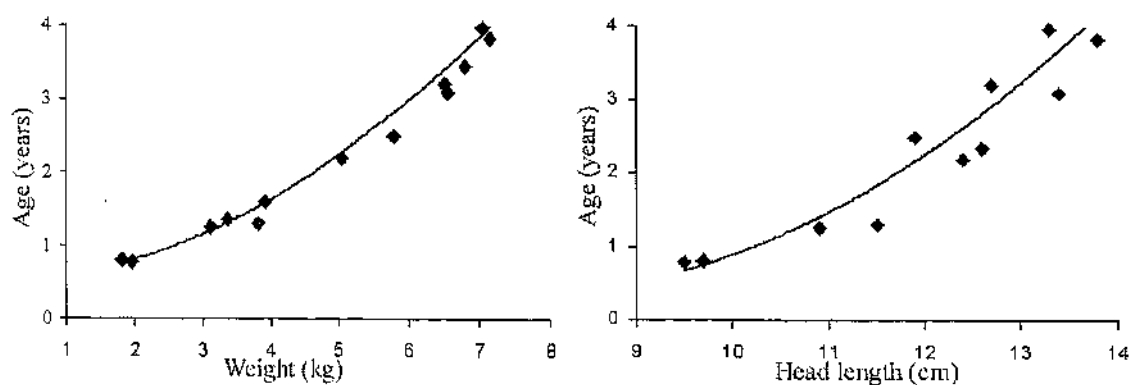


Figure 4.2. Graph of weight and head length growth curves derived from measurements for three female koalas of known age. Two order polynomial curves were fitted and are $y = 0.0656x^2 + 0.0157x + 0.526$ and $y = 0.0987x^2 - 1.4897x + 5.926$, with r^2 values of 0.917 and 0.842, for weight and head length respectively.

Table 4.5. Weight and headlength cut off points used to determine the age of female koalas to 4 years old.

Age (years)	Weight (kg)	Head Length (mm)
2	≥4.62	≥116
3	≥6.02	≥128
4 +	≥7.15	≥136

4.3.6 Size and weight

Animals radiotracked at Wedderburn were mostly female and were observed to generally be in poorer condition than those in Kentlyn. The size and weight of these animals were compared (Table 4.6).

Table 4.6. Average weights and head lengths for female koalas ≥2 years old (≥4.62kg and ≥116mm headlength), with standard deviation. Females from the Kentlyn region were on, or close to, shale soils, whereas those from the Wedderburn region were not. Head lengths were recorded for fewer animals than weights, thus the lower sample sizes.

Category	Number of animals (weight)	Weight (kg)*	Number of animals (head length)	Head length (mm)
Kentlyn region	10	7.28 ± 0.78	9	137.58 ± 4.59
Wedderburn region	6	6.36 ± 0.98	5	135.60 ± 3.80

*Kentlyn and Wedderburn weights significantly different at $p < 0.05$.

Adult female koalas in the Kentlyn region weighed significantly more than those in the Wedderburn region ($t_{14} = 2.097$, $p < 0.05$), but head-lengths were not significantly different ($t_{12} = 0.818$, $p > 0.05$).

Males from the three breeding area subgroups (Fig. 4.1, section 4.2.2) were compared. None of the three regions was significantly different for average body weight ($F_{[2, 14]} = 0.43$, $p > 0.05$), or head lengths ($F_{[2, 12]} = 0.08$, $p > 0.05$). The males from the southern and greater Sydney study subgroups within the areas where sightings of female koalas with young were few were also compared. There was no significant difference in their weights ($t_9 = 0.708$, $p > 0.05$), or head lengths ($t_5 = 0.314$, $p > 0.05$).

Given that no significant differences were apparent for the subgroups within the breeding areas and areas where sightings of female koalas with young were few, the

subgroup data were pooled (Table 4.7). Males from the breeding areas had significantly higher body weights and head-lengths (weight: $t_{28} = 3.854$, $p < 0.005$, head-length: $t_{22} = 2.833$, $p < 0.005$).

Table 4.7. Average adult male (≥ 2 years old: ≥ 6.2 kg and ≥ 129 mm headlength) weights and head lengths with standard deviations. See Fig. 4.1 for areas defined as breeding habitat and areas where sightings of female koalas with young are few.

Category	Number of animals (weight)	Weight (kg)*	Number of animals (head length)	Head length (mm)*
Breeding areas	19	9.25 \pm 1.33	17	160.82 \pm 8.78
Areas where sightings of female koalas with young are few	11	7.42 \pm 1.11	7	148.43 \pm 11.93

*Areas where sightings of female koalas with young are few and breeding categories significantly different ($p < 0.005$).

4.3.7 Condition

Insufficient data were available to compare condition estimates for males from the three breeding area subgroups (Fig. 4.1, section 4.2.2). Condition estimates for males were compared between the areas where sightings of female koalas with young were few and breeding areas, and were significantly different (Table 4.8), and were not significantly different ($\chi^2_{[2]} = 0.23$, $p > 0.05$). However, the expected values for four cells were less than five (condition category one was not included in the χ^2 test due to low values).

Table 4.8. Adult male (≥ 2 years old: ≥ 6.2 kg and ≥ 129 mm headlength) condition estimates from all captures. Due to the few data available, multiple estimates of condition from separate capture occasions were included. Condition estimates came from 12 individuals for the breeding category and 7 individuals for areas where sightings of female koalas with young were few. See Fig. 4.1 for areas defined as breeding habitat and areas where sightings of female koalas with young are few.

Category	Condition Category			
	One	Two	Three	Four
Breeding	0	3	10	4
Areas where sightings of female koalas with young are few	0	2	5	2

Adult female condition estimates for Kentlyn and Wedderburn areas (Table 4.9), were significantly different ($\chi^2_{[3]} = 15.73$, $p < 0.005$). Also, Kentlyn female condition estimates did not differ significantly from pooled adult male estimates ($\chi^2_{[3]} = 3.33$, $p > 0.05$), but Wedderburn female estimates did differ significantly from pooled adult male

estimates ($\chi^2_{[3]} = 12.00$, $p < 0.01$). However, expected values for most of the cells for these tests were less than five.

Table 4.9. Adult male and female (adults defined as ≥ 2 years old, females ≥ 4.62 kg and ≥ 116 mm headlength, males ≥ 6.2 kg and ≥ 129 mm headlength) condition estimates. Due to the low number of estimates available multiple estimates of condition from separate capture occasions were included. Condition estimates came from 9 individuals for the Kentlyn region, 4 individuals for the Wedderburn region, and from 19 individuals for the pooled male data.

Location	Condition Category			
	One	Two	Three	Four
Female Kentlyn*	0	2	12	4
Female Wedderburn* †	1	5	6	1
Male – pooled †	0	5	15	6

* Kentlyn and Wedderburn female condition estimates significantly different ($p < 0.005$).

† Pooled male and Wedderburn female condition estimates significantly different ($p < 0.01$).

These findings are consistent with female koalas in Wedderburn being in poor condition compared to other animals, both male and female.

4.3.8 Fertility Rates

The ages of female koalas in Kentlyn and Wedderburn used to generate fertility rate data were not significantly different ($\chi^2_{[2]} = 0.36$, $p > 0.05$).

Data were available for the ages of two females when they first gave birth. One of these was Molly, a female relocated from Kentlyn to Wedderburn when a juvenile, and was estimated to be 1370 days (3.8 years) old when she first give birth. The other female, Sarah, came from Wedderburn and was 1127 days (3.1 years) old when she first gave birth.

None of seven female 2 year old koalas from either Kentlyn or Wedderburn, that were captured had young (Fig. 4.3). Thus, it appears that female koalas in the southern Sydney region do not have young until 36 months old, or have a very low fertility rate before 36 months of age.

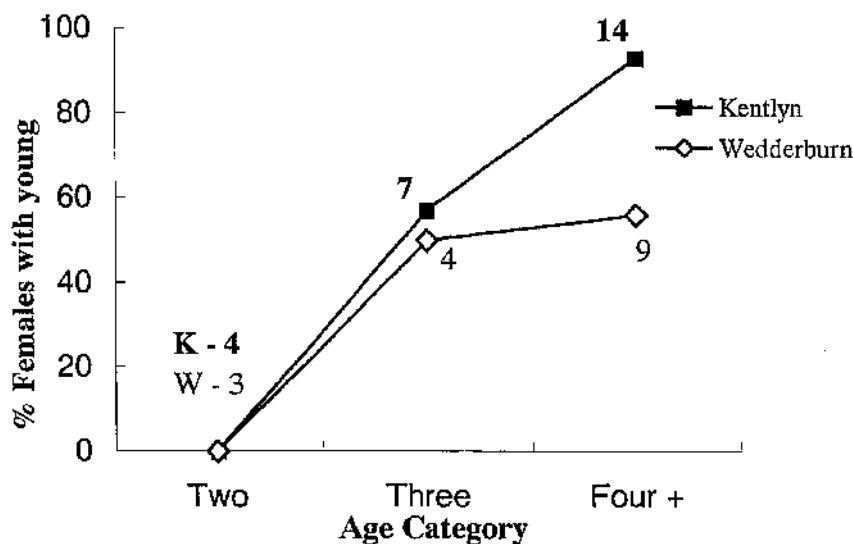


Figure 4.3. Graph of the percentage of females with young within three age categories for the Kentlyn region (shale and sandstone soils) and the Wedderburn region (sandstone soils). The number of observations in that age category is shown in bold text for Kentlyn and normal text for Wedderburn. Note that there are multiple observations of whether individual females produced young (i.e. observations from different years for the same female).

A greater percentage of females had young in the age four plus category than the age three category, for both Kentlyn and Wedderburn. Kentlyn females also had a higher fertility rate for both three and four plus age categories (Fig. 4.3). Data from age categories 3 and four plus were grouped together to provide sufficient data for a chi-square test between Kentlyn and Wedderburn (Table 4.10). Data from two year old female koalas were not used, as females were not observed to breed until they were at least 3 years old. The fertility rates for females three years old or more were significantly different between Kentlyn and Wedderburn ($\chi^2_{[1]} = 4.44, p < 0.05$).

Table 4.10. Data by region, for whether female koalas 36 months or older gave birth to a young in a breeding season. Note that a female koala was moved from Kentlyn to Wedderburn when a juvenile (prior to this study), and accounts for four Wedderburn breeding seasons.

Category	Kentlyn region	Wedderburn region
Had young	17	6
No young	4	7

To allow comparison with other studies, the estimated adult fertility rate, where females 24 months and older are defined to be adults, was 68% and 37.5% for the Kentlyn and Wedderburn regions respectively.

4.3.9 Ages of Male Koalas

Male koalas in the areas where sightings of female koalas with young were few (Fig. 4.1) were significantly younger than those in the breeding areas (Table 4.11, $\chi^2_{[1]} = 6.32$, $p < 0.025$). Unfortunately, the accuracy of the classification of male koalas into the two age classes, particularly given the difficulty in assessing tooth wear for many animals, is unknown.

Table 4.11. Ages of male koalas in breeding and areas where sightings of female koalas with young were few. See Fig. 4.1 for areas defined as breeding habitat and areas where sightings of female koalas with young are few.

Age Category (years)	Breeding	Areas where sightings of female koalas with young are few
3 - 5	11	11
6+	8	0

*Areas where sightings of female koalas with young are few and breeding categories significantly different ($p < 0.025$).

4.4 Discussion

It was expected that capturing koalas would provide new insights into basic aspects about the populations, particularly for the southern Sydney region, which has been the focus of this study. This expectation was met and important outcomes from the analysis of data collected from koala captures were:

- Female koalas in Wedderburn on sandstone soils were in poorer condition and, on average, were 0.92kg lighter than females in Kentlyn with access to the more fertile shale soils.
- The poorer condition of Wedderburn females was associated with lower fertility rates than at Kentlyn.
- No females from either Kentlyn or Wedderburn were found to breed before they were 1095 days (3 years) old in contrast to the findings of Martin and Handasyde (1990a) that females on French Island bred as early as 665 days old.
- Detected koala deaths were significantly male biased, probably because many males were killed by cars and dogs and were thus detected and reported by the community. The situation in natural bushland is unknown.
- Chlamydial infection was detected but no impact upon fertility rates was observed.

- No difference in size, weight or condition was detected between male koalas on shale and sandstone soils.
- Adult male koalas (≥ 2 years) from areas where breeding is known to occur were, on average, older, 1.83kg heavier, and had head lengths 12.4mm longer than males from areas where breeding aggregations of female koalas were not known to occur.
- There were intermittent problems with spectators observing koala catches. This problem was addressed by informing and educating the people observing a koala capture. These persons were asked to remain quiet, and to restrain dogs, which helped to reduce the impacts upon the koalas. It was observed that persons watching capture attempts were less likely to oppose the attempt if they understood the reasons for capturing the animal, the capture techniques, and the koalas' likely behaviour.

I first review differences, and possible explanations for, the observed differences in size, weight and condition of females in Kentlyn and Wedderburn, and males in breeding habitat and areas where sightings of female koalas with young are few.

4.4.1 Size, age, weight and condition

The most feasible explanation for the difference in average body weight, but not head length, for female koalas in the Kentlyn and Wedderburn regions is differences in soil fertility. That is, as predicted by the resource-availability theory (section 1.6.1), eucalypts in low fertility sandstone soils have a higher relative investment in their leaf antiherbivore defenses, leading to Wedderburn females having lower body weights and condition scores.

Given the observed differences between Kentlyn and Wedderburn for female koalas it is remarkable that male koalas did not show a similar trend. Unfortunately, the low number of males captured from Wedderburn sandstone areas made detecting a difference, if present, difficult. However, it is also possible that males' greater movements than females would give them access to a greater range of trees for browsing, and thus they may have access to leaves of higher nutritional value, despite also living in low fertility sandstone habitat. The energetic drain of producing milk and raising young may also make a difference more noticeable in females than males.

Krockenberger (1993a, b) found that food intake by lactating females to meet energetic demands during the time of peak lactation, was 27% greater than that of non-lactating females during the same period. Lower food quality would make it hard to meet energetic demands during lactation, as less energy would be obtained from the same volume of browse, and because there is an upper limit to the amount of food the gut can process over the same period of time. This could therefore account for the significantly lower fertility rate observed at Wedderburn compared to Kentlyn.

The greater head length and weight of males in the breeding areas compared to areas where sightings of female koalas with young were few, but similar condition scores, indicates that adult males in the breeding areas are large, mature animals. The lower head-lengths and body-weights of males in the areas where sightings of female koalas with young were few, suggest that these animals are still maturing and most are not yet large enough to compete for access to females for mating.

Comparing the age estimates of males from the breeding areas, and areas where sightings of female koalas with young were few, it was found that the males in the areas where sightings of female koalas with young were few were young, as all were estimated to be 5 years, or less, in age. This finding must be treated with caution, however, as the accuracy of the classification of male koalas into the two age classes is unknown.

The finding that although there were older males present in the breeding area, and there were still many young males present, is consistent with the hypothesis of Mitchell (1990a) that there is a bimodal male population structure within breeding habitat. The finding that younger, smaller males occur in areas where it is thought breeding female koalas are rare, or do not occur, is also consistent with this hypothesis. These findings may be due to young male koalas making dispersing through habitat where breeding females are rare.

4.4.2 Fertility Rates

Given that Wedderburn females were in poorer condition than those from Kentlyn, it is not surprising to find that Wedderburn females had a lower adult fertility rate. Thus, as

has already been argued, it appears females having access to vegetation on the more fertile shale soils encounter lower levels of plant defenses, or more nutrients, in the leaves consumed, allowing these animals to more adequately meet the energy demands of raising young.

Differences in adult fertility rate, however, could be due to variation in chlamydial infection rates. The adult fertility levels for Kentlyn females are comparable to studies on some populations in Queensland (White and Kunst 1988, Gordon *et al.* 1990b), and New South Wales (Gall 1980), whilst the adult fertility rate for Wedderburn females are comparable to the Inverness population in Queensland, which had a high level of chlamydial infection induced infertility (Gordon *et al.* 1990b). However, the rate of chlamydial infection was higher in Kentlyn (23.5%) than Wedderburn (13.3%), whereas if chlamydial infection was the cause of the observed variation in fertility rates, the Wedderburn infection rate should be higher than the Kentlyn infection rate. Chlamydial infection causing the difference in fertility rates also seems unlikely given that clinical signs of chlamydial infection were not observed in any animal examined. Still, the chlamydial testing techniques used in this study had a low level of sensitivity; therefore, further testing to clarify whether chlamydial infection varies between Kentlyn and Wedderburn would be useful.

The difference in fertility rates between Kentlyn and Wedderburn females, which I suggest is due to whether these females have access to shale soil vegetation, or to sandstone soil vegetation alone, is significant for management of koalas in both the southern and greater Sydney regions. Most of the remnant habitat left in the southern Sydney region occurs on sandstone soil. The data from Wedderburn females show that breeding populations can survive in these areas, although the reproductive output of these animals is greatly reduced. Appropriate conservation of remnant vegetation on shale soils is thus important for the southern Sydney koala population (see section 7.2.3). However, the greatest human development in the southern Sydney region has occurred on these more fertile soils, and little shale vegetation remains. Thus, conservation of remnant vegetation on shale based soils should be a high priority. Phillips and Callaghan (2000) also considered that the occurrence of shale soils, as well as the distribution of *E. punctata* and *E. agglomerata*, were important factors limiting the distribution and abundance of koalas in the Campbelltown region.

Due to a low number of females being captured from the greater Sydney region it was not possible to determine the fertility rate for this area but presumably the same trend of better condition and greater female productivity in higher fertility soils would also be the case for this region. Thus, remnant vegetation on high fertility soils should also be conserved wherever possible in this region.

No females in this study were observed to have young until three years of age. This contrasts with work of Martin and Handasyde (1990a) who documented females giving birth at as young as 665 days of age. Thus, it seems that the generally low fertility levels results in a slower growth rate and because of this, breeding of females may be delayed by one year.

Alternatively, Martin and Handasyde (1990a) proposed that the female koalas they observed were generally around 6kg in weight when they bred, and that body weight may be a better indicator of sexual maturity than age. Results from this study are consistent with this hypothesis, as females did not reach 6kg in body weight until just before they were three years old, and no female was observed to breed until age three. Again, however, this indicates that breeding is delayed in the Sydney area, as Victorian koalas are larger than those in New South Wales (section 1.2).

4.4.3 Capture Success and Sex Ratio

Concessions of either aborting or not attempting a catch were recommended by Bali and Delaney (1996) to minimise risk to koalas from an attempted capture. This recommendation was followed in this study, and the capture success rate of 85% was considered good.

It was expected that there would be a bias towards males in the animals caught, because most animals were located through community reports. A bias towards males was found, but this trend differed significantly from a 1:1 sex ratio only for koalas that had died.

4.4.4 Mortalities and Parasites

A bias towards deaths due to vehicle impacts and towards males was observed. The bias in deaths towards human associated trauma was expected, due to the use of community reports. The bias towards male mortality also appears to be related to the use of community reports. Males have greater movements than females, thus increasing their chance of encountering dogs, or crossing a road and being hit by a vehicle. However, the male bias in these deaths means that males appear to be more susceptible to impacts from urban areas. Furthermore, animals making dispersal movements, which are important to maintain gene flow between populations, appear to face increased risks of death or injury, particularly due to road traffic.

Deaths due to stress combined with renal failure or dehydration, occurred in three animals from Wedderburn (sandstone soils). These deaths indicate that koalas have difficulty in coping with the conditions in this area. It also indicates that water balance and kidney problems may be issues for these animals.

Deaths due to dog attacks were significant, with three deaths being recorded. As roaming dogs in the Campbelltown area are common, it is likely, however, that some deaths occurred away from humans, and thus went unreported.

Although a heavy tapeworm load contributed to the death of one koala, parasites appear to have a low overall impact in both the southern and greater Sydney regions.

The immunofluorescence technique used to detect chlamydial infection is not sensitive enough to detect all infected animals, but is unlikely to return a false positive, although the animals that had 'suspect' positives may not have been infected. Thus, the only definitive statement I can make is that chlamydial infection was present in the southern Sydney region during this study. Moreover, the record of 143 captures and no definite clinical signs compares favourably with 22 captures and 5 animals with clinical signs of chlamydial infection at Pine Creek State Forest (northern New South Wales) in 2000 (Close pers. comm.).

Thus, it appears that chlamydial infection is present within the southern Sydney region, but that the incidence of infection is low, and does not affect fertility rates.

5 Sightability and Home Range.

5.1 Introduction

Some of the captured koalas were fitted with radiocollars, and located during the day using a hand-held receiver and antennae, at varying time intervals. Radiocollared koalas were followed for as long as possible, with the longest being Shirley, a female captured as a juvenile and later radiotracked as an adult for four and a half years. The long periods of tracking allowed multiple fixes to be collected and observations of tree usage (see chapter 6). This led to high quality individual data, but it was only possible to gather this kind of information for a few individuals, as most animals threw their radiocollars or disappeared at some point, and often could not be relocated. Thus, whilst few individuals met the requirements for confidence in the home range estimate, analysis is still presented for those individuals with insufficient data for comparison.

Once a koala was found, the tracker rated how hard it was to spot on a subjective "sightability" index developed in this study. This index was used to investigate if the ease by which koalas could be spotted by humans varied with location, and between males and females, within the southern Sydney study region.

There is a long history of human predation of koalas, with Aborigines hunting koalas for their meat (see section 1.8). Europeans also hunted koalas for their furs from the 1880s to 1920-30s. Such hunting in the Campbelltown region has been documented in this study (see section 3.3.8). Given the risk of predation by humans, it thus seems reasonable that koalas would seek to reduce detection by humans. Koalas living near human habitation might, therefore, choose locations such as dense vegetation, where they would be harder to spot. The proportion of koalas detected by survey techniques relying on human observers could therefore differ between areas, affecting the survey results.

Females with young, particularly back young, might specifically seek dense cover, because the female's ability to elude humans would be reduced because of the encumbrance of her young. If threatened she might have to abandon her young, therefore losing her considerable investment.

For each radio-tracking fix, details of the tree the koala was found in were recorded, as well as its location. Radiocollared koalas' diurnal home ranges are analysed in this chapter and tree preferences are analysed in the following chapter (chapter 6).

Information on an animal's home range can provide useful biological information including insights into distribution of resources and use of habitat (Harris *et al.* 1990). I first review the definition of the home range concept, then appropriate techniques for investigating home range, issues associated with home range analyses, and the findings of other studies that have investigated koala home ranges.

5.1.1 Definition of Home Range

One definition of home range is "*that area traversed by an individual in its normal activities of food gathering, mating and caring for young*" (Burt 1943, White and Garrott 1990). The difficulty, however, is deciding what constitutes "normal" movements (White and Garrott 1990). For example, movements made by individuals during migration, or by dispersing animals would be excluded from this home range definition (Burt 1943).

Aebischer *et al.* (1993), however, noted that an animal actually describes a trajectory; a moving path through space and time. Robertson *et al.* (1998) used this concept to redefine home range as "*an area within which lies a specified proportion of an animal's trajectory over a specified period*". This definition removes the problem of defining what constitutes "normal" activities for an animal and hence is utilised in this study.

5.1.2 The Effect of Sex and Age on Home Range

Besides the time period over which the home range was measured, both the sex and age class of individuals may affect home range size. This information should therefore be provided with home range estimates (Harris *et al.* 1990). Sex variation in home range size has certainly been found in koalas. Five studies found that male koala home ranges were significantly larger than female home ranges (Hindell 1984, Mitchell 1990b, White 1994, Melzer 1994, White 1999). Hull (1985) and Mitchell (1990b) also found that males move further, and more often than females. Two studies, however, found no

significant difference between the sexes in home range size (Faulks 1990, Hasegawa 1995).

5.1.3 Home range Analysis Techniques

A range of techniques has been developed for home range analysis (Harris *et al.* 1990). Two techniques were used in this study: the minimum convex polygon (MCP) and harmonic mean.

Minimum Convex Polygon

The MCP method consists of a boundary, a convex polygon, encompassing the outlying fixes (Fig. 5.1). It is the only technique that is strictly comparable between studies, and therefore its inclusion is beneficial (Harris *et al.* 1990, White and Garrott 1990). However, the MCP method can include areas that are rarely, if ever, utilised by the animal, so this technique was not used for further analysis (Fig. 5.1).

Also commonly calculated in conjunction with the MCP is the range span, the distance between the two furthest fixes (Fig. 5.1).

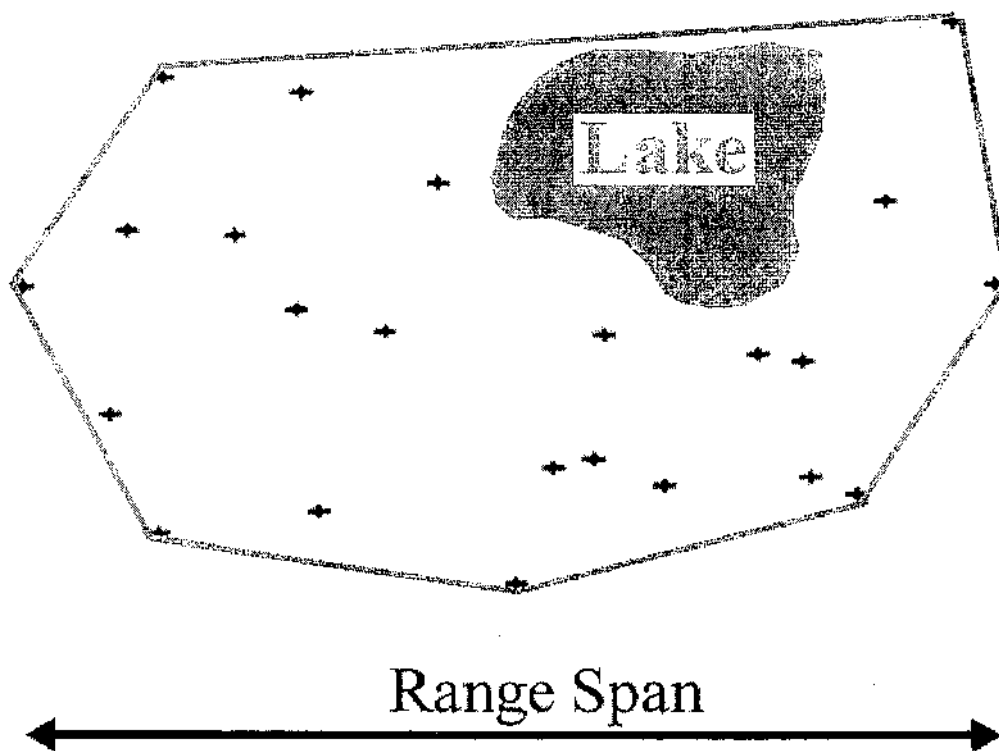


Figure 5.1. Diagram of a theoretical minimum convex polygon (MCP) home range. Crosses represent fixes and the line surrounding them represents the MCP boundary. The lake shows how an area may not be utilised by an animal, but be included in the MCP home range. The range span is also shown, which is the distance between the two furthest fixes.

Harmonic Mean

This is a “probabilistic” technique, which means that the technique predicts the probability of an animal’s occurrence in space (Harris *et al.* 1990). Thus, different isopleths represent boundaries within which a certain proportion of fixes occur (i.e. 90% of fixes would lie within the 90% harmonic mean isopleth). This technique also allows centres of activity within a home range to be examined, and the technique does not assume, like some others, that there is one centrally placed centre of activity and that the animal’s use of space is normally distributed around this centre of activity (Harris *et al.* 1990).

To calculate the isopleth boundaries for the harmonic mean method, an arbitrary grid is superimposed on the fixes and is used to calculate areal moments for the fixes (Dixon and Chapman 1980). Computer programs currently exist which can use this arbitrary grid to calculate the isopleths. Comparisons between studies are difficult, because computer programs often use different computational algorithms and grid cell sizes, which can alter the estimated isopleth boundaries (Harris *et al.* 1990, Larkin and Halkin 1994). Thus, the analysis software used should be explicitly stated as part of the methodology (Lawson and Rodgers 1997).

5.1.4 Issues in Home Range Analysis

Radiotracking involves sampling an animal’s movements. Home range analysis techniques use these sampled data to predict the area used by an animal, or that animal’s use of their home range. However, home range analyses, like all analytical techniques, assume that the sampled data used represent that animal’s true movements, although this may not always be the case. Furthermore, the analytical techniques need sufficient data (i.e. number of fixes) to make predictions. Thus, there are several issues in data sampling which should be resolved prior to conducting home range analyses, as studies may have different objectives, and may therefore use different techniques to address these issues, which are reviewed below.

5.1.4.1 Fix Resolution

Defining the fix resolution (i.e. how accurate, on average, fixes are) is most commonly a problem where the animal is not actually seen, and its location is estimated from the

transmitter's signal (White and Garrott 1990). However, though koalas can usually be located with a hand held receiver and antennae, there will be some level of error inherent in determining the grid reference. Fix positions are commonly calculated by using either a handheld global positioning system (GPS unit), or by determining the koala's grid reference using a map and the distance from known landmarks. As many koala fixes were estimated using the latter method, the fix resolution for this study was estimated.

5.1.4.2 Location Autocorrelation

Fixes obtained during a study are distributed both in space (i.e. x and y coordinates), and in time. When the period between fixes for a study animal is too low, the animal's next location will have been influenced by its previous one. That is the locations will be autocorrelated (i.e. not independent), and this causes problems for all home range estimators (Hansteen *et al.* 1997). Increasing the time interval between fixes will resolve the problem, but may make it difficult to obtain the number of fixes required. Thus, studies must often reach an appropriate compromise, which should be based on an assessment of the level of autocorrelation (Swihart and Slade 1985a).

Swihart and Slade (1985b) developed a method to test for the time to independence. The method calculates Schoener's t^2 / r^2 ratio for increasing time intervals between successive observations and plots these values against the time interval. Use of the t^2 / r^2 ratio was first suggested by Schoener (1981), where t^2 is the mean squared distance between successive observations, and r^2 is the mean squared distance of observations from the geometric center. Schoener's t^2 / r^2 ratio must reach a critical value of 1.96 for successive locations to be independent, but some t^2 / r^2 ratio values may actually fall below this critical value even once the time period required for independence has been reached. For this reason Swihart and Slade (1985b) suggested that the time of independence be defined as the smallest time interval with a t^2 / r^2 ratio value above 1.96, and with two successive t^2 / r^2 ratio values also above 1.96, and that this be investigated by plotting the time interval between observations against the t^2 / r^2 ratio (see section 5.2.2).

5.1.4.3 Isopleth Value Selection

Selection of suitable isopleth values is an important part of the analysis procedure. Many radiotracking studies have used a 95% isopleth to define “home range”, but without any biological justification (White and Garrott 1990). Some analyses have also used a “centre of activity”, or “core” area, and they denote areas with a significantly higher proportion of an animal’s fixes (Harris *et al.* 1990). Core isopleth values can be selected by plotting the percentage of the maximum (99% isopleth) home range area against increments in the isopleth value (Harris *et al.* 1990). For most animals there will be a point where the gradient of the slope changes, and the isopleth value at which the slope changes should be selected for the “core” isopleth value (Fig. 5.2).

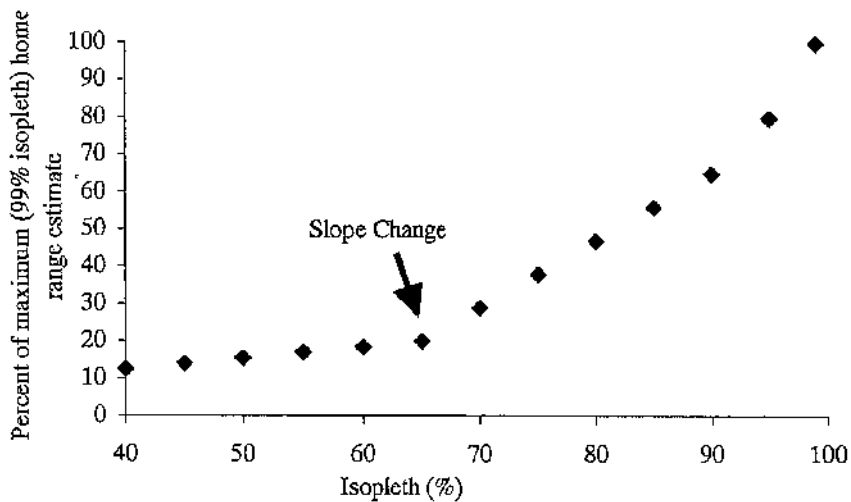


Figure 5.2. Theoretical plot of isopleth values, in 5% increments, against the percentage of the maximum home range size (99% isopleth) for that isopleth value. The point where the slope changes is marked by an arrow. This isopleth value is appropriate for examining home range “core” areas.

5.1.4.4 Number of Fixes Required

The number of fixes required to give an adequate estimate of home range size is determined by plotting the number of fixes against home range size (Harris *et al.* 1990). The point at which an asymptote in home range size is achieved is the minimum number of fixes required. Unfortunately, not all animals will reach an asymptote, even with a large number of fixes (Harris *et al.* 1990). This problem was encountered by Krockenberger (1993a) who found that although the MCP range reached an asymptote at 60 observations, the harmonic mean range had still not reached an asymptote at 70 observations.

5.1.5 Koala Home Range Studies

A review of koala home range studies showed that the minimum number of fixes used to determine koala home range size ranged from 11 to 40 sightings, and the minimum time between fixes was often 1 day, but varied from 7 hours to 7 days (Table 5.1). MCP and HM analysis methods tend to dominate, as do the use of 95% and 90% isopleths (Table 5.1). However, there is clearly no consistent standard within koala studies for addressing home range analysis issues, or for comparison with other studies.

There was also considerable variation in the average home range size between studies, ranging from 0.15 to 316.5 ha (Table 5.1). Despite the fact that the analysis technique will affect the home range size estimate, koala home range sizes appear to be inversely correlated with density (Table 5.1).

Studies on other species have found that females will use the minimum home range size required to meet their energy requirements (Davies and Hartley 1996, Tufto *et al.* 1996, Hubbs and Boonstra 1998), and that males and / or females may expand their ranges to find partners for mating in low density populations, depending upon the social system of the species (Labisky and Fritzen 1998).

Krockenberger (1993a) suggested that koala home ranges in poor quality habitat were likely to be larger than those in good quality habitat as acceptable foliage would be sparser in the poor quality habitat. That is, animals will need to expand their home range to ensure a sufficient resource base to meet their energy requirements (Krockenberger 1993a). As soil nutrients have been found to affect the quality of foliage available, I therefore propose that low fertility soils will lead to less foliage acceptable to koalas, and that large home ranges will be expected in these areas. As this study radiotracked animals on low fertility soils, finding comparatively large home ranges compared to other published studies will be consistent with this hypothesis.

Table 5.1. Comparison of published home range areas (Table from Melzer 1994 with modifications). HM = Harmonic Mean, JTE = Jenric-Turner Estimator (centre of activity), MCP = Minimum Convex Polygon, MCCP = Minimum Concave Polygon, K = Kernel.

Location	Minimum number of fixes	Min. time between fixes	Density (koalas ha ⁻¹)	Analysis Method	Average female area (ha)	Average male area (ha)
Eden, NSW ¹	18	1 day	0.006	MCP	316.5 *	149 *
				90% HM	132.5 *	83.3 *
Norwood Creek, Springsure, Qld ²	20	24 hours	0.4	MCP	37.6	79.5
				95% HM	39.2	86.5
Brisbane Ranges, Vic ³	15	24 hours	0.7 – 1.6	90% HM	2.08	3.14
Point Halloran, Brisbane, Qld ⁴	10	Usually 7 days	1.9 – 2.5	95% MCP	3.6	2.8
				95% JTE	5.6	4.3
				95% HM	3.3	3.1
French Island, Vic ⁵	>10 [†]	1-2 days [†]	3.9 – 8.9	90% HM	1.18	1.70
Phillip Island, Vic ⁶	>25	7 hours	5.3	JTE	0.35	1.07
				MCCP	0.15	0.26
Ballarat, Vic ⁷	25	Not given	-	MCP	15.2	14.4
				MCP	2.18 *	12.76 *
Lismore, northern NSW ⁸	40	<1 day	-	Modified MCP	0.40 *	2.70 *
				MCP	L 3.6, NL 9.6 [‡]	-
Nowendoc, NSW ⁹	15	1 day	-	95% HM	L 1.6, NL 3.2 [‡]	-
				90% HM	L 1.2, NL 2.4 [‡]	-
				70% HM	L 0.4, NL 1.0 [‡]	-
				JTE	13.75	19.67
Sheldon, Brisbane, Qld ¹⁰	unknown	unknown	-	JTE	13.75	19.67
Mutdapilly, Qld ¹¹	15	Not given	-	70% HM	3.5	8
Lismore ¹²	19	1 day	-	MCP	19.4 *	35.6
				90% HM	3.6 *	6.6
Mutdapilly, Qld ¹³	30	3 days	-	95% K	15.0	34.4
				70% K	5.0	12.5

1 = Jurskis and Potter 1997

2 = Melzer 1994

3 = Hindell 1984

4 = Hasegawa 1995

5 = Mitchell 1990b

6 = Sharpe 1980

7 = Hull 1985

8 = Faulks 1990

9 = Krockenberger 1993a[‡]

10 = Nyo 1993, cited in Melzer 1994

11 = White 1994

12 = Harris 1999b

13 = White 1999

* = Average calculated from documented home ranges.

[†] = Independent sightings which were defined by Mitchell (1990b) as "the animal was in a different location to that in which it was last seen, or if the animal was in the same tree, but two days had passed since the last independent sighting: after two days, most animals had moved to a different location".

[‡] = "L" represents a lactating koala, and "NL" a non-lactating koala. Males were not tracked in this study.

5.1.6 Objectives

The objectives for this chapter were:

1. To investigate if the ease with which koalas could be spotted by humans varied with location, and between sexes.

2. To investigate appropriate analytical techniques for determining koalas' home ranges.
3. To determine the average home range sizes of both male and female koalas in the Campbelltown region, utilising the most appropriate analytical techniques.
4. To investigate whether data from this study were consistent with the hypothesis that koalas from low density populations have large home ranges.

5.2 Methods

Selected animals were fitted with radiocollars purchased from Titley Electronics Pty Ltd. The collars weighed approximately 80g and had an expected battery life of 8-10 months. Radiocollars were fitted so that they could slide off the animal's head if they became caught in foliage. When radiocollars were replaced animals were checked for signs of chafing, or other adverse effects due to the collar, but none were observed.

Animals were tracked using a portable Regal 2000 receiver and H-frame or yagi antenna. Tracking was primarily performed by Steven Ward, Lynn Coxall, Robert Close, Wayne Foster, and Miroslav Belik, together with many volunteers. Once an animal was located, the tree species was recorded and the tree marked with a numbered metal tag, or if already tagged, the tag number recorded. *E. agglomerata*, *E. capitellata*, *E. eugenioides* and *E. globoidea* were all referred to as stringybarks due to difficulties in distinguishing these species. This was particularly necessary given the number of radiotrackers. Circumference of the tree trunk at 120cm height from the ground was also recorded and later converted to diameter at breast height by dividing by π . The height of the tree or shrub was estimated by eye.

From 7th December 1996, the position of the koala was also used to determine the score for a sightability index. This index was based on how easily the koala could be seen by the trackers from all angles. A subjective score between 1 and 5 was used where 1 represented the koala being easy to spot and 5, extremely difficult.

5.2.1 Fix Resolution

Universal transverse mercator (UTM) grid locations for tree locations were determined using the zone 56 Australian Geodetic Datum (1966). Prior to the commencement of

this study locations were determined using a hand-held Trimble GPS unit in either UTM or latitude and longitude (later converted to UTM coordinates using Redfearn's formulae). These GPS locations were affected by errors deliberately introduced by the United States Department of Defense through a process called selective availability. This process was disabled in May 2000 (Hulbert and French 2001).

From September 1996, to 28th July 2000, notes were taken on estimated distances from landmarks, and UTM coordinates later estimated from these notes. From 29th July 2000, after the US introduced error was turned off, locations were determined using a Magellan 320 GPS unit, and repeated measurements were observed to be within 30m. Fixes were then taken from as many previously marked trees as possible, with these GPS locations being used in preference to previous UTM estimates. To determine the accuracy of fixes prior to 29th July 2000, 27 locations were selected at random, and the distance between the previous, and the Magellan 320 GPS estimates, determined. The mean location error (\pm sd) prior to 29th July 2000, assuming that the GPS locations from 29th July 2000 were correct, was 82.7 ± 69.9 m.

The fix resolution for all koala home ranges was then determined as per White and Garrott (1990) where:

The error standard deviation, obtained by accuracy testing, can then be used to construct 95% confidence areas around each location estimate by delineating a circle centered on the point estimate with a radius of 1.96 times the error standard deviation, where 1.96 is a z statistic.

Thus, the fix resolution was determined to be 1.96 times the error estimate for locations prior to 29th July 2000, or a resolution of 137m. This fix resolution was used for all data analysis, and was considered to adequately account for fix location errors, as the bulk of GPS estimates were the more accurate fixes taken after the 28th July 2000. All home range estimates were performed in Ranges5, version 2.05 (Kenward and Hodder 1996), with the default settings being used except where explicitly stated.

5.2.2 Time between Fixes

Shirley, an adult female koala at Kentlyn was located daily from 21st November to the 24th December 1996, except from the 6th to 8th December. These data were used with the technique from Swihart and Slade (1985b, see section 5.1.4.2) and a sample interval of 12 hours to determine the time period needed for fixes to be independent. From this analysis, the time to independence was 7920 minutes, or 5.5 days (Fig. 5.3).

To minimise the loss of data (from discarding fixes taken within 4 days of each other), and the level of autocorrelation between fixes, the time between fixes was set at 5 days (7200 minutes). The first location for each animal was examined, and any fixes within 4 days of the first fix were discarded. Subsequent remaining fixes were then examined in the same way until all locations were examined.

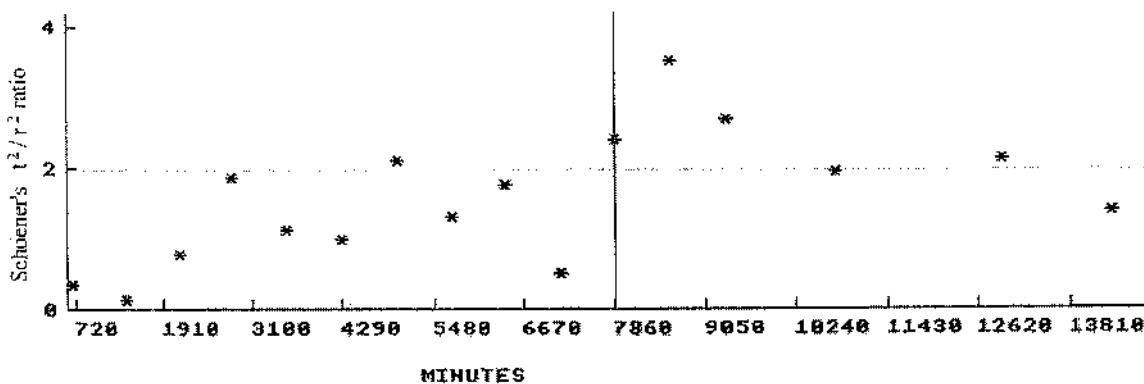


Figure 5.3. Graph of Schoener's t^2/r^2 ratio against the time between paired daily locations for Shirley, an adult female koala. The horizontal line represents the critical value for the t^2/r^2 ratio (t^2 = mean squared distance between successive observations, r^2 = mean squared distance of observations from the geometric center), and the vertical line represents the time to independence as defined by Swihart and Slade (1985b).

5.2.3 Isopleth Values

Isopleth values in 5% increments were plotted against the percentage of the maximum harmonic mean home range size for the five adult male and female animals with the greatest number of locations (Fig. 5.4). Following Harris *et al.* (1990), isopleth values were visually selected by noting where the gradient of the slope changed (see Fig. 5.2). This visual assessment gave core isopleth values of 60% for females and 75% for males (Fig. 5.4). The 60% isopleth was selected for both sexes, as this lower value would better represent high use "core" areas.

The 95% and 90% isopleth plots were examined and, as the 95% harmonic mean isopleth included substantial areas where location fixes did not occur for some animals, the 90% isopleth was selected for all home range area estimates.

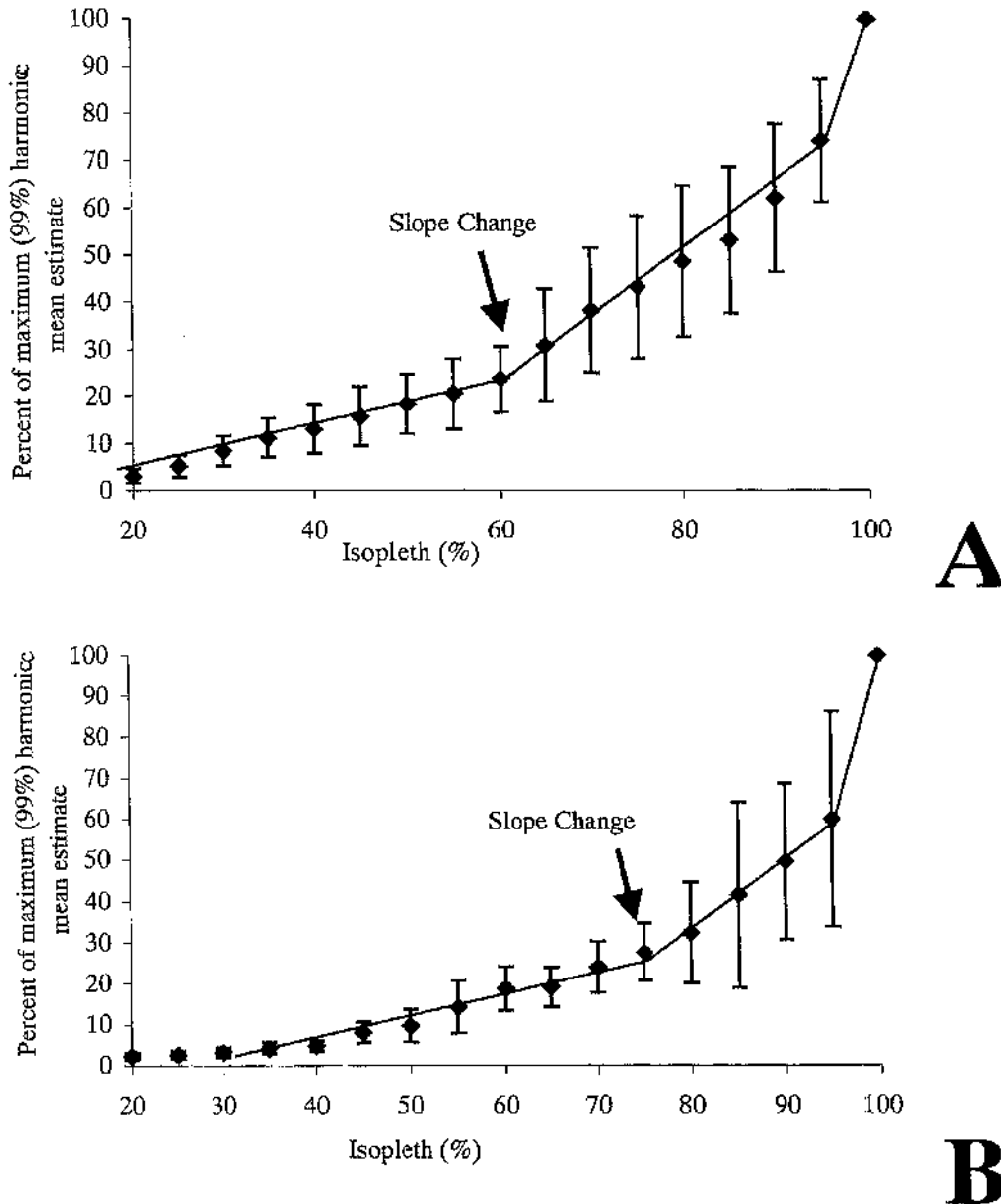


Figure 5.4. Plots used to select core home range isopleth values. Percentage of the maximum (99% isopleth) harmonic mean home range size estimate is graphed against isopleth values in 5% increments. Mean percentages and standard deviations are given for: A) five adult female, and B) five adult male koalas. Lines and arrows are shown to indicate slope changes for selecting core home range isopleth values.

5.2.4 Number of Fixes

The number of locations required before the home range size asymptote was reached for the 60% and 90% harmonic mean isopleths, for both males and females was

assessed (Fig. 5.5). Note that an increase in fixes can actually result in a decrease in the home range size estimate. That is, if fixes occur close to the center of that animal's home range, the home range isopleths will contract inwards towards the center of the home range, thus leading to a reduction in the home range size estimate.

The asymptote in fixes for home range size was estimated to be 60 locations for females, for both 60% and 90% isopleths (Fig. 5.5). For males, the 90% isopleth appeared to reach an asymptote at 20 locations, whereas the 60% isopleth did not appear to reach an asymptote (Fig. 5.5). Because of this variation, males may have had an insufficient number of locations to reach an asymptote in home range size. This meant that there were sufficient locations to reach the home range size asymptote for three adult females only: Franchesca, Lyn and Shirley. Although there were 61 locations for Sarah, many of these came from when she was a juvenile (Table 5.1) as were some observations for Shirley, Molly, Victor and Ray. Victor was not collared, but was sighted periodically during the tracking of others.

The behaviour of juvenile and subadults was expected to differ from that of adults. Therefore, "adult" home range data analysis used in this chapter refers to females estimated to be ≥ 3 years old (headlength $\geq 128\text{mm}$), and males estimated to be ≥ 4 years old (headlength $\geq 155\text{mm}$), to exclude locations for both juveniles and subadults.

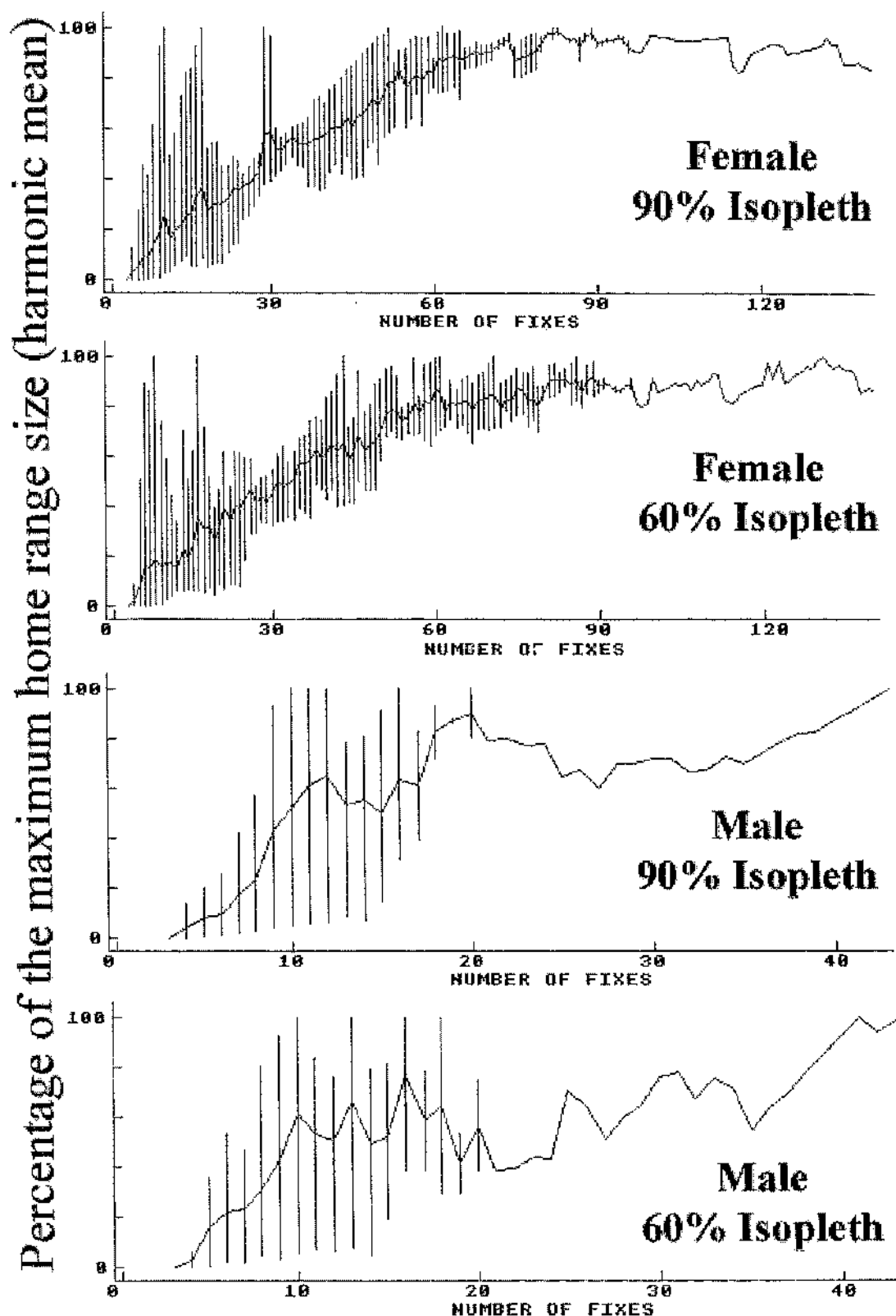


Figure 5.5. Graph of the percentage of the maximum home range size (harmonic mean) versus the number of fixes for seven male and seven female koalas with 10 or more locations. The maximum harmonic home range size is the largest home range size reached for each individual, for the 60% or 90% isopleths. Vertical lines represent the range in percentages of the maximum home range size for all individuals at that number of fixes. Note that as the number of fixes increase, the number of animals represented by the vertical lines decrease as those individuals with insufficient fixes (see Table 5.2) are no longer included.

5.3 Results

5.3.1 Home Range Size

Seven male and seven female koalas were located 10 or more times, with locations at least 5 days apart (Table 5.2).

Table 5.2. Details for koalas that had ≥ 10 radiotracking observations. Asterisks denote the three female koalas that had a sufficient number of locations, with a 5-day gap, to reach the asymptote in home range size.

Sex	Koala	Location	Number of locations (with 5 day gap)	Time Periods	Notes
Female	Shirley	Kentlyn	140 *	22/9/93 - 15/5/94 16/11/96 - 5/4/2001	Approximately 1.75 years old at 22/9/93.
	Franchesca	Wedderburn	96 *	15/9/95 - 25/10/96 21/3/97 - 7/4/01	
	Lyn	Leumeah and Kentlyn	79 *	10/2/96 - 17/2/96 16/2/98 - 9/12/2000	
	Sarah	Wedderburn	61	21/3/97 - 20/3/01	Franchesca's daughter. Two years old when first started tracking.
	Molly	Wedderburn	52	20/5/94 - 24/2/95 2/8/95 - 24/3/98 24/6/00	Moved to Wedderburn from Kentlyn at 20/5/94 and was approximately two years old. Went into care once for dehydration and once for a broken leg.
	Amanda	Leumeah	17	31/8/97 - 22/7/98	
	Phea	Wedderburn	10	6/8/92 - 27/12/92	Approximately two years old.
Male	Old Boy	Wedderburn	43	8/6/92 - 1/11/93	
	Kevin	Kentlyn	20	17/10/95 10/6/97 - 17/2/98 19/8/00 - 2/10/00	
	Jacob	Kentlyn to Minto Heights	16	12/9/97 - 11/2/99	
	Gary	Kentlyn	13	10/4/95 11/7/97 - 15/12/97 12/11/99 10/12/00	
	Elmo	Wedderburn	13	16/9/94 - 1/6/95	
	Victor	Wedderburn	12	31/8/99 - 30/12/00	Franchesca's son (juvenile). Observations from sightings made whilst tracking other animals.
	Ray	Kentlyn to Wedderburn	10	8/11/97 - 27/3/98 18/12/98	Subadult - 3 years of age at 8/11/97. Dispersed from Kentlyn to Wedderburn between 27/3/98 and 18/12/98.

For both males and females, the estimates of home range area based on the MCP technique were at least twice as large as the 90% harmonic mean estimates (Table 5.3 and 5.4).

For both techniques, there was considerable variation in home range size amongst females. Despite having only 17 available locations, the largest home range, which spanned slightly over 2km, was for Amanda, a koala living in Leumeah and Kentlyn (Table 5.3). However, the averages (\pm sd) for the three adult females with sufficient locations to reach the home range size asymptote were: MCP 45.9 ± 32.8 ha, range span 766 ± 534.3 m, 60% harmonic mean 6.40 ± 2.98 ha, 90% harmonic mean 19.9 ± 16.1 ha.

Table 5.3. Home ranges size for female koalas with 10 or more locations 5 days apart. Asterisks denote the three adult female koalas that had a sufficient number of locations to reach the asymptote in home range size.

Koala	Time Period	Number of locations	Minimum Convex Polygon (ha)	Range span (m)	60% Harmonic Mean (ha)	90% Harmonic Mean (ha)
	All	140	30.98	542	4.65	11.32
Shirley *	< 3 years old	11	15.80	385	0.89	1.66
	≥ 3 years old *	129	30.87	535	4.98	12.19
Franchesca *	All (≥ 3 years)	96	28.21	465	4.84	11.61
Lyn *	All (≥ 3 years)	79	78.73	1298	9.38	35.98
	All	61	118.77	1551	20.06	47.78
Sarah	< 3 years old	24	21.60	483	1.62	7.32
	≥ 3 years old	37	113.56	1551	13.75	44.98
	All	52	47.07	733	10.52	20.90
Molly	< 3 years old	15	34.52	719	1.21	3.13
	≥ 3 years old	37	43.37	689	6.12	19.77
Amanda	All (≥ 3 years)	17	128.83	2006	24.72	61.51
Phea	All (<3 years)	10	25.29	496	0.46	2.06

Table 5.4. Home ranges size for male koalas with 10 or more locations 5 days apart.

Koala	Time Period	Number of locations	Minimum Convex Polygon (ha)	Range span (m)	60% Harmonic Mean (ha)	90% Harmonic Mean (ha)
Old Boy	All (≥ 4 years)	43	387.43	3730	72.41	164.69
Kevin	All (≥ 4 years)	20	194.64	1901	17.76	72.17
Jacob	All (≥ 4 years)	16	238.99	2540	27.01	107.12
Gary	All (≥ 4 years)	13	97.31	1420	6.43	12.10
Elmo	All (≥ 4 years)	13	38.03	1120	6.85	14.21
Victor	All (<2 years)	12	15.58	486	0.33	2.60
Ray	All (<4 years)	10	845.52	9391	63.17	257.25
Ray (outlier excluded)	8/11/97 – 27/3/98	9	137.26	1825	5.10	28.18

Range spans for males (≥ 4 years) also varied considerably, but were generally large, with the minimum range span being 1120m (Table 5.4). The largest home range and range span was observed for Ray, a subadult male, as this animal appears to have made a dispersal movement of 9.4km from Kentlyn to Wedderburn.

The 90% harmonic mean home ranges for adult male koalas ranged between 12.1 to 164.7ha (Table 5.4). However, many of these individuals had few locations, so it is likely that their home ranges were underestimated. An indication of this is that the ratio of the MCP to the 90% harmonic mean estimate increases from 2.35 for the Old Boy with 43 locations, to 8.04 for Gary, with 13 locations. That is, the harmonic mean home range estimate is more sensitive to a low number of locations than the MCP. This accounts for some of the variation in home range size. Note that MCP and range span data are presented because they are the only ones strictly comparable between studies, but because of MCP's limitations (see section 5.1.3), this technique is not used further.

Although no males (≥ 4 years) had a sufficient number of locations to reach the asymptote in home range size, the three males with >15 locations gave the best available estimate of adult male home range size. These animals had averages (\pm sd) of: MCP 273.1 ± 140.7 ha, range span 2724 ± 1306 m, 60% harmonic mean 39.1 ± 40.5 ha, 90% harmonic mean 114.7 ± 65.9 ha.

5.3.2 Male versus Female Home Range Size

Because home range size estimates vary with the number of locations, the first 15 locations for those adults with sufficient locations were used to test if male home ranges were larger than females (Table 5.5). A Wilcoxon ranked sum test was used as the ranges vary markedly in size, indicating that they may not be normally distributed. Male 90% harmonic mean home range estimates were significantly larger than female estimates, despite Amanda, a female, having a large home range [$W_s=22$, $p = 0.048$].

Table 5.5. Comparison of male and female home range size. 90% isopleth harmonic mean home range size estimates (ha) are given for adult male (≥ 4 years) and female (≥ 3 years) koalas using 15 locations spaced at least 5 days apart over a period of 17 months or less.

Male Name	Home range size (90% isopleth)	Female Name	Home range size (90% isopleth)
Jacob	97.78	Amanda	51.63
Kevin	31.77	Molly	6.82
Old Boy	10.18	Lyn	4.86
		Sarah	4.78
		Shirley	3.87
		Francesca	2.43

5.3.3 Female Home Range Shapes

No consistent pattern in the shape of home ranges for female koalas was apparent (Fig. 5.6). The shape for Phea, a juvenile at Wedderburn, was probably not accurate, and instead reflected the small number of locations available. The home range shape for Amanda probably also suffered from a low number of locations, but the home range core seemed to be concentrated to the north. The number of core areas, as defined by the 60% isopleth, also varied from one continuous core for Shirley, Molly and Lyn, to four core areas for Francesca.

Three female koalas were tracked both as an adult (≥ 3 years), and as a juvenile or subadult (< 3 years), (Fig. 5.7). For these females, the juvenile range was markedly smaller and the adult range overlapped at least some of the juvenile range. Molly showed the least overlap between her juvenile and adult home ranges, perhaps due to early explorations after being translocated (Table 5.2). However, Sarah also utilised a large area as an adult, which was also separate to, and to the south of, her juvenile range (Fig. 5.7). However, few locations were available for all juvenile ranges; therefore, these may have been underestimated (Table 5.3).

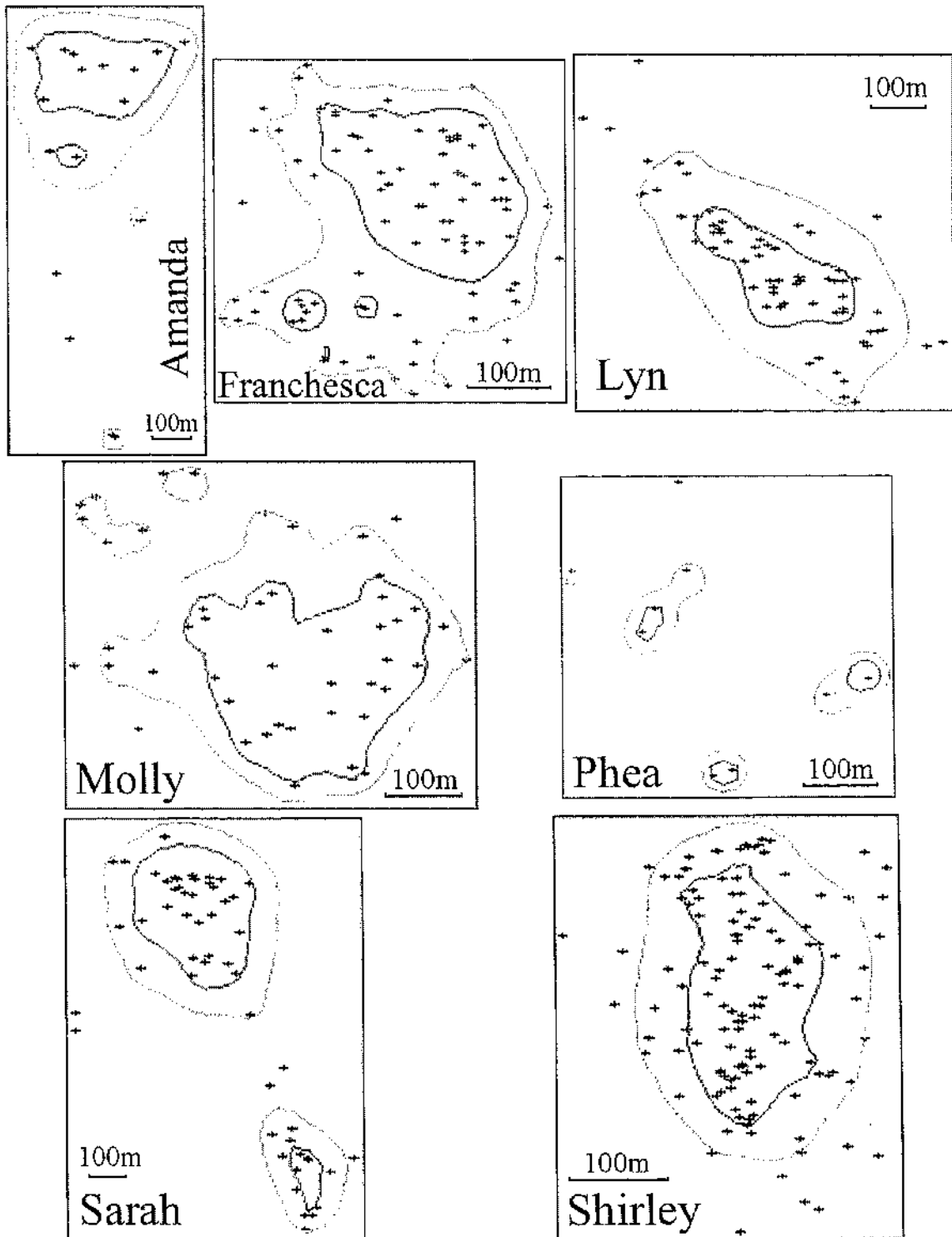


Figure 5.6. Plots of 60% and 90% harmonic mean isopleths for seven females with ≥ 10 locations. All locations at least 5 days apart. Scales for the plots vary, as indicated by 100m scale bars.

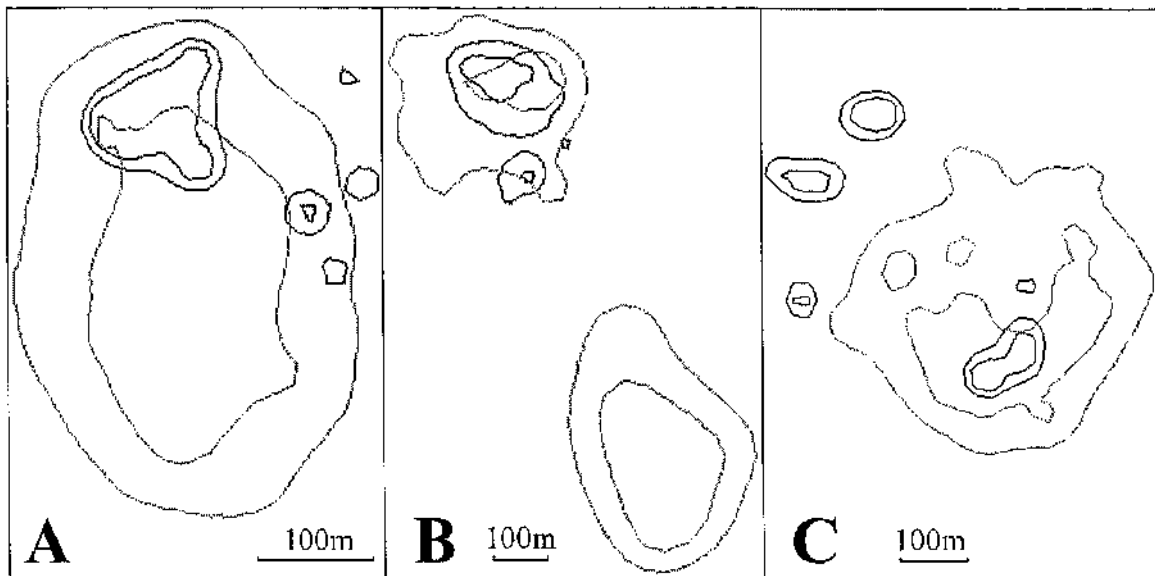


Figure 5.7. Overlay of adult and juvenile 60% and 90% harmonic mean isopleths for three female koalas, A) Shirley, B) Sarah, and C) Molly. Juvenile / subadult (<3 years) ranges are shown by black lines, whilst adult (≥ 3 years) ranges are shown in grey. Note that Molly was translocated from Kentlyn to Wedderburn after receiving care and was removed for 6 weeks after she broke a femur.

5.3.4 Male Home Range Shapes

No consistent pattern in the shape of male koala home ranges was apparent (Fig. 5.8), although as none had sufficient locations to reach the home range asymptote, their size and shape may not have stabilised. As for Phea, the shape of the home range for Gary may have been inaccurate due to insufficient locations.

The number of core areas for males, as defined by the 60% isopleth, and as for females, varied from one to four core areas (Fig. 5.8). The shape and size of the isopleths for Ray appears to have been distorted by the outlier approximately 9km to the southwest, which appears to be due to a dispersal movement by this individual. The home range for Ray was much smaller when this outlier was removed (Table 5.4), with the 60% and 90% isopleths contracting to around the closely spaced locations (Fig. 5.9).

The “Old Boy” also appears to have made a dispersal movement as this animal shifted home range from the south, moving to the north and not returning to the southern portion of the home range. Whilst Ray was a subadult male the “Old Boy” was an adult male weighing 7.2-8.3kg with 178mm headlength, worn teeth and positive for chlamydial infection, who was tracked prior to this study.

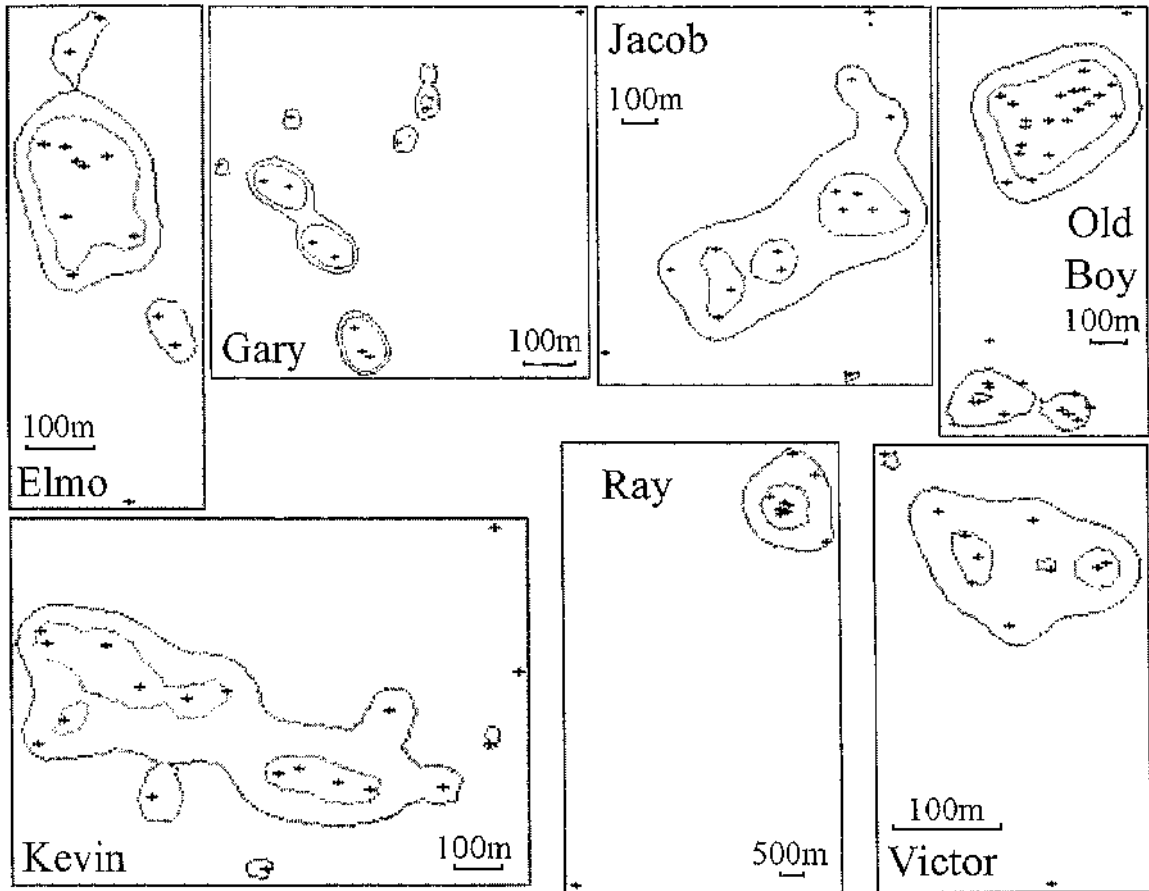


Figure 5.8. Plots of 60% and 90% harmonic mean isopleths for male koalas with ≥ 10 locations. All locations at least 5 days apart. Scales for the plots vary, and are indicated by scale bars within each plot. Names of the koalas are supplied for each plot.

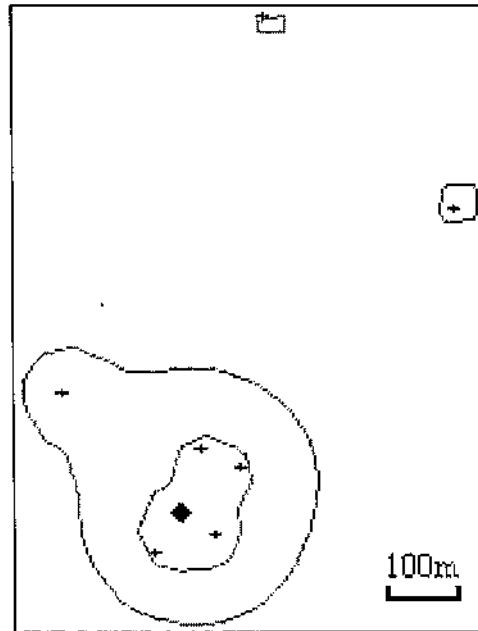


Figure 5.9. Plot of 60% and 90% harmonic mean isopleths for the male koala, Ray, with the outlier on 18/12/98 removed.

5.3.5 Sightability

Radiotracked adult females from both Kentlyn and Wedderburn were observed to have consistent trends for the sightability index, and there were no significant differences among animals from these areas (Kentlyn: $\chi^2_{[4]} = 1.75$, $p > 0.05$; however, Amanda was excluded due to low expected cell values, Wedderburn: $\chi^2_{[8]} = 3.41$, $p > 0.05$). As these trends were consistent, the data for Wedderburn and Kentlyn were pooled and were significantly different ($\chi^2_{[4]} = 50.21$, $p < 0.005$). Kentlyn adult females had a higher proportion of scores >3 , which indicates that they were, on average, harder to spot than the Wedderburn females (Fig. 5.10). No data were available for Wedderburn males, and as there were few locations for individual Kentlyn males, the data were pooled, but no trend was apparent (Fig. 5.11). The pooled data from Kentlyn males and females were significantly different ($\chi^2_{[4]} = 14.86$, $p < 0.005$), and Kentlyn males were easier to spot than females as they had a higher proportion of scores <3 .

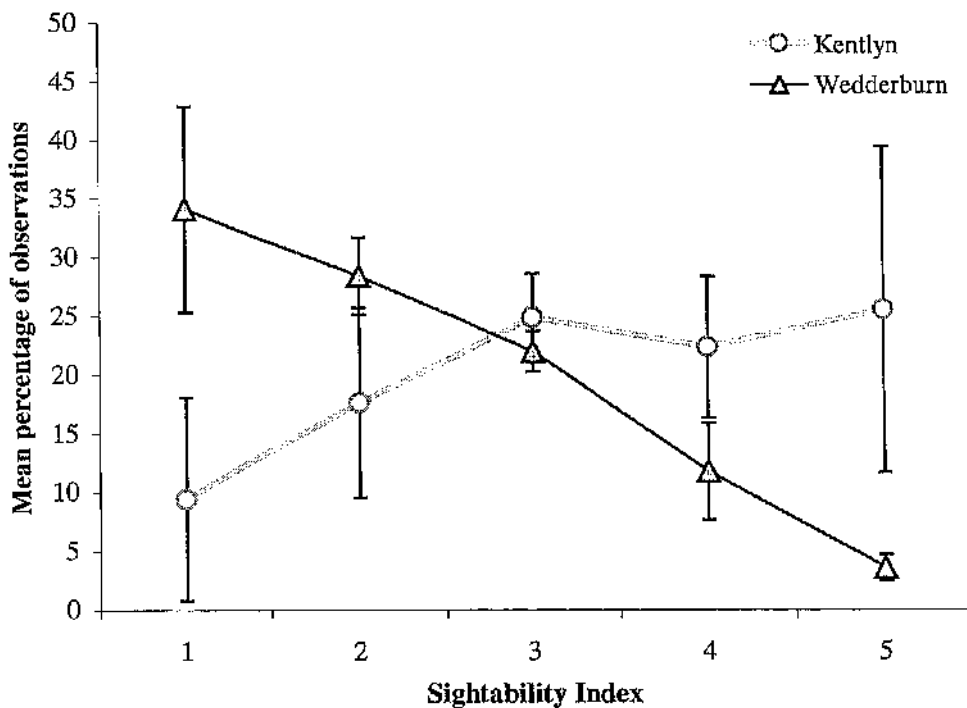


Figure 5.10. Graph of the mean percentage of locations for 3 radiotracked adult female koalas from Kentlyn and Wedderburn in a subjective sightability index score. The score was a subjective estimate by the radiotracker of how hard the koala was to spot, ranging from 1 representing “easy to spot” to 5 representing “extremely difficult to spot”.

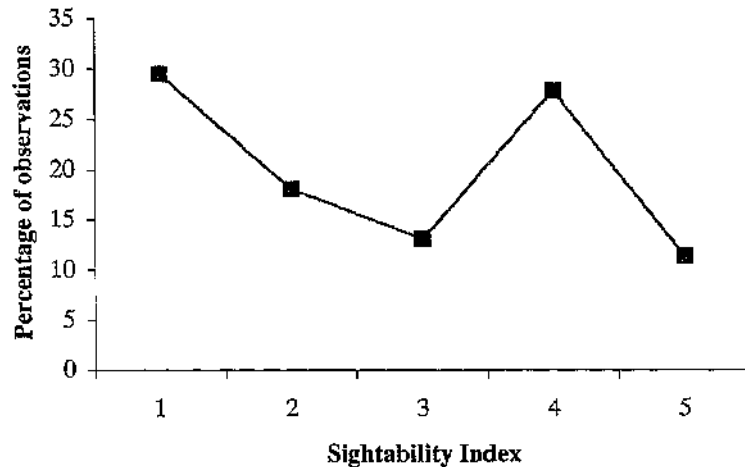


Figure 5.11. Graph of the percentage of 73 pooled sightability index scores for three radiotracked adult male koalas from Kentlyn. The score was a subjective estimate by the radiotracker of how hard the koala was to spot, ranging from 1 representing “easy to spot” to 5 representing “extremely difficult to spot”.

Due to insufficient data for comparing individual adult females, pooled individual data were used to compare the sightability of Kentlyn and Wedderburn of females with pouch young, young that had emerged from the pouch (referred to as back young), or no young. Although Kentlyn females, with either pouch and back young, had similar sightability scores, and had more of the “hard to spot” scores than observations where there was no young (Fig. 5.12), the difference was not significant for either Kentlyn ($\chi^2_{[8]} = 5.41, p > 0.05$), or Wedderburn ($\chi^2_{[8]} = 15.48, p > 0.05$).

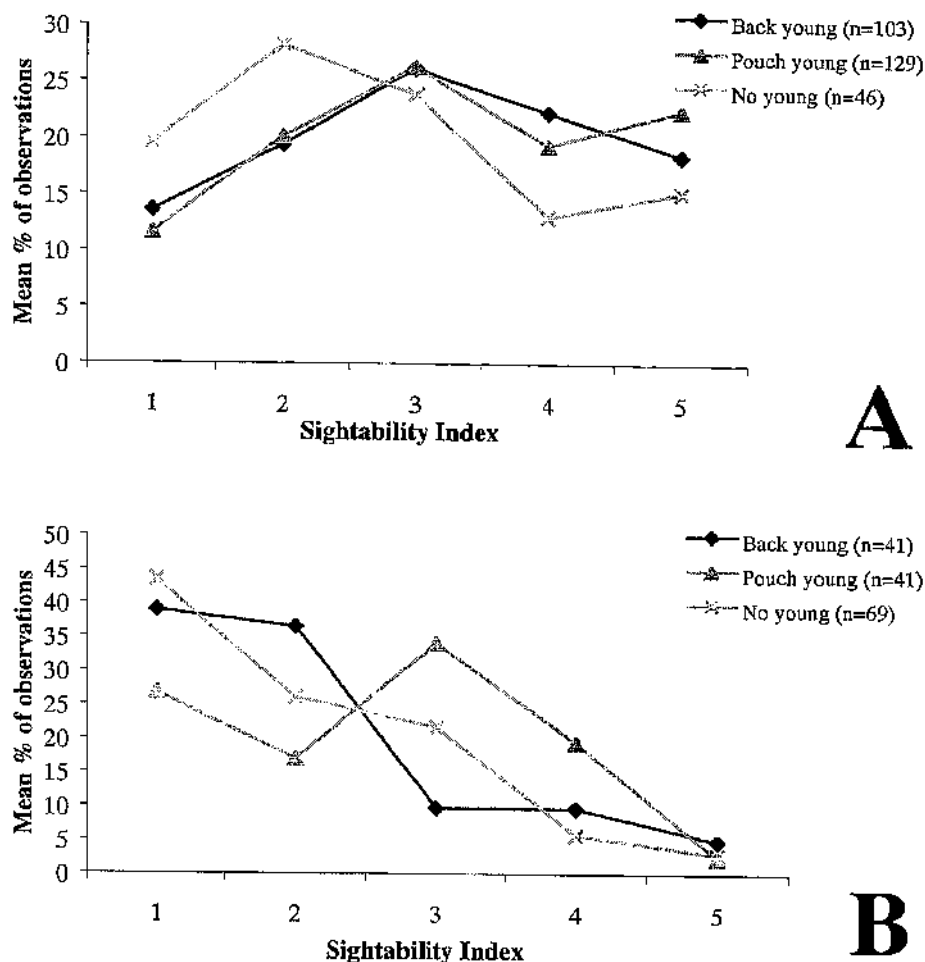


Figure 5.12. Graph of the percentage of pooled locations for a sightability index score for females with back young, pouch young, or no young. Scores for three radiotracked adult female koalas were pooled for both A) Kentlyn and B) Wedderburn. The score was a subjective estimate by the radiotracker of how hard the koala was to spot, ranging from 1 representing “easy to spot” to 5 representing “extremely difficult to spot”.

5.4 Discussion

5.4.1 Comparison with Published Koala Studies

Given the variation in techniques used by other researchers, the home range size estimates obtained from this study could not be compared statistically to others. However, the home range estimates from this study were approximately comparable to estimates from two other studies, moderately larger than five studies, and considerably larger than six studies (Table 5.6). Animals from this study therefore have comparatively large home ranges compared to individuals from populations with published home range estimates. Both studies that had approximately comparable home range estimates (Melzer 1994, Jurskis and Potter 1997), were also from low density

populations. Thus, data from my study were consistent with the hypothesis that koalas from low density populations have large home ranges.

The cause of the large home ranges observed, however, may be the low fertility soils in the southern Sydney region. Krockenberger (1993a) proposed that koalas deal with low soil fertility by expanding their home range to ensure a sufficient resource base to meet their energy requirements. The low fertility of soils in the Campbelltown area and the large home ranges of the koalas observed in this study are consistent with this hypothesis. There was, however, no observable difference in home range size between the sandstone soils at Wedderburn and the sandstone and shale soils, which are more fertile than sandstone alone, at Kentlyn. This may be because the difference in soil fertility was not large enough to generate detectable differences in home range size, or possibly because movements due to territorial disputes, or other social interactions (see section 5.4.2), created large variations in home range size, masking any differences present. Alternatively, because shale soils often occur in lenses the koalas living in the Kentlyn region may have comparable home ranges to the animals at Wedderburn as they must move through large regions of sandstone vegetation to reach patches of remnant shale soil vegetation.

Table 5.6. Subjective comparison of home range size estimates from this study to estimates from other studies. See Table 5.1 for locations, details of home ranges sizes and analysis techniques for these studies.

Home range size estimates from this study are...	Studies
Considerably larger than:	Sharpe (1980) Hindell (1984) Mitchell (1990b) Faulks (1990) Hasegawa (1995) Harris (1999b)
Moderately larger than:	Hull (1985) Krockenberger (1993a) Nyo (1993, cited in Melzer 1994) White (1994) Ramsay (1999)
Approximately comparable to:	Melzer (1994) Jurkis and Potter (1997)

Thus, soil fertility, rather than population density, may determine koala home range size. That is, low fertility soils may lead to both low koala population densities (see

section 1.6.1) and large home ranges. Therefore, the trend for koala home range size to increase, as population density declines, may be due to soil fertility affecting both density and home range size simultaneously.

5.4.2 Size and Shape

That the MCP home range estimates were larger than those for the 90% harmonic mean was expected, as the MCP technique included all fixes, whereas the harmonic mean isopleth boundary included only 90% of fixes. Furthermore, the MCP technique can include areas not utilised by an animal (section 5.1.8), whilst the harmonic mean technique will tend to exclude these areas.

As with most other studies, male koalas were found to have significantly larger home ranges than females. Adult home ranges were also found to be larger than juvenile home ranges; however, the lower number of juvenile observations may account for part of this difference. The observation that all three female koalas tracked as juveniles or subadults continued to utilise some, or all, of this home range as an adult, is consistent with the hypothesis of Mitchell and Martin (1990) that in established breeding koala populations most females are philopatric, whilst young males disperse.

The shapes of the home ranges were also highly variable. There was also variation in the number, and size, of core home range areas. These variations may be due to social interactions, heterogeneous distribution of preferred habitat (e.g. gully of ridgetop), or the occurrence of preferred vegetation. Separating these factors was beyond the scope of this study, but I suggest that habitat utilisation patterns in the southern Sydney region are due to interactions of all of these factors, and this may be a productive area of investigation for future studies. The shift in home range for “Old Boy” and the dispersal movement by Ray, for example, are consistent with the hypothesis of Mitchell (1990a, b) that male koalas develop dominance hierarchies. That is, Ray was a juvenile animal and the “Old Boy” had worn teeth, indicating old age, so both animals may have been forced to move by larger, dominant males.

5.4.3 Analysis Techniques

Fix resolution, location autocorrelation, appropriate harmonic mean isopleth values, and the number of fixes required to reach an asymptote in harmonic mean home range size were assessed in this study. Whilst many studies have used a time period of one to two days between fixes, I found this period to be insufficient for this study, with a period of 5.5 days being required before fixes were independent. Whilst the time to independence was estimated from only one female koala tracked over a four week period, it suggests that other studies may have used autocorrelated data, and the findings of these studies may have been affected. However, autocorrelation is not the only consideration, as a low time between fixes could be appropriate for estimating the home range over a short period. This study tracked animals over long periods of time, however, so autocorrelation of fixes was a serious consideration, but a compromise 5 day period between fixes was used to minimise the number of fixes discarded to reduce autocorrelation.

Most studies also used a minimum of 10 to 30 sightings to estimate home range size. It is possible that this may have been sufficient for other studies, although few researchers objectively assessed the number of fixes required. In contrast, I found that a minimum of 60 locations was required to reach an asymptote in home range size for females, with no male koalas having sufficient locations to reach the home range size asymptote. I suggest that future home range studies should also objectively assess the issues addressed in this study, which will make comparisons between studies more meaningful.

5.4.4 Sightability

Variation in how easily koalas are seen in an area will affect the efficiency of koala surveys, including community reports. Thus, the finding that there was significant variation in sightability between Kentlyn and Wedderburn has important implications for detecting koalas in different areas. For example, no reports have been received from the Long Point area (see section 3.3.3). Koalas could, however, occur in this region, but be hard to spot. This variability in animal visibility should therefore be considered when comparing community sighting data from different areas.

The reasons for the difference in the visibility of koalas between Kentlyn and Wedderburn, however, are not clear, but may be due to avoiding detection by humans. The koalas at Kentlyn would be more likely to encounter humans than would the Wedderburn animals, so the Kentlyn animals may deliberately chose “hard to spot” locations. An alternative explanation is that the koalas at Kentlyn had access to vegetation with denser foliage, which they used for increased shelter. Consequently they were harder to spot, an unintended result of this choice.

As expected the females at Kentlyn were harder to spot than the males. This difference may be due to females with young putting more effort into avoiding being detected by humans to minimise risks to both themselves and their young. This could explain why only 10.4% of all reported sightings in this study were of females with young (section 3.3.6). However, there was no significant difference in sightability scores for females with, and without, young. This may be due to insufficient data to detect a difference, however, as females with young did have a higher percentage of the “hard to spot” scores than females without young.

Whatever the reasons for differences in koala “sightability”, researchers surveying for koalas should note that variation between locations, and between groups within a population of koalas, could significantly affect their results.

6 Tree Use and Preferences.

6.1 Introduction

Koalas, like any other animal, must utilise the resources available to them to survive and reproduce. The trees they select can reveal much about their use of the available resources. This chapter investigates diurnal tree use and preferences within the southern Sydney study region. Tree usage and preferences can provide information about which species koalas use to fulfil their dietary and shelter needs, and this information can be then be used to assess the whether vegetation will support koalas.

6.1.1 SEPP44

Knowing tree preferences of koalas is important as they are incorporated into New South Wales SEPP44 (see section 1.10). An initial step in a development application is to identify whether the land is potential koala habitat, which is defined as:

“Areas of native vegetation where the trees of the types listed in Schedule 2 constitute at least 15% of the total number of trees in the upper or lower strata of the tree component” Anon (1995).

The ten species listed in Schedule 2 of SEPP44 are all eucalypts (Anon 1995). Of these ten species, three occur in the southern Sydney region: *E. haemastoma*, *E. punctata*, and *E. tereticornis*. However, only one species, *E. punctata*, is widely distributed through habitat used by koalas, and then often in low numbers. Thus, the definitions within the SEPP44 legislation may need to be adjusted to be relevant to the southern Sydney region. First, however, a definition of “tree preference” is required.

6.1.2 Definition and Assessment of Tree Preferences

Hindell (1984) and Hindell *et al.* (1985) developed equations for assessing koalas’ tree preferences. The equations assume that if a koala does not exhibit a preference for a species then that species should be utilised in the same proportion as it occurs in the habitat. If a koala prefers a species, then it will use that species more often than its relative abundance would suggest, and less often if it is avoiding that species. That is, it is assumed that *“the koalas encounter the trees in proportion to this abundance (the*

species abundance in the landscape), and having encountered them, climb them (or reject them) according to their preference value for that species of tree” (Hindell et al. 1985). Thus, to obtain koala preference data, information about the vegetation utilised by the koalas, and the vegetation available to the koalas, is required.

In this study, tree use by individual koalas was investigated for those animals located ≥ 15 times. For investigating tree preferences, however, defining the available vegetation from which the koalas make their choice, is crucial. The 90% harmonic mean home range isopleth was used in this study to define the trees available for use by each animal. As described in chapter 5, the 90% isopleth was selected as the 95% isopleth included substantial areas where location fixes did not occur for some animals. It is not clear whether koala home range boundaries were determined by avoiding unsuitable vegetation, or by interactions with other animals. In any event, the majority of observations of tree use were within this boundary (around 90% as some fixes were excluded in the home range analysis). Thus, it is reasonable to compare observations of tree use against the trees available within the area selected by each animal.

To properly define the home range, however, 60 fixes were required (the number required to reach the asymptote in home range size, see section 5.2.4). Of the radiotracked koalas, only three adult females met this requirement. Therefore, whilst tree usage was investigated for a number of animals, tree preferences were only investigated in the three adult females with >60 fixes.

Koalas also appear to utilise trees or shrubs which meet minimum size requirements, as vegetation which is too small is probably either too difficult to climb, or will not support their weight. Hindell (1984) noted that koalas were rarely seen in trees with a diameter at breast-height (dbh) of <10 cm, and so counted all stems >10 cm dbh. This 10cm dbh cut-off has now become common in subsequent koala studies (Pahl and Staines 1993, Phillips *et al.* 1996, Phillips and Callaghan 1996, Jurskis and Potter 1997, Harris 1999b). White and Kunst (1990), however, counted all trees >5 cm dbh on transects through their study area. Unfortunately, the reasons for selecting this dbh are not given. However, in my study I often observed female koalas in vegetation <10 cm dbh. Thus, although >10 cm dbh is commonly used in studies as a minimum size for use

by koalas, in some areas such a minimum value could exclude vegetation used by koalas.

6.1.2.1 Relative Utilisation

White and Kunst (1990) used relative exploitation, instead of the tree preference index. Relative exploitation (RE) is the proportional tree use by koala(s), divided by that tree species' proportional abundance. For non-selective tree use $RE = 1$, avoidance $RE < 1$, and preference $RE > 1$. White and Kunst (1990) also suggest that the "value" of a tree species to a koala is a function of both the preference for that species, and its abundance. That is, a tree species could be highly preferred, but if rare, it would probably not contribute significantly to the koalas' survival in that area. White and Kunst (1990) therefore further developed the equations from Hindell *et al.* (1985) to derive an importance index: the RE for a tree species multiplied by that species' abundance, over the sum of all individual RE values multiplied by individual abundances (see section 6.2.1 for equations). White and Kunst (1990) considered that the importance index "*takes into account the range of situations that may occur due to different [tree] species abundance and distribution, and individual koala preference and behaviour. As such, it provided a more realistic appraisal of how koalas are using the trees available*".

6.1.3 Roost Trees and Feed Trees

Koalas utilise trees both as a food source and for shelter (roosting). Some Victorian and New South Wales studies found that the trees used for shelter were also used as a fodder source (Robbins and Russell 1978, Hindell *et al.*, 1985). Subsequent studies have shown, either through continuous monitoring (Melzer 1994), or identification of cuticle fragments in faecal pellets (Hasegawa 1995, Ellis *et al.* 1997, Ellis *et al.* 1999), that not all koala populations use the same trees for both food and shelter. In particular, Sluiter *et al.* (2002; see Appendix 3) examined faecal pellets collected from animals radiotracked in this study, and found that faecal pellet fragments and radiotracking observations were significantly different. This difference suggests that the observations of diurnal tree use collected in this study are more likely to reflect preferences for shelter, rather than for fodder, as koalas have been found to feed mainly at night (Robbins and Russell 1978, Faulks 1990).

6.1.4 Tree Size Preferences

Koalas have consistently been found to prefer “large” trees. Hindell (1984), and Hindell and Lee (1987), found that at Brisbane Ranges National Park, Victoria, koalas preferred trees in higher categories of estimated tree foliage weight. Achurch (1989) found that koalas close to Brisbane, Queensland, most preferred “big” (>47.7cm dbh), then “medium” (12.7-47.7cm dbh), and lastly “little” (<12.7cm dbh) trees. White (1994, 1999) found that 90% of radiotracking observations in the Bremmer River catchment, southwest of Brisbane, were in *E. crebra* and *E. tereticornis*, and that trees less than 15.5cm dbh were avoided, while trees >55.5cm dbh were most preferred. Ramsay (1999) found that radiotracked koalas, both adult and juvenile, near Nowendoc, New South Wales, avoided trees <40cm dbh and preferred trees >40cm dbh.

Koalas thus seem to prefer trees of 40-50cm dbh, or larger, throughout their range, although depending on the location, trees of this size may occur infrequently. This preference may be related to nutritional aspects of the foliage, or larger trees may offer more opportunities to shelter from adverse weather conditions or predators such as wedge-tailed eagles and powerful owls. Alternatively, the greater leaf resource present in the canopy of large trees may produce an energy saving by reducing energetic costs due to travelling between trees. There is no evidence, however, that koalas using large trees move less frequently between trees (Hindell and Lee 1987, 1990), but large trees may have deeper root systems, better access to the water table and hence a higher leaf water content, which is strongly preferred by koalas (see section 1.5).

6.1.5 Reuse of Trees

Koalas have also been found to exhibit considerable faithfulness to particular trees (Eberhard 1978, Hindell and Lee 1987, 1990, Faulks 1990). Eberhard (1978), for example, observed one female koala 82 times in the same tree, out of 106 sightings. Sharpe (1980), however, found that, apart from a few exceptions, koalas at Westernport Bay, Victoria, did not show preferences for individual trees. Thus, faithfulness to particular trees may not occur in all koala populations.

6.1.6 Objectives

The objectives of investigating koala tree use and preferences in the southern Sydney region were:

1. To investigate whether habitat used by breeding female koalas met the SEPP44 definition for “potential koala habitat”.
2. To investigate the diurnal use of tree species, and to investigate tree preferences for the three adult female koalas which had sufficient locations to reach the asymptote in home range size.
3. To investigate whether koalas used roost trees.
4. To investigate whether koalas in the study region frequently used the same trees, and to compare these results against data from other studies.
5. To investigate tree size usage and preferences.

6.2 Methods

Data for Franchesca, Lyn and Shirley, all of which reached the harmonic mean home range size asymptote, were used to investigate tree preferences. For each of these animals, 10 random UTM grid coordinates within the 90% harmonic mean home range isopleth were generated. These coordinates were then located as accurately as possibly in the field with the handheld Magellan 320 GPS unit in May and June 2001, and this point used as the corner for a 20m by 20m quadrat, which was placed randomly to either the NE, SE, SW or NW of this point. For Lyn, most of the randomly selected locations were on private property and five locations could not be accessed. New random locations were generated until 10 accessible locations were obtained.

For each tree or shrub with a circumference $\geq 118\text{mm}$ (3.8cm dbh), and height, estimated by eye $\geq 3\text{m}$, the species, circumference and height were recorded for each quadrat. These dimensions were the lowest recorded circumference and height of vegetation used by Franchesca, Lyn or Shirley. Those plants branching at less than 50cm above ground level were recorded as separate stems, as long as both stems met the circumference and height requirements. Circumference was converted to dbh by dividing by π .

6.2.1 Formulae for Relative Utilisation

Preference for vegetation was investigated using the RE and importance index concepts derived from Hindcell *et al.* (1985) and White and Kunst (1990). Individual preferences for each of the three females were calculated using the equations given below.

n_i = number of observations of a koala in species i

$\sum n_i$ = sum of the number of observations of a koala in all species

q_i = number of stems of species i , in all quadrats, for each individual koala

$\sum q_i$ = sum of number of stems, for all species, in all quadrats, for each individual koala

u_i = proportional utilisation of species $i = n_i / \sum n_i$

a_i = proportional abundance of species $i = q_i / \sum q_i$

where $\sum u_i = \sum a_i = 1$

$RE_i = u_i / a_i$

Importance index (I_i) = $\frac{100 \times RE_i \times n_i}{\sum (RE_i \times n_i)}$

6.3 Results

6.3.1 Tree Use

Both male and female adult koalas were found to reuse a low percentage of trees (Table 6.1). Trees were not used more than three times, although five females were observed to reuse trees three times. Male koalas, however, were not observed to reuse trees more than twice.

Females had a significantly higher average number of sightings per tree than males (Table 6.1, $t_9 = 2.061$, $p < 0.05$). When compared to four other studies where the average number of sightings per tree could be calculated, both male and female koalas from this study had significantly lower number of sightings per tree than all four studies (Table 6.2).

Table 6.1. Reuse of individual trees by adult koalas (females ≥ 3 years, males ≥ 4 years) located ≥ 15 times on different days. The letters for the tables represent A) females and B) males. Note that locations from when Shirley, Sarah and Molly were juveniles or subadults have not been included.

A	Number of sightings in the same tree	Number of trees					
		Shirley	Francesca	Lyn	Sarah	Molly	Amanda
	3	4	4	2	1	-	1
	2	24	5	9	-	1	-
	1	140	92	66	42	37	21
	Total sightings	200	114	90	45	39	24
	Average sightings / tree	1.19	1.13	1.17	1.05	1.03	1.09
	% of trees used >1	16.67	8.91	14.29	2.33	2.63	4.55

B	Frequency of sightings	Number of trees				
		Old Boy	Kevin	Jacob	Gary	Elmo
	2	7	1	-	-	1
	1	60	25	19	17	17
	Total sightings	74	27	19	17	19
	Average sightings / tree	1.10	1.04	1.00	1.00	1.06
	% of trees used >1	10.45	3.85	0.00	0.00	5.56

Table 6.2. Average number of sightings per tree for adult male and female koalas. Note that the statistics for Eberhard (1978) and Sharpe (1980) were calculated from the data provided. n = number of animals, sd = standard deviation, t-test value = Students t-test comparing this study against the published study for animals of the same sex, p = p value for the students t-test.

Sex	Author	n	Average sightings per tree	sd	t-test value	p
Female	Eberhard 1978	11	3.97	2.81	2.45	p < 0.025
	Sharpe 1980	6	1.94	0.22	1.94	p < 0.005
	Faulks 1990	3	3.15	1.61	3.34	p < 0.01
	Mitchell 1990b	18	1.61	0.36	3.32	p < 0.005
	This study	6	1.11	0.06	-	-
Male	Eberhard 1978	8	3.55	2.40	2.30	p < 0.025
	Sharpe 1980	10	1.40	0.06	11.91	p < 0.005
	Faulks 1990	4	1.83	0.75	2.39	p < 0.025
	Mitchell 1990b	13	1.44	0.24	3.64	p < 0.005
	This study	5	1.04	0.04	-	-

6.3.2 Tree Use by Sex and Location

For the following chi-square tests, where cells had expected values of <5 they were combined with other cells, and all tests used data from adults (Table 6.3, females ≥ 3 years, males ≥ 4 years). Kentlyn females and Wedderburn males were consistent in their tree species selections ($\chi^2_{[8]} = 7.37$ and $\chi^2_{[3]} = 1.83$ respectively, p > 0.05 for both), whereas Wedderburn females and Kentlyn males varied in their tree species selections ($\chi^2_{[8]} = 27.13$, p < 0.005 and $\chi^2_{[4]} = 12.24$ respectively, p < 0.025 for both).

Table 6.3. Number of observations in different tree species for adult koalas (females ≥ 3 years, males ≥ 4 years) located ≥ 15 times. The letters represent A) Kentlyn females, B) Wedderburn females, C) Kentlyn males, and D) Wedderburn males.

	Tree Species	Shirley	%	Lyn	%	Amanda	%	Total	%
A	<i>E. punctata</i>	33	16.8	23	25.3	5	20.8	61	19.6
	Stringybarks *	1	0.5	7	7.7	0	0.0	8	2.5
	<i>E. piperita</i>	0	0.0	0	0.0	0	0.0	0	0.0
	<i>E. pilularis</i>	29	14.7	12	13.2	2	8.3	43	13.3
	Other eucalypts †	7	3.6	1	1.1	2	8.3	10	3.2
	<i>Syncarpia glomulifera</i>	81	41.1	32	35.2	9	37.5	122	38.1
	<i>Corymbia gummifera</i>	5	2.5	8	8.8	0	0.0	13	4.2
	<i>Angophora costata</i>	13	6.6	1	1.1	1	4.2	15	4.8
	Other non-eucalypts ‡	28	14.2	7	7.7	5	20.8	40	12.8
Total	197	100.0	91	100.0	24	100.0	312	100.0	
	Tree Species	Fran	%	Sarah	%	Molly	%	Total	%
B	<i>E. punctata</i>	29	25.9	9	20.0	12	30.8	50	25.5
	Stringybarks *	43	38.4	5	11.1	11	28.2	59	30.1
	<i>E. piperita</i>	13	11.6	7	15.6	3	7.7	23	11.7
	<i>E. pilularis</i>	3	2.7	0	0.0	2	5.1	5	2.6
	Other eucalypts †	1	0.9	1	2.2	1	2.6	3	1.5
	<i>S. glomulifera</i>	0	0.0	0	0.0	0	0.0	0	0.0
	<i>Co. gummifera</i>	11	9.8	4	8.9	4	10.3	19	9.7
	<i>A. costata</i>	10	8.9	18	40.0	6	15.4	34	17.3
	Other non-eucalypts ‡	2	1.8	1	2.2	0	0.0	3	1.5
Total	112	100.0	45	100.0	39	100.0	196	100.0	
	Tree Species	Kevin	%	Jacob	%	Gary	%	Total	%
C	<i>E. punctata</i>	11	61.1	4	20.0	6	23.1	21	32.8
	Stringybarks *	10	55.6	2	10.0	0	0.0	12	18.8
	<i>E. piperita</i>	0	0.0	0	0.0	2	7.7	2	3.1
	<i>E. pilularis</i>	1	5.6	1	5.0	2	7.7	4	6.2
	Other eucalypts †	0	0.0	0	0.0	2	7.7	2	3.1
	<i>S. glomulifera</i>	3	16.7	5	25.0	5	19.2	13	20.3
	<i>Co. gummifera</i>	0	0.0	1	5.0	1	3.8	2	3.1
	<i>A. costata</i>	0	0.0	2	10.0	0	0.0	2	3.1
	Other non-eucalypts ‡	1	5.6	5	25.0	0	0.0	6	9.4
Total	18	100.0	20	100.0	26	100.0	64	100.0	
	Tree Species	Old Boy	%	Elmo	%	Total	%		
D	<i>E. punctata</i>	12	16.0	3	16.7	15	16.1		
	Stringybarks *	49	65.3	13	72.2	62	66.7		
	<i>E. piperita</i>	1	1.3	0	0.0	1	1.1		
	<i>E. pilularis</i>	4	5.3	0	0.0	4	4.3		
	Other eucalypts †	2	2.7	0	0.0	2	2.2		
	<i>S. glomulifera</i>	0	0.0	0	0.0	0	0.0		
	<i>Co. gummifera</i>	6	8.0	1	5.6	7	7.5		
	<i>A. costata</i>	0	0.0	0	0.0	0	0.0		
	Other non-eucalypts ‡	1	1.3	1	5.6	2	2.2		
Total	75	100.0	18	100.0	93	100.0			

* *E. agglomerata*, *E. capitellata*, *E. eugenioides*, *E. globoidea*.

† *E. crebra*, *E. haemastoma*, *E. multicaulis*, *E. sieberi*, *E. tereticornis*.

‡ *Acacia* spp., *Angophora bakeri*, *Banksia serrata*, *Co. eximia*, *Casuarina* spp., *Ceratopetalum gummiferum*, *Callitris rhomboidea*, *Glochidion ferdinandi*, *Ce. apetalum*, fence, *Ligustrum lucidum*, *Melaleuca* spp., *Pittosporum undulatum*.

6.3.3 Relative Utilisation

RE values of >1 indicate that a koala used that species proportionately more than it was available within its home range, and proportionately less for RE values <1 . Thus, RE values of >1 and <1 are hereafter referred to as preference and avoidance respectively (see sections 6.1.2.1 and 5.2.1 for a greater discussion of RE and the formulas used).

RE values were generated for three adult female koalas, Shirley, Franchesca and Lyn, because they had sufficient adult fixes to define their 90% harmonic home range boundary, and all trees within this boundary were considered to be available to that individual. All three females preferred stringybarks, *E. punctata*, and *E. pilularis* (Table 6.4). *S. glomulifera* did not occur in Franchesca's home range, but both Lyn and Shirley preferred this species. Similarly, Franchesca preferred *E. piperita*, which did not occur in either Lyn or Shirley's home ranges. All three koalas avoided Acacias (various species), *Co. gummifera*, *Persoonia* (various species), and stags or stumps (Table 6.4).

Franchesca, Lyn, and Shirley differed in which tree species had high importance index values (Fig. 6.1). This is not surprising given the variation in tree species available to each female. For both Franchesca and Lyn the top three RE rankings matched the importance index rankings (Table 6.4 and Fig. 6.1). For Shirley, however, the species ranked first for the importance index, *S. glomulifera*, had the third highest RE value, the species ranked second in importance index, *E. pilularis*, had the highest RE value, and the species ranked third in importance index, *E. punctata*, had the sixth highest RE value (Fig. 6.1).

Table 6.4. Relative utilisation (RE) for three adult female koalas, of stems with a diameter at breast-height (dbh) of ≥ 3.8 cm and a height of ≥ 3 m. For Francesca (Fran) and Shirley some species that were used ≤ 3 times were not detected in the quadrats, and as their RE could not be quantified it is given as >1 . The stringybark category included *E. agglomerata*, *E. capitellata*, *E. eugenioides* and *E. globoidea* and the Acacias category included *Acacia decurrens*, *A. implexa*, *A. longifolia*, and *A. terminalis*.

Koala	Over Exploited RE > 1		Under Exploited RE < 1		Negligible RE = 0
Fran	Stringybarks	4.69	<i>Angophora costata</i>	0.98	Acacias
	<i>Eucalyptus punctata</i>	1.96	<i>Corymbia gummifera</i>	0.77	<i>Hakea</i> spp.
	<i>E. piperita</i>	1.50	<i>Banksia serrata</i>	0.16	<i>Ceratopetalum gummiferum</i>
	<i>E. pilularis</i>	>1			<i>Leptospermum</i> spp.
	<i>E. sieberi</i>	>1			<i>Persoonia levis</i> Stag / Stump
Lyn	<i>Syncarpia glomulifera</i>	7.98	<i>Co. gummifera</i>	0.94	<i>Acacia</i> spp.
	<i>E. pilularis</i>	3.40	<i>Pittosporum undulatum</i>	0.51	<i>Angophora bakeri</i>
	<i>E. punctata</i>	1.52			<i>Casuarina</i> spp.
	<i>A. costata</i>	1.42			<i>E. baueriana</i>
	<i>E. haemastoma</i>	1.42			<i>E. crebra</i>
	Stringybarks	1.42			<i>Kunzea</i> spp.
					<i>Parsonsia straminea</i> <i>Olea africana</i> <i>Persoonia linearis</i> Stag / Stump <i>Ligustrum sinense</i>
Shirley	<i>E. pilularis</i>	7.63	<i>A. costata</i>	0.42	<i>E. baueriana</i>
	<i>Ce. gummiferum</i>	4.58	<i>Co. gummifera</i>	0.27	<i>E. saligna</i>
	<i>S. glomulifera</i>	3.34	<i>Casuarina</i> spp.	0.24	<i>Exocarpus cupressiformis</i>
	<i>E. crebra</i>	1.53	<i>Acacia</i> spp.	0.15	<i>Kunzea</i> spp.
	<i>Ligustrum lucidum</i>	1.33	<i>A. bakeri</i>	0.12	<i>Leptospermum</i> spp.
	<i>E. punctata</i>	1.28			<i>P. linearis</i>
	<i>E. tereticornis</i>	>1			Stag / Stump
	<i>Glochidion ferdinandi</i>	>1			
	<i>Melaleuca</i> spp.	>1			
	<i>Ceratopetalum apetalum</i>	>1			
	Stringybarks	>1			

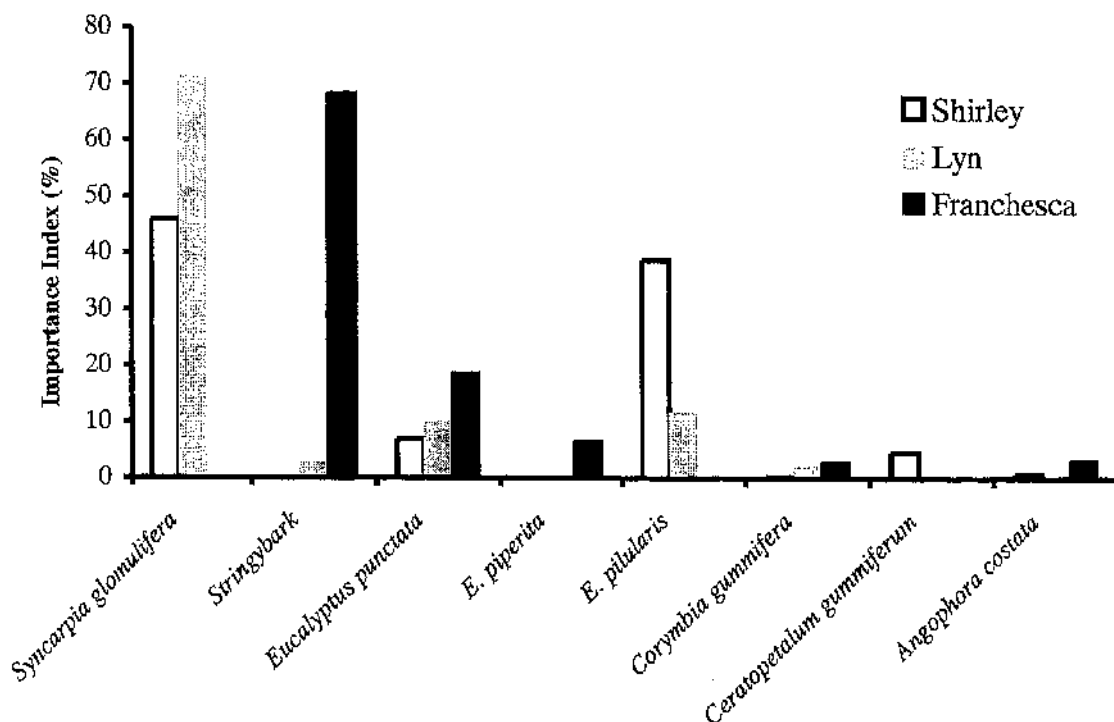


Figure 6.1. Graph of importance index values against tree species for diurnal fixes from three adult female koalas. The stringybark category included: *E. agglomerata*, *E. capitellata*, *E. eugenioides* and *E. globoidea*. For eight species: *Angophora bakeri*, *Acacia* spp., *Banksia serrata*, *Casuarina* spp., *E. crebra*, *E. haemastoma*, *Ligustrum lucidum*, and *Pittosporum undulatum*, the importance index values were <2% for all three koalas, and are not shown. The importance index could not be calculated for a further five species: *Ceratopetalum apetalum*, *E. sieberi*, *E. tereticornis*, *Glochidion ferdinandi*, and *Melaleuca* spp., as although they were utilised by at least one of the females, they were not detected in the quadrats and hence it was not possible to calculate a relative utilisation (RE) value. Where RE values were negligible (RE=0), the importance indices were also zero, and, therefore, are also not shown.

6.3.4 Schedule 2 SEPP44 Vegetation

The percentage of vegetation listed in schedule 2 of SEPP44 (*E. haemastoma*, *E. punctata*, or *E. tereticornis*; see section 6.1.1) was assessed for Franchesca, Lyn and Shirley using the counts from the quadrats. When stems of the lowest recorded height and dbh observed to be used ($\geq 3\text{m}$ height, $\geq 38\text{mm}$ dbh) were counted, the females had the following percentages of schedule 2 SEPP44 vegetation: Franchesca = 11.7%, Lyn = 16.4%, Shirley = 11.2%. As this included many shrubs, and the SEPP44 definition relies upon the percentage of schedule 2 listed trees, the percentage of SEPP44 stems was calculated using vegetation $\geq 8\text{m}$ in height, which eliminated the majority of shrubs, and gave: Franchesca = 14.8%, Lyn = 45.2%, Shirley = 21.5%. Thus the definition used affected the results, but with either method the vegetation in Franchesca's home range does not meet the requirements of the SEPP44 legislation for "potential koala habitat", and Franchesca is a breeding female.

6.3.5 Tree Size Preferences

For tree size preference, stems of <20cm dbh were consistently avoided, whatever their species, and those of ≥ 20 cm dbh were generally, but not always, preferred. Furthermore, the highest preference values were for vegetation with a dbh between 30 and 39.9cm (Fig. 6.2). Although the RE values for vegetation with a dbh of 3.8-10cm for all three females was <1, these low RE values were due to a large number of these stems being available, and 7% of both Lyn and Shirley's radiotracking observations were in stems of this size (0% for Franchesca).

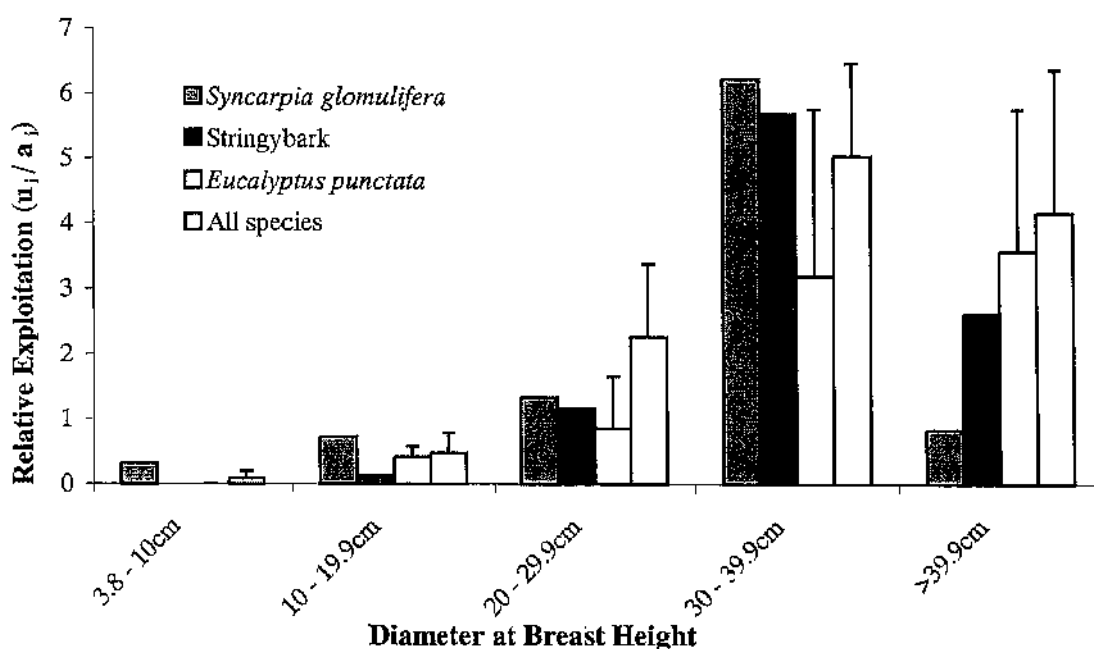


Figure 6.2. Graph of relative exploitation (RE) of trees ≥ 3 m in height against breast height diameter. The RE values for *S. glomulifera* are for Shirley only, and stringybark (*E. agglomerata*, *E. capitellata*, *E. eugenioidea* and *E. globoidea*) values are for Franchesca only. RE values for *E. punctata* and all species are mean values for three adult female koalas, Franchesca, Lyn and Shirley, with the error bars being the standard deviation.

6.4 Discussion

6.4.1 SEPP44

The results from the radiotracking study have important implications for the management of koalas, particularly in relation to NSW SEPP44 legislation (see section 6.1.1). The vegetation in Franchesca's home range clearly was under the SEPP44 15% requirement to meet the definition of "potential koala habitat". As Franchesca was a breeding female, clearly this area was not only "potential", but was actually "core",

koala habitat. Thus I propose that the definition of “potential koala habitat” in the SEPP44 legislation should be amended to be 10% of the total number of trees.

For all three female koalas, for which tree usage was examined, stringybarks were preferred ($RE > 1$). For Franchesca, living on sandstone soils at Wedderburn, stringybarks had the highest RE and importance index values. Phillips and Callaghan (2000) found that *E. agglomerata*, one of the species included in the “stringybark” category, was preferred only when it occurred on shale soils. However, Sluiter (2000) and Sluiter *et al.* (2002) found that 25.5% of cuticle fragments in the faecal pellets of Sarah, another female living on sandstone soils at Wedderburn, were from *E. agglomerata*. Thus, whilst I agree, with Phillips and Callaghan (2000), that shale soils are an important factor in the occurrence of breeding groups of koalas in the Campbelltown region, the evidence from both this study and a faecal pellet study (Sluiter 2000, Sluiter *et al.* 2002) is consistent with *E. agglomerata* being preferred by, and important to, koalas on both shale and sandstone soils.

Given that both Phillips and Callaghan (2000) and this study agree that *E. agglomerata* is important to koalas in the southern Sydney region, I propose that SEPP44 should be amended to include *E. agglomerata* in the schedule 2 list of tree species. Furthermore, because stringybark species are difficult to distinguish in the field, consultants will need to be careful when identifying *E. capitellata*, *E. eugenioides* and *E. globoidea*, and if uncertain they should count these stringybark species as if they were *E. agglomerata*.

Sluiter (2000) consistently found *Co. gummifera* cuticle fragments in Shirley’s faecal pellets, although no fragments of this species were found in the faecal pellets of two other females. I found, however, that Franchesca, Lynn and Shirley all avoided *Co. gummifera*. Therefore, I feel that more evidence, particularly from faecal pellet studies, is required before recommending that this species also be included in SEPP44. Further faecal pellet work may help to discover if other tree species are used as browse trees.

6.4.2 Tree Species Preferences

Diurnal selection of tree species is complex, with individual variation in selection being exhibited by both Wedderburn females and Kentlyn males, and sex and location also influencing tree species selection. There were clear differences in the species available between Kentlyn and Wedderburn, as, for example, turpentines were common at Kentlyn, but absent at Wedderburn. Thus, it is not surprising that location should affect diurnal tree species selection. The relative utilisation of tree species by Franchesca, Lynn and Shirley, and the importance of these species to each animal, certainly appeared to depend on what was available to them.

Gender may affect tree species selection because adult males and females have different priorities. The priority for males should be to mate with as many females as possible, so as to make as large a contribution to the gene pool as possible, and this is consistent with the behaviour of adult male koalas who have been observed to attempt to mate in most male-female interactions (Mitchell 1990a). Raising young, however, constitutes a large drain on a female's resources (see section 4.4.1); therefore, the priority for lactating females should be to gather more resources, and/or reduce their energy expenditure, and to minimise the risks to their young.

6.4.3 Tree Size Preferences

Trees ≥ 30 cm dbh of all species were most preferred by the three female koalas examined. This preference for "large" trees is consistent with the findings of other studies, although most of these studies defined "large" trees as being >40 - 55.5 cm dbh (Achurch 1989, White 1994, 1999, Ramsay 1999). This difference may be because trees >40 cm dbh are uncommon in the southern Sydney region. Only 4.0% of the trees available to Shirley, 7.1% for Lynn, and 10.5% for Franchesca, were >39.9 cm dbh. Thus, koalas in the southern Sydney region may prefer trees >39.9 cm dbh; but because few are available, they use somewhat smaller trees.

These trends, however, may not be true for all tree species. Shirley exhibited markedly lower RE values for *S. glomulifera* >39.9 cm dbh, compared to those 30- 39.9 cm dbh, as did Franchesca for stringybarks. It may be that the energetic costs of climbing trees >39.9 cm dbh are higher than for smaller trees, and that if the trees are being selected

for shelter, then this reduces their attractiveness to koalas. If trees have high quality foliage, however, the trees would probably still be attractive as there appears to be limited high quality foliage in the southern Sydney region.

Although all three females avoided vegetation <10cm dbh, these trees were used, and constituted 7% of the observations for Lyn and Shirley. Thus I contend that >10cm dbh, which has become the commonly accepted “minimum” size for use by koalas, is artificial. Thus, studies examining vegetation preferences should carefully consider the minimum size for inclusion as the dbh of vegetation used by koalas may vary between populations. Although the 5cm dbh value used by White and Kunst (1990) will not include the smallest stems used by koalas in this study, if a study has insufficient time to investigate the smallest size stems used in that area, I suggest that using the 5cm dbh value as a “minimum” will be an appropriate compromise.

6.4.4 Roost versus Feed trees

This study showed that individual koalas exhibited preferences for tree species providing shelter, particularly *S. glomulifera*, a tree with very dense foliage. These results are consistent with the conclusions of other studies that koalas in some populations will use separate trees for roosting and for food (see section 6.1.3).

The diurnal preference for shelter trees may also account for the low faecal pellet “strike rate”, the percentage of trees with a koala faecal pellet within 1m of the trunk of stems ≥ 10 cm dbh (Phillips *et al.* 1996), in the Campbelltown region (Phillips and Callaghan 1996, 2000). That is, as many species were utilised for shelter, less time is spent in any one particular species; consequently, fewer faecal pellets will be deposited under that species, lowering its “strike rate”. Thus where koalas use separate trees for shelter and food, studies using faecal pellet counts will need more replicates to reach meaningful conclusions, particularly for populations of low density, such as in the southern and greater Sydney regions.

6.4.5 Tree Reuse

This study found significantly lower levels of tree reuse than did other studies. The reason for this difference is unclear, but may be related to home range size. Adults

radiotracked in this study had large home ranges; 90% harmonic mean estimates for the three females with sufficient fixes ranges from 11.6ha to 36.0ha. Home range estimates were available for three of the four other studies with tree reuse data, and their home range estimates were smaller than those of this study: 0.15 – 1.07ha, Sharpe (1980); 0.40 – 12.76ha, Faulks (1990); 1.18 – 1.70ha, Mitchell (1990b). Thus, koalas with large home ranges may reuse trees less, perhaps because they have more trees available, or because they may not know the trees as well as individuals with smaller home ranges.

Alternatively, the individuals in this study may use any available tree which is suitable for shelter during the day, which is when they were observed, and may then use a few trees for fodder at night. Nocturnal radiotracking of animals from the southern Sydney would be required to test this hypothesis.

7 Koala Management in the Southern and Greater Sydney Regions

7.1 Introduction

In this chapter, I use the information gathered on sex ratio, condition, fertility rates, home range, movements and tree preferences to make management recommendations for the southern and greater Sydney regions. Good management is required to mitigate the increasing impacts on koala populations due to increasing human populations (see section 1.9). I first briefly review the findings of this study, then the importance of population size to the persistence of a population (the small population paradigm), the tools available for management planning, and finally I discuss issues relevant to the southern and greater Sydney koala populations and make prioritised recommendations for actions to be taken.

7.1.1 Review of Relevant Findings from this Study

From compiling reports of koala sightings in the southern and greater Sydney study regions, I found that koalas were widespread. Sightings of koalas came from the following ten LGAs: Blue Mountains, Campbelltown, Hawkesbury, Liverpool, Mulwaree, Oberon, Sutherland, Wingecarribee, Wollondilly, and Wollongong (Fig. 7.1). Breeding koalas in the southern Sydney region were found to occur in remnant vegetation along the eastern edge of Campbelltown, and appeared to be associated with shale soils. Breeding groups also occur in the Cordeaux, Avon and Nepean Dam catchments, in the Joadja, Canyonleigh and Yerrinbool areas, possibly at Darkes Forest, and between Springwood and Lapstone. Other breeding colonies may also exist in areas not comprehensively surveyed, and animals appear to be scattered through the Sutherland region and the Blue Mountains

Soil fertility was found to be an important factor for koalas, as predicted by the resource-availability hypothesis (see section 1.6.1). In summary, low fertility soils also mean low quality browse is available for koalas as the eucalypts produce more defensive compounds than in higher fertility soils. I found that females with access to

vegetation on the more fertile shale soils were in better condition and bred more successfully than those on sandstone alone.

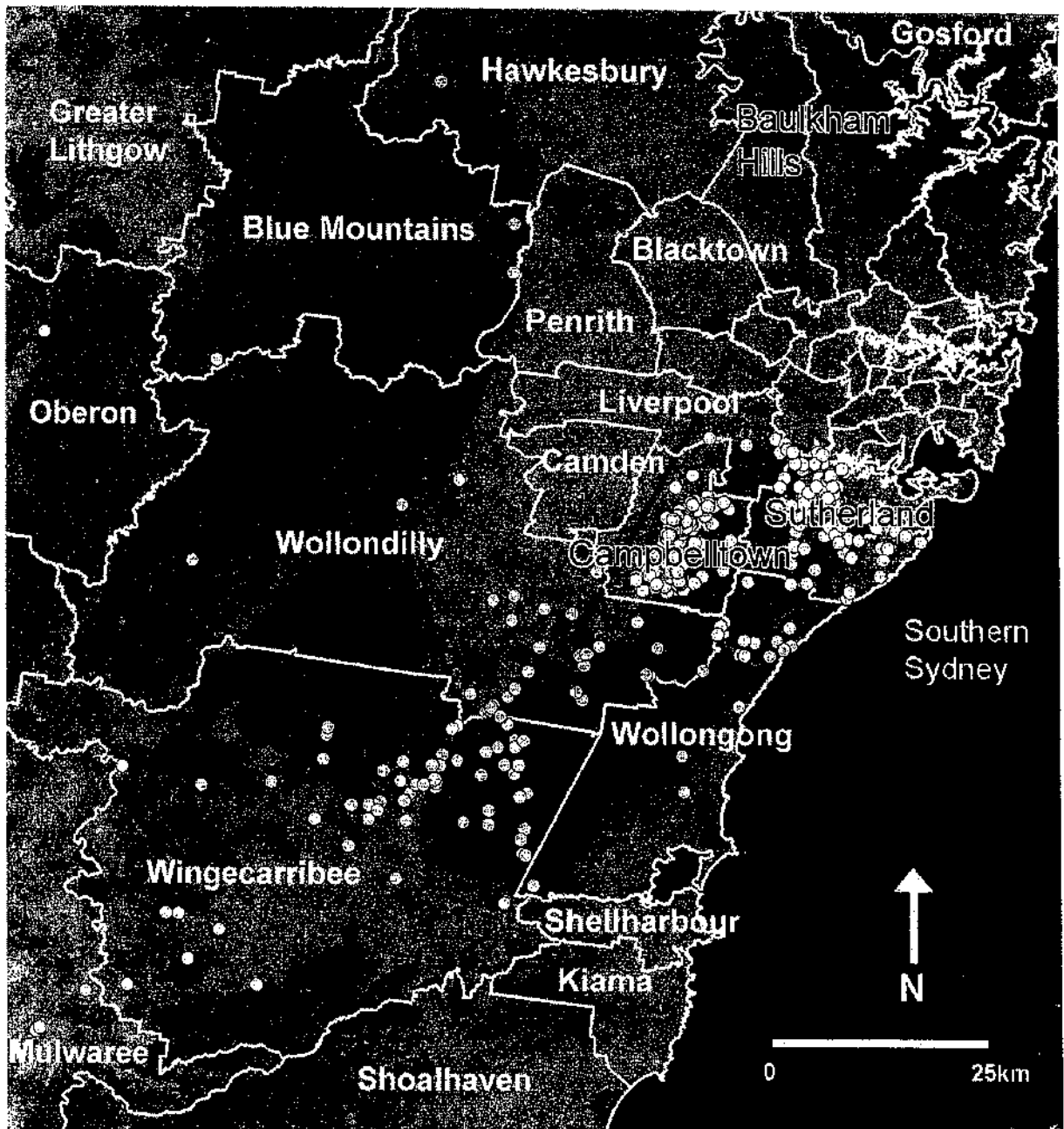


Figure 7.1. Map of koala sightings and Local Government Boundaries for the southern and greater Sydney regions. White lines indicate the boundaries of Local Government Areas, most of which are labelled. Dots represent all credible and historical koala sightings from this study.

Fatalities caused by vehicles (42.3%), stress and renal failure or dehydration (11.5%), and dog attacks (11.5%) were found to be significant causes of mortality. It is likely, however, that the use of community reports of koala sightings caused a bias to human-induced koala mortalities. No fatalities due to fire were detected, but anecdotal reports suggest that large, intense fires can greatly reduce koala populations. Chlamydial

infection was detected in animals captured, but no clinical signs of the disease were observed, and thus its effect on the study populations appears to be low.

Koala home ranges were found to be large, with harmonic mean home range size estimates for the three females with sufficient fixes ranging from 11.6 - 36.0ha (90% isopleth), and 4.8 - 9.4ha (60% isopleth). Male home ranges were found to be significantly larger than female home ranges.

Koalas in the southern Sydney region reused trees infrequently, with no animal being observed to reuse more than 17% of the total number of trees visited.

All three females for whom tree preferences were investigated were found to prefer *Eucalyptus punctata*, *E. pilularis* and stringybarks (*E. agglomerata*, *E. capitellata*, *E. eugenioides*, or *E. globoidea*). *Syncarpia glomulifera* and *E. piperita* were also preferred by those of the three females with access to these species. There is no evidence that *S. glomulifera* was browsed and I therefore believe that this species was preferred as a shelter tree. Large trees, between 30 and 39.9cm diameter at breast height (dbh), were most preferred by the three females. Trees <10cm dbh, although avoided, did constitute 7% of the observations for two of the adult females.

The current SEPP44 legislation was found to be inadequate to control threats to koalas in the southern and greater Sydney regions because (i) Sutherland Shire LGA was not covered by this legislation, and (ii) habitat used by females known to be breeding did not meet the SEPP44 definition of "potential koala habitat". However, with modifications this legislation can be made applicable to habitat in the southern and greater Sydney regions, and additional tree species can be listed in KPOMs adopted by councils.

All observations were consistent with koala populations in both the southern and greater Sydney study regions occurring at low density. The density for the southern Sydney population using the modified bounded transect method was estimated to be 0.035 ± 0.087 koalas ha^{-1} , and 0.049 koalas ha^{-1} with the home range method, both estimates excluding dependent young. The size of the koala population in the southern Sydney region was estimated to be, excluding dependent young, 90-200 animals, with a

further 170-700+ individuals in the greater Sydney region. These estimates, however, should be used with caution.

7.1.2 The Declining-Population and Small-Population Paradigms

Caughley (1994), in a review of research examining extinction processes, described two paradigms: small-population and declining-population. The declining-population paradigm deals with the causes of low population size. Addressing causes of population decline will clearly be beneficial to preventing the loss of the koala populations investigated in this study. These causes, and recommendations for their management, are addressed later in this chapter.

The small-population paradigm deals with the effect of small size on the persistence of a population. This is relevant because I estimated that both the southern, and greater Sydney region koala populations are small (see section 3.3.13). The small-population paradigm proposes that even without a systematic pressure pushing it towards extinction, small populations face the possibility of extinction through chance events: demographic, environmental and genetic stochasticity and natural catastrophes (Shaffer 1981, Simberloff 1988, Lande 1993). Shaffer (1981) defined these events as follows:

- *natural catastrophes*, such as floods, fires, droughts, etc., which may occur at random intervals through time,
- *demographic stochasticity* which arises from chance events in the survival and reproductive success of a finite number of individuals
- *environmental stochasticity* due to temporal variation of habitat parameters and the populations of competitors, predators, parasites and diseases
- *genetic stochasticity* resulting from changes in gene frequencies due to founder effect, random fixation or inbreeding.

Whilst all of these types of chance events are of concern, genetic stochasticity can cause long-lasting problems, even if the population should later increase in size. An example of the effects of genetic stochasticity is the koala population on Kangaroo Island, South Australia. This population has been through at least two founder events (where a small number of individuals were used to establish new populations). A study

of this population found a strong correlation between low levels of genetic diversity, and the incidence of testicular aplasia, where the testis descends into the scrotum but does not develop (Montgomery *et al.* 2000). Thus, this condition may cause reduced male fertility in the future.

Whilst all of the types of chance events are of concern, consideration of the problems of the genetic stochasticity concept has led to the development of the minimum viable population size concept.

7.1.3 Minimum Viable Population Size

The minimum viable population is the lowest number of individuals that will “*provide for the maintenance of fitness and adaptive potential*” (i.e. minimise risks from genetic stochasticity, Soulé 1980). It has been estimated that for a genetically isolated population an *effective* population size of 50 is required for the population to persist over the short-term, and 500 individuals for the long term (Franklin 1980). Lande (1995), however, cited studies, which found that the production of genetically adaptive mutations is an order of magnitude lower than the total mutational variance, and concluded that a long-term effective population size of 5000 is required. The study was disputed by Franklin and Frankham (1998), because the studies included non-adaptive genetic variance, and they recommend that an effective population size of 500-1000 is appropriate.

7.1.3.1 Effective Population size

The minimum effective population size (N_e) is distinct from the total number of adults in a population (N). Crow and Kimura (1970, cited in Frankham 1995) defined the effective population size as “*the size of an idealized population that would give rise to the same variance of gene frequency, or rate of inbreeding, as in the actual population under consideration*”. The total number of adults in a population is usually much larger than the effective population size. N_e/N ratios are affected by fluctuations in population size, variance in the number of progeny, taxonomic group, and unequal sex ratios, and have been found to average 0.11 (Frankham 1995). However, a review of comprehensive estimates of N_e/N ratios (across all taxonomic groups and incorporating the effects of fluctuations in population size, variance in family size, and unequal sex

ratios, and excluding an outlier), found the ratios to range from 10^{-6} to 0.57 (Frankham 1995). N_e/N ratio estimates have not yet been published for koalas. However, if the short and long-term minimum population sizes of 50 and 500-1000 (Franklin 1980, Franklin and Frankham 1998), are divided by the average N_e/N ratio of 0.11 (Frankham 1995), then the minimum true population size required to avoid short-term loss of genetic variation would be 455 individuals, and 4545-9091 individuals to avoid long-term loss of genetic variation. However, the minimum population size required to avoid short-term loss of genetic variation could range from 88 to 5×10^7 individuals, and from 877 to 10^9 individuals to avoid long-term loss of genetic variation. This range in short and long-term minimum viable population sizes is large, so an estimate of the N_e/N ratio for koalas to estimate the true value would be useful. As this was not available, minimum population sizes estimated with the mean N_e/N ratio were used to examine possible outcomes for the southern and greater Sydney koala populations.

This estimation of minimum viable population size has important implications for the southern and greater Sydney koala populations. Because these populations are estimated to be small (see section 3.3.13), they may face problems due to genetic stochasticity. The effect of genetic stochasticity can be minimised by preventing further population size reduction, by facilitating, if possible, an increase in population size, and by enhancing gene flow between populations. Preventing further population size reduction through habitat conservation and minimising mortality rates is addressed in this chapter (sections 7.2.3 and 7.2.4, respectively). Facilitating an increase in population size could be achieved through rehabilitation of cleared land, but this is unlikely given the continuing pressure for further development (see section 1.9). Enhancing gene flow between populations can be achieved by facilitating koala movements. This can be done by maintaining habitat linking populations to encourage koala movements, and by providing means, such as culverts, for dispersing koalas to cross roads and railways (see section 7.2.4.1), and should be a high priority.

7.1.4 Koala Plans of Management (KPoM)

As described in chapter 1 (section 1.10), SEPP44 provides for assessment of development proposals on a case by case basis, or a KPoM can be prepared (Anon 1995).

A KPoM, or for that matter any regional plan, is a useful tool, as it extends and combines current information into one document. This information is then used to make management recommendations including appropriate land use zonings within Local Environment Plans (LEPs). There are also advantages for developers: appropriate types of developments are made clearer, and because of this, development applications are less likely to end up in court, or opposed by protestors. Examples of community opposition from the southern Sydney region are Dobson (1990) and Talbot (1993). There are also advantages from a conservation point of view to KPoMs: decisions about development applications are guided by a framework based on what is needed to sustain the population in that region using information current at the time the plan was written. Issues such as the impact of roads, which are not normally included in case-by-case development assessments, are also considered in a KPoM.

7.2 Discussion

7.2.1 Koala Numbers

In section 7.1.3.1, the short-term minimum viable population, using the mean N_e/N ratio, was estimated to be 455 individuals. The combined population estimates for the southern and greater Sydney regions may be sufficient to meet this hypothetical minimum viable population size. However, if each region is considered on its own, only the greater Sydney region may meet the hypothetical short-term minimum viable population size, and both fall far short of the long term minimum viable population size estimate of 4545-9091 individuals, even if they can be considered as one population (i.e. population estimates added together).

It appears unlikely that either the southern, or the greater Sydney populations, could meet the long-term minimum viable population size. This failure indicates that there is a reasonable risk that the southern and greater Sydney populations will not be able to avoid loss of genetic diversity in the long term. Thus management to prevent further decline of the koala population, and to facilitate an increase in size, is necessary.

So far, I have discussed the southern and greater Sydney regions as if one koala population exists in each. Analysis of mitochondrial DNA, however, suggests that the koala populations in the southern and greater Sydney regions are genetically distinct

(Houlden pers. comm.). Furthermore, as the greater Sydney region is large, there may, in fact, be a number of distinct populations within this region. This means that there may be a number of small populations, increasing the risks from chance events. Further research into genetic relationships and minimum viable population sizes may help to evaluate what these risks are, but these risks can be reduced by preventing further decreases in koala populations, and by facilitating koala movements, and thus gene flow.

7.2.2 Revising SEPP44 Legislation

All LGAs, except Sutherland, are included in Schedule 1 of SEPP44, which lists those councils to which the legislation applies (Anon 1995). I have now collated 103 reports of koala sightings, excluding hoaxes, false alarms, unreliable and multiple reports, from the Sutherland LGA (see Fig. 7.1). I therefore recommend that the Sutherland LGA should be added to the SEPP44 Schedule 1 list.

I also found that females known to be breeding utilised habitat that did not meet the definition, under SEPP44, of "potential koala habitat" (section 6.3.4). This mean that approval for a development could be given, even if breeding animals utilised that habitat. I believe this can be corrected by lowering the requirement for potential koala habitat to 10% of Schedule 2 listed trees.

I also recommend that consideration be given to including *E. agglomerata* in Schedule 2 of SEPP44 (see section 6.4.1). As *E. agglomerata* can be difficult to identify in the field, consultants working in the southern and greater Sydney region should also count other stringybark species (*E. capitellata*, *E. eugenioides* and *E. globoidea*) as if they were *E. agglomerata*, if there is doubt as to the species identification.

7.2.3 Habitat Clearing

The finding that females with access to vegetation on the more fertile shale soils were in better condition and bred more successfully than those with access only to sandstone soil vegetation, has important management implications. Clearly, conserving remnant vegetation on shale, and other fertile soils, must be the priority for both the southern and greater Sydney regions. Given that fertile soils are also more likely to have been

cleared for farming (see section 2.5), then conserving what remains is even more crucial.

In the southern Sydney region most of the remnant vegetation occurs on sandstone soils, with shale soil vegetation occurring close to the eastern suburbs of Campbelltown (see section 2.2). Further development in the areas with shale soil will have the greatest impact and thus control of development pressures in these areas is urgently needed. Campbelltown Council has already had a KPoM prepared (Callaghan *et al.* 1998). However, none of the recommendations in this KPoM has yet been adopted. Preparation of a LEP which sets restrictions on developments affecting remnant shale soil vegetation should be prepared, exhibited and adopted as soon as possible, and should be considered to be the highest priority for Campbelltown Council. Other councils should also conserve remnant shale soil vegetation.

In the greater Sydney region, many koala sightings occur in, or close to, the Cordeaux, Nepean and Avon dam catchments (Fig. 7.1). A number of sightings also occur to the west of the water catchment from Hill Top/Colo Vale west to Joadja, and in the southwest from Canyonleigh to Marulan. Scattered sightings also occur in the Blue Mountains. These sightings cover a large number of Local Government Areas, but the majority falls within the boundaries of the Wollondilly and Wingecarribee Councils. Therefore, I recommend that Wollondilly and Wingecarribee Councils prepare KPoMs.

In addition, a high priority is to conserve links between remnant habitat. Whilst this should be a priority for many different management authorities it is particularly relevant to the Roads and Traffic Authority, Railways Australia, Wollondilly and Wingecarribee Councils (see section 7.2.4.1).

7.2.4 Mortalities

7.2.4.1 Road and Rail

Roads and railways have two types of impacts upon koalas: death or injury from vehicle impact, and barriers to gene flow.

A study in Queensland (Nattrass and Fiedler 1996) found that road purpose, speed limit, overhead lighting, and width and volume of traffic were the major influences for determining the risk of koala mortality. Risks to koalas in 60km/h zones were low to negligible, increased for 70km/h zones (22% of road fatalities) and was highest for 80km/h zones (74%), the maximum legal speed limit in the study area. Moreover, good lighting for motorists lowered risks to koalas.

I identified three koala blackspots in the southern Sydney region: Heathcote Road, Wedderburn Road, and Peter Meadows Road (section 3.4.8). Appin Road was also identified to have a high risk of koala injury or mortality (Fig. 7.2). Combined road and rail mortalities were also identified along a 50km stretch of the Southwestern Freeway, Hume Highway and Main Southern Railway in the greater Sydney region (Fig. 7.3). As these locations encompassed most known koala fatalities I recommend that attempts to lower koala fatalities on roads and railways should be concentrated in these areas.

Probably the most effective option to reduce koala fatalities is to lower the speed limit. However, most of the identified areas with a high risk of koala mortalities occur on major roads, with large volumes of traffic. Lowering speed limits will therefore be difficult, but is an option where a road passes through a gully. The speed limit would be lowered for only a short section of road, and would also improve road safety. Other relatively cheap options include improving lighting and driver visibility, although clearing of habitat should be avoided. Erecting signs to inform drivers of the presence of koalas may also assist in slowing down traffic, and some have already been erected in the southern Sydney region on Heathcote Road, Peter Meadows Road, Georges River Road, and four other locations in the Campbelltown LGA.

Swareflex reflector posts at the side of the road could also be trialed. These are posts with reflectors that bounce the light from a vehicle's headlamps into surrounding bushland. The reflected light can dissuade animals from using a road whilst a vehicle is travelling along it. Although I am unaware of any trials upon koalas, Lundie-Jenkins (2000) in a review of the Proserpine rock wallaby (*Petrogale persephone*) recovery program in Queensland, concluded that *"Although the trial has not been conducted in a statistically rigorous manner, there has been a noticeable reduction in rock-wallaby road deaths in areas where reflectors have been installed"*.

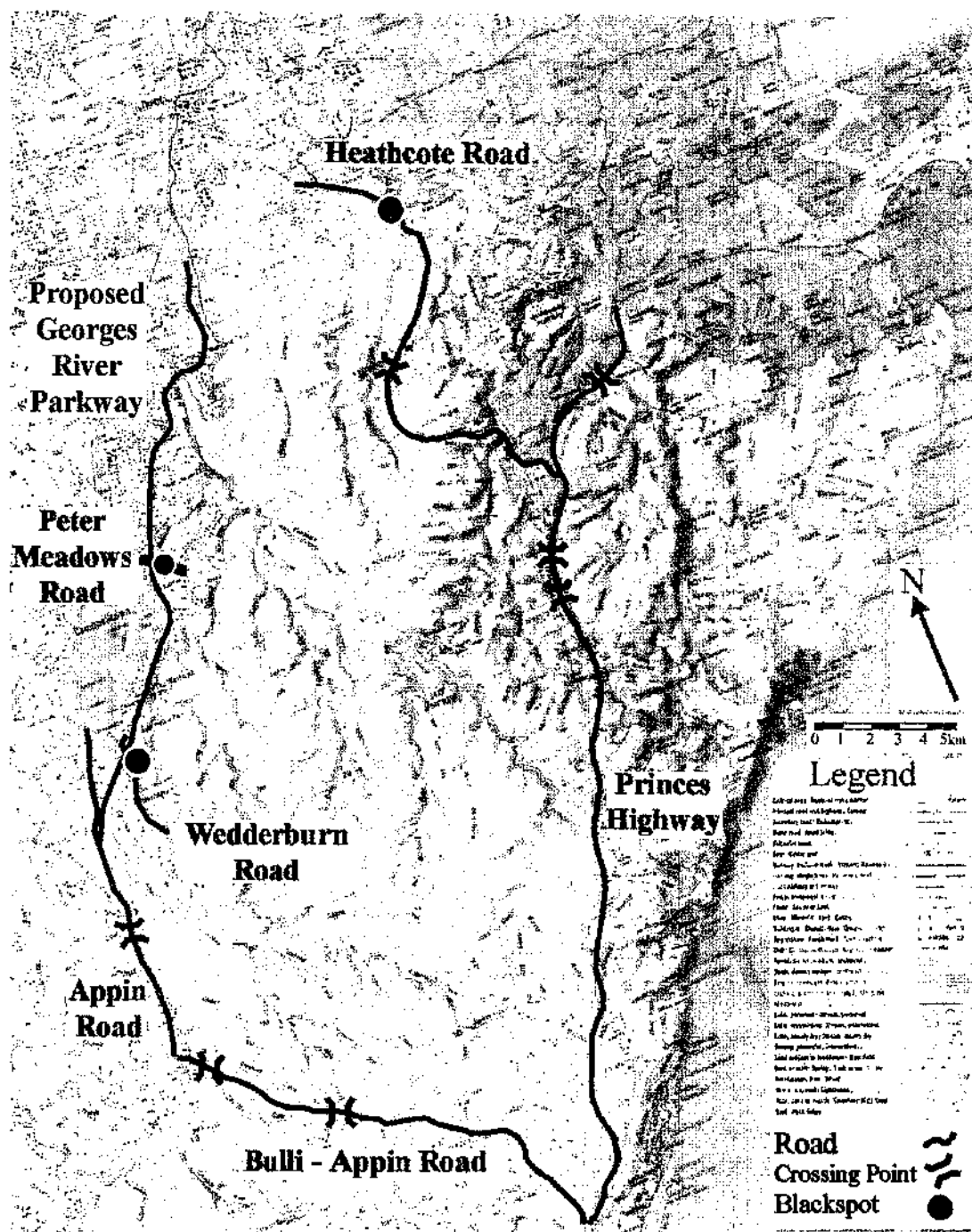


Figure 7.2. Map of roads of concern, koala blackspots and potential crossing points for koalas in the southern Sydney region. Note that all of Appin Road is considered a problem for koalas attempting to cross this road. A “blackspot” is considered to be a short length of road with a high risk of koala mortality. A “crossing point” is a location where installation of a culvert would facilitate koala movements.

Another option to reduce road and rail koala fatalities is to exclude animals from the danger area through fencing, preferably combined with passes to allow koala movement. Culverts have been used by other mammals (Finch 2000), and combined with 1.5m high “floppy top” fauna exclusion fencing have also been utilised by koalas (Phillips 1999). There is also evidence that larger culverts encourage koala movements

(Phillips 1999). Therefore, if built, larger culverts should be used where possible, or bridges over gullies should serve the same purpose by allowing animals to pass underneath. The fauna exclusion fencing in koala blackspots, particularly around gullies, could also be used to keep animals off the road, and to direct both koalas and other fauna towards a culvert, or under a bridge. This option would be costly, but for railways, it is likely to be one of the few effective methods of reducing fatalities, apart from reducing train speeds.

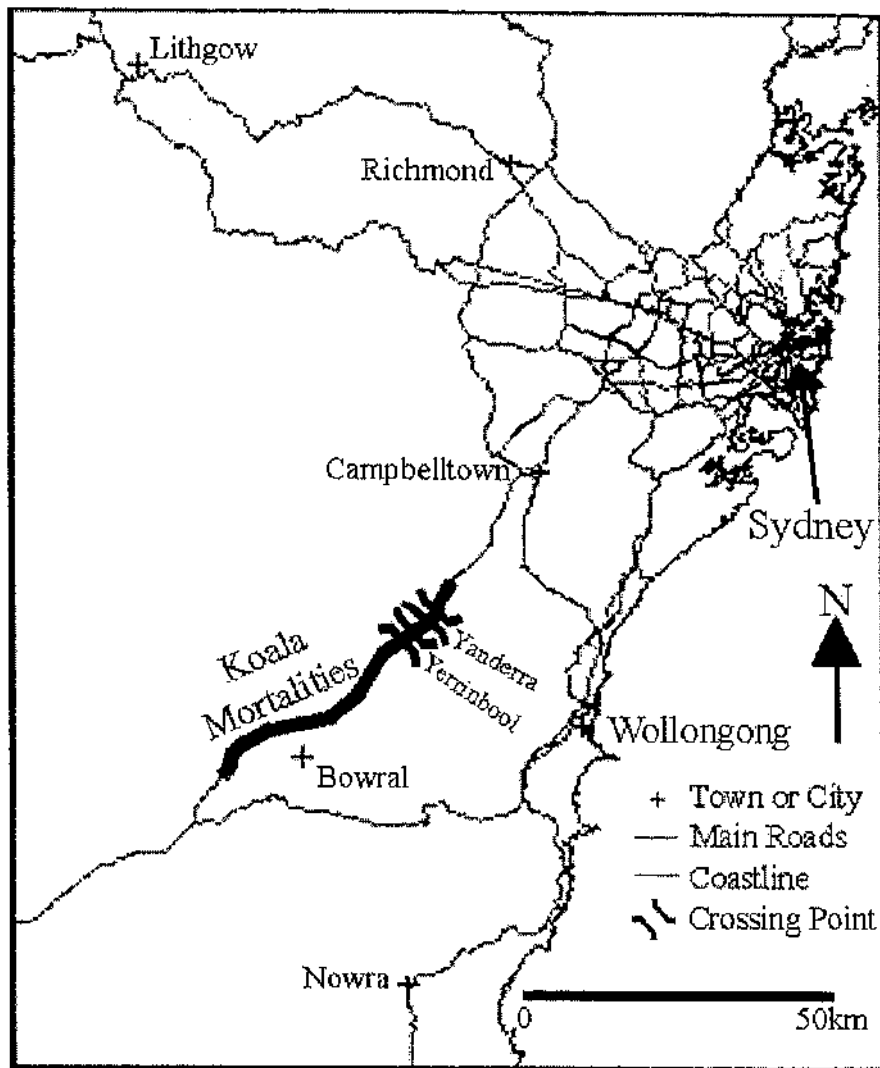


Figure 7.3. Map of road and rail koala mortalities and possible crossing points in the greater Sydney region. Mortalities are concentrated in the area indicated by the thick dark line between Campbelltown and Bowral. A "crossing point" is a location where installation of a culvert would facilitate koala movements.

Installing culverts also has the advantage of encouraging koala and other animal movements. Animal movements are important to allow gene flow and to prevent inbreeding (Sherwin and Murray 1990, Aars and Ims 1999), and given the low

estimated population sizes of koalas I believe it is particularly important to facilitate these movements. A total of seven crossing point locations were identified in the southern Sydney region, and two in the greater Sydney region (Figs 7.2 and 7.3). In these locations installing culverts would be useful in facilitating koala movements, and may help to reduce koala fatalities. These crossing points have been placed as close to gullies as possible, as data from this study suggests that koalas will be more likely to move along gullies, or between closely spaced gullies (section 3.4.8).

In five of the crossing locations the culverts would need to cross both a road and a railway: at Yanderra and Yerrinbool in the greater Sydney region, and the three locations identified for crossing the Princes Highway and Illawarra railway line in the southern Sydney region. Liaison between the relevant LGAs, the Roads and Traffic Authority and Railways Australia will be required for the construction of effective culverts in these areas.

Whilst culverts and bridges in appropriate locations will help koalas to cross road and rail barriers, corridors of vegetation can be used to facilitate movements between populations. Soulé and Gilpin (1991) define a corridor as:

A linear two-dimensional landscape element that connects two or more patches of wildlife (animal) habitat that have been connected in historical time; it is meant to function as a conduit for animals.

Evidence of the effectiveness of corridors is scant, but they enhanced gene flow in an experiment with voles (Aars and Ims 1999). Moon (1990) found that koalas used corridors with sparsely distributed food trees (average of 2 per ha over the study site) in Lismore, New South Wales. This observation suggests that a narrow, sparsely vegetated corridor may be sufficient to facilitate koala movements, but these findings may not apply to low density koala populations, and the width of a corridor is generally considered an important characteristic (Soulé and Gilpin 1991). Well vegetated corridors may therefore be needed to facilitate movements for low density populations.

For the southern Sydney region, there is a very wide band of habitat connecting the Campbelltown koala population with vegetation to the south in the Cataract, Cordeaux,

Avon and Nepean Dam catchments. There is also a smaller corridor of vegetation at Woodhouse Creek (the crossing point shown on Appin Road in Fig. 7.2), and at Mallaty and Menangle Creeks, which occur south and north of Woodhouse Creek respectively. Whilst all three corridors may facilitate koala movements, the Woodhouse Creek corridor is the widest and most continuous in providing a link between the Georges and Nepean River systems, and was thus chosen as the best location for a crossing point over Appin Road.

In the greater Sydney region, much habitat around the Cataract, Cordeaux, Avon and Nepean dam catchments has been cleared, but there is an even larger area of remnant vegetation to the west consisting of the Nattai National Park, Kanangra Boyd and Blue Mountains National Parks. These areas are linked through a corridor that passes through the Bargo River catchment, in the region of the small towns of Yanderra and Yerrinbool. The importance of this corridor has been highlighted by Ware (1993), and Belik and Close (1997). I recommend that the installation of culverts in the identified crossing points at Yanderra and Yerrinbool should be investigated as soon as possible to facilitate movements of koalas, and other animals, along this corridor.

Whilst I have so far concentrated on mitigating the impacts of existing roads, there is a proposed road, the Georges River Parkway, which is of particular concern. This road would pass to the east of St Helens Park and Airs, and through Kentlyn (Fig. 7.2). The road, if built, would require clearing of breeding koala habitat upon shale soils, would be likely to cause a high number of koala fatalities (from vehicle impacts), and would act as a barrier to movements from along Campbelltown's eastern border to habitat in the Georges River. Thus, if built, this road will have a high impact upon the most productive areas of breeding habitat in the southern Sydney region. I therefore recommend that this road should not be built, or that major changes be made to avoid construction in, or near, remnant vegetation.

7.2.4.2 Dogs and Feral Animals

Only 3 of 26 known koala mortalities (11.5%) could be attributed to dogs. However, deaths due to dogs may not be reported or occur out of sight of a dog's owner, or other witnesses. Roaming dogs are also a problem in many Campbelltown suburbs (pers. obs), so 11.5% dog fatalities may therefore be an underestimate.

Legislation allows a council to designate a public place as a wildlife protection area (section 14-1h, Companion Animals Act 1998). These areas must have conspicuous notices placed at “reasonable intervals” that dogs are prohibited. It is then an offence to bring a dog into that area and any unaccompanied dog can be seized by any person, including authorised officers.

A dog can also be defined as a “nuisance” if it is habitually at large (section 21-1a, Companion Animals Act 1998). An authorised council officer can then issue an order to the owner of the dog requiring the owner to prevent such behaviour, and the order lasts for a period of 6 months. If the owner does not comply with this order then they will have committed an offence.

The ability to designate a place as a wildlife protection area, and to issue notices to the owners of nuisance dogs under the Companion Animals Act (1998), should be useful tools for councils to manage the problem of roaming dogs in bushland areas. However, the goal is to persuade animal owners to control their animals. Publicising the problems dogs can cause, and owners’ responsibilities, will be of assistance in achieving this goal.

No koala deaths could be attributed to animals other than dogs in this study, but foxes might pose a threat to young koalas. Although feral animals are often difficult to eradicate, designing and implementing plans to control both these and domestic animals could be beneficial.

7.2.4.2.1 Disease

Although the results from chlamydial tests were inconclusive, the infection rate is at least 7.4% (2 positive results from 27 animals), but with no clinical symptoms being observed. Stress combined with renal failure or dehydration appeared to be a greater problem, causing 3 deaths out of 26 known mortalities.

Given the low incidence of disease I recommend that animals from other colonies that may carry diseases, particularly new chlamydial strains, not be introduced into either the southern or greater Sydney region. This may be an issue if animals from

overpopulated islands in South Australia or Victoria continue to be translocated, and if the southern or greater Sydney regions are ever considered as release areas.

7.2.4.3 Fire

Responses from some community members indicated that large, intense fires can threaten koala populations (section 3.3.8). However, the common method to reduce the risk of high intensity bushfires occurring is to use hazard reduction burning (Whelan 1995). This technique involves burning in cool weather conditions and reduces the amount of fuel available to subsequent fires, thus reducing their intensity.

The maximum fuel load considered controllable in adverse weather condition is between 5 t ha⁻¹ to 15 t ha⁻¹ (Good 1981, Fensham 1992, Chaffe 1989). Fuel loads can reach 15 t ha⁻¹, the upper limit of acceptable fuel, in approximately 4 years for wet sclerophyll forest, and 8 years for dry sclerophyll forest, with a dense canopy (Williams 1983). Thus, the frequency of burning required to maintain a low fuel load varies, but in most Australian habitats, hazard reduction burns would be required every two to seven years (Good 1981, Recher and Christensen 1981, Benson 1985, Chaffe 1989, Burrows 1990). Burning at this frequency, however, can lead to the elimination of plants that regenerate from stored seeds (Fox 1988). Consequently, frequent hazard reduction burning is not recommended to minimise the risk to koalas. Gully habitat may, however, act as a refuge from fires. Five fires from 1992 to 2002 have been observed to burn to the edge, and partially into, the O'Hares Creek gully, but stopped at the gully (Close pers. comm.). Thus, deep gullies appear to rarely be burnt.

Designing appropriate fire regimes is difficult because, as just described, fire behaviour and also ecosystem responses to fire, vary with habitat type and location, so it is not possible to prescribe a simplistic fire regime for the region. Furthermore, given that the fire regime will affect the whole ecosystem, I believe it is inappropriate to manage a fire regime for the benefit of only one species. Instead, I recommend that fire management regimes be drafted with scientific input about the environmental impact of that fire regime. Also, to help monitor fire history, notes should be kept on the date and intensity of fires, and their extent mapped.

Another impact associated with fire management is the construction of fire trails. These trails require habitat to be cleared, and increase access for others, including mountain bikers, motorbike riders, horseback riders, four-wheel drivers, and walkers, some of whom take their dogs, usually unleashed (pers. obs.). The impacts associated with the increased access can include dispersing weeds, usually inadvertently, increased access by feral and domestic animals, increased levels of littering and rubbish dumping, increased fire frequency (from fires lit deliberately or started inadvertently), increased damage to plants, animals or natural features such as rock formations (including the removal of bush rock), and damage to the trails themselves (pers. obs.). Thus, the minimum number of fire trails necessary should be used, and those groups which cause the greatest impact should be excluded as much as possible through signposting and the installation of appropriate gates and fences. Gates and fences must also be monitored in case persons try to force entry by damaging them.

7.2.5 Habitat Restoration

Restoration or rehabilitation projects may be helpful in the conservation of koala populations. However, given that it is difficult to restore an area to its pre-existing state prior to damage (Lake 2001), the first priority should be to conserve remnant vegetation. Restoring areas to form, or enhance, movement corridors, however, will be useful as will restoration of habitat on fertile soils.

7.2.6 Education

Many of the management recommendations made here seek to modify residents' behaviour. This change in behaviour is more likely to occur if people understand the problem, and how changing their behaviour will help. Thus, educating the community is likely to be of assistance.

During this study, much time was spent on providing information about research being carried out, and why it was needed. Thus, much community education has already occurred. However, for the education to be truly effective, it will need to reach as many groups as possible within the community, and to be ongoing (Anderson and McKaige 1998). Reaching all members of the community will require considerable effort, but I suggest that simple low-cost methods, such as providing information handouts free of

charge, can help to raise community awareness, and thereby increase the support for management measures. Koala handouts, relevant to the southern and greater Sydney regions, are provided in Appendix 4.

7.2.7 Addressing Information Gaps on Koala Ecology in Sydney

There is a lack of information on the distribution and abundance of koalas in much of the greater Sydney region and within the Holsworthy Army Range in the southern Sydney region. This information is highly relevant in a management context, but will be much more useful if all the information is collated. I therefore suggest that all koala sightings from both the southern and greater Sydney regions should continue to be reported to Associate Professor Robert Close at the University of Western Sydney via the koala hotline: (02) 9962 9996. Targeted surveys will also be useful for those areas where knowledge is lacking or scant, such as in the Nattai National Park and in the Blue Mountains.

Future reports can be added to the database constructed during this study. The time required to deal with each report varies, but it takes approximately 30 minutes per report to record the details of the sighting, obtain UTM grid coordinates, and enter the details into the database (pers. obs.). Complicated reports, or those that require follow up, can, however, take significantly longer. Since 1997 approximately 75 reports per year, of all types, have been received from the public. It is estimated that the cost (including labour and ancillary costs, but excluding the time and cost of obtaining further media publicity) to continue to collect and collate reports via the established system will cost \$2000 per year (Close pers. comm.). Given the low cost and potential benefits of the database I believe that such funding would be well worthwhile.

To access the koala sighting information within the database, requests can be directed to A. Prof. Close. This will allow future development proposals to be evaluated with the most up to date information available. Furthermore, the conclusions and the management recommendations made in this study can be reviewed and updated periodically using up-to-date information. Given the difficulties of gathering distribution data from low density koala populations the database will be particularly useful, and is demonstrated by the fact that since information has been made available

in August 2001, there have been 6 requests for data (2 from NPWS, 2 from Australian Museum, and 2 from environmental consultants).

Obtaining a reliable density estimate would be useful to improve population estimates, although these data are difficult to obtain.

Continuing to collect sightings of ear-tagged koalas, as in this study, may provide further information about movements between koala populations. Whilst observations of koala movements is evidence that koalas are moving between populations, a lack of observations may be either because the movements are not occurring, or because they have not been observed. Genetic analysis that provides information about genetic variation, and gene flow between koala populations in the Sydney region, may indicate more reliably if populations are isolated. This question is particularly relevant with small koala population size estimates for the southern and greater Sydney regions, because the chance of extinction is higher for isolated populations than for connected populations.

7.2.8 Tourism

The koalas' worth to the Australian tourism industry is estimated to be \$1.1 billion (Hundloe and Hamilton 1997). This value should increase as the number of international visitors to Australia is predicted to increase at a rate of 8.9% per year until 2005 (Hundloe and Hamilton 1997). Given this demand, a tourism enterprise taking people into the bush in the southern or greater Sydney regions may be feasible. However, tourism can cause significant environmental impacts (Grey *et al.* 1991), which should be considered.

The main problem with a tourism venture using koalas as the main attraction is the difficulty of locating animals reliably without radiotracking them. This is a problem, as tourists want to actually see a koala (Hundloe and Hamilton 1997). There have certainly been numerous requests during this study to take various groups, from school classes to international visitors, on radiotracking surveys.

I believe that occasional groups of up to 25 people do not constitute a significant disturbance, provided they are kept on existing trails as much as possible, instructed not to damage rock formations or to leave rubbish, and are supervised when a koala is found, to keep disturbance to a minimum. Furthermore, I believe that there is significant value in educating certain groups, such as school students, about issues for koala conservation in the region by this method, as many issues (e.g. weeds) are more readily apparent when students are actually in the field.

However, if groups were taken frequently to see the same radiocollared animals (say ≥ 1 -2 times per week), this could constitute a significant impact upon these animals. Furthermore, as radiotracked animals are rarely close to trails there are other associated impacts with persons walking off the trails to see the animals. In particular, the Broad-headed snake (*Hoplocephalus bungaroides*) lives under loose sandstone rocks that lie on top of other rocks (Phillips *et al.* 1996). These rocks are fragile and significant damage could be caused by large numbers of people, however well intentioned.

If a koala tourism venture should be undertaken in either the southern or greater Sydney regions I propose that the groups be taken to a zoo or wildlife park so that they can see a koala, and then taken along trails to point out other relevant features such as koala food-trees, gullies, scratches on trees, pellets, etc. In addition, keeping the groups to pre-existing trails will help to minimise damage, such as to sandstone rock formations, and visitors should be warned that their chances of actually spotting a koala are low.

7.2.9 Translocations

Sherwin *et al.* (2000) stated that there were “*no data to suggest that any (natural Australian koala) population requires genetic supplementation*”, and that care must be taken when translocating animals due to the possibility of introducing novel strains of *C. pecorum* to a naïve population. Although chlamydial infection was present within some animals examined, it appears that *C. pecorum* may not be present in the southern and greater Sydney koala populations. Consequently, I recommend that no animals be translocated into these regions from other populations. Furthermore, to minimise the

chance of transmitting this pathogen, any captured animals should be released as close as possible to their capture point.

As the population sizes are estimated to be small, it may be that in the future the level of genetic variation decreases to the extent that translocations may become necessary. At this stage, however, I feel that, as genetic variation is not depressed, the possibility of introducing pathogens makes translocating in new animals an unwarranted risk.

7.3 Recommendations

Recommendations are itemised below, and the priority of each recommendation for various organisations is given in Table 7.1.

1. That the Department of Urban Affairs and Planning revise the SEPP44 legislation, with consideration given to:
 - i. Including Sutherland Shire Council in the Schedule 1 list of LGAs to which SEPP44 applies.
 - ii. Including *E. agglomerata* in the Schedule 2 list of koala browse species.
 - iii. Revise the definition of “potential koala habitat” to be 10% of the total number of trees listed in Schedule 2, instead of the current 15%.
2. That the council (see Table 7.1) prepares, exhibits and adopts a KPOM as per NSW SEPP44 legislation.
3. That the council (see Table 7.1) prepares, exhibits and adopts a Local Environment Plan which:
 - i. Limits clearing and impacts upon habitat used by koalas, with conserving remnant vegetation on fertile soils, such as shale, being a high priority.
 - ii. Preserves corridors of remnant vegetation to facilitate koala movements.
 - iii. Also addresses management recommendations 4 to 10 (below).
4. That the authority (see Table 7.1) forwards all reports of koala sightings to Associate Professor Robert Close at the University of Western Sydney. Such sightings can be reported via the hotline pager number on (02) 9962 9996.

5. That the authority (see Table 7.1) prepares a prioritised list of areas for habitat restoration and liaises with groups undertaking restoration work.
6. That if any koala blackspot or potential crossing areas identified in this study come under the authority's jurisdiction (see Table 7.1) that it looks to minimise koala fatalities and facilitating koala movements through:
 - i. Installing bridges or culverts at least 2.5m by 2.5m in the koala crossing locations identified in Fig. 7.2 and Fig. 7.3.
 - ii. Erecting warning signs in koala blackspot areas.
 - iii. Consider reducing speed limits, trialing reflector posts, improving lighting and driver visibility in koala blackspot and crossing areas.
 - iv. Using fauna exclusion fencing in koala blackspot areas, particularly to direct koala movements to go through culverts or under bridges.
7. That the authority (see Table 7.1) prepares, exhibits and implements a feral and domestic animal management plan which should incorporate the following:
 - i. Promotion of responsible pet ownership (noting that dogs and cats, both domestic and feral, pose a threat to koalas and other wildlife).
 - ii. Increasing the public's awareness of the problems caused by feral and domestic animals.
 - iii. Designating significant areas as wildlife protection zones, signposting them appropriately, and enforcing penalties on owners whose dogs enter such a zone.
 - iv. Issuing "nuisance dog" orders to those owners who allow their dogs to roam, and enforcing penalties if such orders are breached.
 - v. Seek to reduce or eliminate feral animal populations through trapping, baiting, culling, or other control measures as appropriate.
8. The authority (see Table 7.1) prepares, exhibits and implements a fire management plan which includes the following:
 - i. Defining the hazard reduction burning regime, if any, and methods to be used to control wildfires in different types of habitat and terrain.
 - ii. Scientific input regarding environmental impacts of the recommended actions in the fire management plan.

- iii. The extent, design, construction and maintenance of fire trails. The extent, width and number of easements for fire trails should be minimised. Trails should also be constructed to minimise soil erosion. Solid gates and fences should be installed to minimise unwanted trail use, with regular checks of both gates and fences, and maintenance as required.
 - iv. That provision be made for the mapping of all fires, and noting of the date(s) and intensity of fires.
9. That the authority (see Table 7.1) educates residents about koalas and management measures. Approval is given for the information and koala hotline handouts (Appendix 4) to be used without charge, provided that the content is not changed, and that the condition of use section for the information handout is included in all copies made. The 19 minute video "Koala Tales: koalas in southern Sydney" (Ward and Close 1999) also contains relevant information and can be purchased from Associate Professor Robert Close at the University of Western Sydney.
10. That the authority (see Table 7.1) considers the impacts of any proposed koala tourism ventures. Commercial tour groups should be appropriately supervised and kept to existing trails.
11. That the NSW National Parks and Wildlife Service and all wildlife carer groups:
 - i. Do not translocate animals from other areas into the southern or greater Sydney regions.
 - ii. Release any captured koalas as close as possible to its capture point.

Table 7.1. Priority list for relevant authorities of management recommendations made in this study. Note that these recommendations are based upon the findings of this study, apply to koalas only, and may need to be revised in the future when more information is available. H = High priority, M = Medium priority, L = Low priority, RTA = Roads and Traffic Authority, SCA = Sydney Catchment Authority, NPWS = New South Wales National Parks and Wildlife Service, DUAP = Department of Urban Affairs and Planning.

Recommendation	Brief Description	Campbelltown	Wollondilly	Wingecarribee	Sutherland	Liverpool	Mulwaree	Blue Mountains	Wollongong	Oberon	Hawkesbury	RTA	State Rail Authority	SCA	Australian Army	NPWS	Wildlife Carers	DUAP	
1	Revise SEPP44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H
2	KPoM	H*	H	H	M	M	M	M	L	L	L	-	-	-	-	-	-	-	-
3	Local Environment Plan	H	H	H	M	M	M	M	L	L	L	-	-	-	-	-	-	-	-
4	Report koala sightings	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	-
5	Habitat restoration	L	L	L	L	L	L	L	L	L	L	-	-	L	L	L	-	-	-
6	Road / rail	H	H	H	H	M	M	-	-	-	-	H	H	L	L	M	-	-	-
7	Dogs	M	M	M	L	L	L	L	L	L	L	-	-	M	M	M	-	-	-
8	Fire	H	H	H	M	M	M	M	L	L	L	L	L	H	H	H	-	-	-
9	Education	M	M	M	M	M	M	M	M	M	M	L	L	L	M	M	M	-	-
10	Tourism	L	L	L	L	L	L	L	L	L	L	-	-	-	-	-	-	-	-
11	Translocations	-	-	-	-	-	-	-	-	-	-	-	-	-	-	H	H	-	-

* = A Koala Plan of Management has already been prepared for Campbelltown City Council (Callaghan *et al.* 1998). No recommendations from this Plan of Management, however, have yet been adopted.

8 References.

- Aars J. & Ims R.A. (1999). The effect of habitat corridors on rates of transfer and interbreeding between vole demes. *Ecology*. **80**: 1648-55.
- Abbott I., Van Heurck P., Burbidge T. & Williams M. (1993). Damage caused by insects and fungi to eucalypt foliage: spatial and temporal patterns in Mediterranean forest of Western Australia. *For. Ecol. Manage.* **58**: 85-110.
- Achurch H.M. (1989). Tree utilization by koala (*Phascolarctos cinereus*) populations with regard to their geographic distribution within close proximity to the city of Brisbane. Honours Thesis, Dept. of Geographical Sciences, University of Queensland.
- Aebischer N.J., Robertson P.A. & Kenward R.E. (1993). Compositional analysis of habitat use from animal radio-tracking data. *Ecology*. **74**: 1313-25.
- Agar N.S., Ogawa E., O'Callaghan S.S. & Hume I.D. (1998). The effect of eucalyptus oils on the erythrocytes of koalas. *Comp. Haematol. Int.* **8**: 225-9.
- Allen C. (1995). Koala research in the Tantawangalo State Forest. In: *Koala conservation in the south-east forests: proceedings of an expert workshop*, Eds. S. Cork, S. Feary and C. Mackowski, pp. 24-35. NSW National Parks and Wildlife Service, Canberra.
- Allen C. (2000). Surveying koalas. *National Parks Journal*. **44**: 10.
- Andersen A.N. & McKaige B.J. (1998). Burning issues: communicating fire research in northern Australia. In: *Ecology for Everyone: communicating ecology to scientists, the public and politicians*, Eds. R.T. Wills and R.J. Hobbs, pp. 88-96. Surrey Beatty & Sons, Chipping Norton.
- Andrew D. (2001). 1996 Post fire vertebrate fauna survey - Royal and Heathcote National Parks and Garrawarra State Recreation Area. NSW National Parks and Wildlife, Sydney.
- Anon (1995). State Environmental Planning Policy No.44-koala habitat protection. *NSW Gov. Gazette*. **1**: 18-23.
- Australian Bureau of Statistics (2000). 1996 Census of Population and Housing – Basic Community Profiles: Australia, *AusStats*. Available: <http://www.abs.gov.au/websitedbs/d3310108.nsf/f9996d24c8f22d024a256500001c8576/569af0d15c2201964a2565010007a32f?OpenDocument> (Accessed: 17th August 2001).
- Axis Environmental & AMBS Consulting (1996). Holsworthy Training Area Environmental Area. Appendices A to H. Department of Defence, Sydney.
- Backhouse G. & Crouch A. (1990). Koala management in the Western Port region, Victoria. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 313-7. Surrey Beatty and Sons, Chipping Norton.
- Bakker H.R. & Main A.R. (1980). Condition, body composition and total body water estimation in the quokka, *Setonix brachyurus* (Macropodidae). *Aust. J. Zool.* **28**: 395-406.
- Bali R. & Delaney R. (1996). A Review of Koala Radio-collaring Research, consultancy for the South East Forests Koala Research Committee. Biosis Research Pty Ltd, Sydney.
- Belik M. & Close R.L. (1997). *Bargo River Issues Paper: unpublished report for the Upper Nepean Catchment Committee*. University of Western Sydney, Campbelltown.
- Benson D.H. (1985). Maturation periods for fire-sensitive shrub species in Hawkesbury sandstone vegetation. *Cunninghamia*. **1**: 339-49.

- Benson D. & Howell J. (1990). *Taken for granted: the bushland of Sydney and its suburbs*. Kangaroo Press, Sydney.
- Betts T.J. (1978). Koala acceptance of *Eucalyptus globulus* Labill. as food in relation to the proportion of sesquiterpenoids in the leaves. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 75-86. Zoological Parks Board of NSW, Sydney.
- Blanshard W.H. (1994). Medicine and husbandry of koalas. In: *Wildlife: The TG Hungerford refresher course for veterinarians*, pp. 547-625. Post Graduate Committee in Veterinary Science, University of Sydney, Sydney.
- Braithwaite L.W., Turner J. & Kelly J. (1984). Studies on the arboreal marsupial fauna of Eucalypt forests being harvested for woodpulp at Eden N.S.W. III. Relationships between faunal densities, Eucalypt occurrence and foliage nutrients, and soil parent materials. *Aust. Wildl. Res.* **11**: 41-8.
- Brown A.S., Girjes A.A., Timms P. & Woolcock J.B. (1987). Chlamydial disease in koalas. *Aust. Vet. J.* **64**: 346-50.
- Buckland S.T., Anderson D.R., Burnham K.P. & Laake J.L. (1993). *Distance sampling: estimating abundance of biological populations*. Chapman and Hall, London.
- Burrows N. (1990). Seasoned with fire. *Landscape*. **5**: 28-34.
- Burt W.H. (1943). Territoriality and home range concepts as applied to mammals. *Journal of Mammalogy*. **24**: 346-52.
- Butler R. (1978). Patterns in koala mortality. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 174-5. Zoological Parks Board of NSW, Sydney.
- Callaghan J., Phillips S., Thompson J. & Curran T. (1998). Draft Comprehensive Koala Plan of Management: Campbelltown Local Government Area. Australian Koala Foundation, Brisbane.
- Callaghan J., Leathley S. & Lunney D. (1994). Port Stephens Koala management plan: Draft for public discussion, 27th September 1994. Port Stephens Council, Raymond Terrace.
- Campbell P., Prentice R. & McRae P. (1979). Report on the 1977 koala survey. *Wildlife in Australia*. **16**: 2-6.
- Campbelltown City Council (1995). Campbelltown City Council State of the Environment Report 1994-1995. Campbelltown City Council, Sydney.
- Canfield P.J. (1987). A mortality survey of free range koalas from the north coast of New South Wales. *Aust. Vet. J.* **64**: 325-8.
- Canfield P. (1990). Disease studies on New South Wales koalas. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 249-54. Surrey Beatty and Sons, Chipping Norton.
- Carrick F. (1990). Towards a rational debate on koala conservation issues. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 149-56. NSW National Parks and Wildlife Service, Sydney.
- Caughley G. (1977). *Analysis of Vertebrate Populations*. John Wiley and Sons, Brisbane.
- Caughley G. (1994). Directions in conservation biology. *Journal of Animal Ecology*. **63**: 215-44.
- Chaffe C. (1989). Towards 1990 - a review of NPA's fire policy. *National Parks Journal*. **33**: 20-2.
- Close R.L. (1993). Campbelltown's koalas: what is their future? *National Parks Journal*. **37**: 22-5.

- Close R.L., Belik M. & Fellenberg S. (2000). Lower Blue Mountains Koala Survey. University of Western Sydney Macarthur and Wild Scenes Ecological Services, Campbelltown.
- Chulow J. (1996). Analysis of a ten year urban koala database (Port Stephens, NSW; 1986-1995). In: *1st Science Conference: Miniposter Booklet*, Cooperative Research Centre for the Conservation and Management of Marsupials, Brisbane.
- Cocciolone R.A. & Timms P. (1992). DNA profiling of Queensland koalas reveals sufficient variability for individual identification and parentage determination. *Wildl. Res.* **19**: 279-87.
- Coley D., Bryant J.P. & Chapin F.S. (1985). Resource availability and plant antiherbivore defense. *Science*. **230**: 895-9.
- Common I.F.B. & Horak M. (1994). Four new species of *Telanepsia* Turner (Lepidoptera: Oecophoridae) with larvae feeding on koala and possum scats. *Invertebr. Taxon.* **8**: 809-28.
- Companion Animals Act (1998). New South Wales Act No. 87, updated 22 January 2001.
- Copley P.B. (1994). Translocations of native vertebrates in South Australia: a review. In: *Reintroduction biology of Australian and New Zealand Fauna*, Ed. M. Serena, pp. 35-42. Surrey Beatty and Sons, Sydney.
- Cork S.J. (1992). Polyphenols and the distribution of arboreal, folivorous marsupials in *Eucalyptus* forests of Australia. In: *Plant Polyphenols*, Eds. R.W. Hemingway and P.E. Laks, pp. 653-63. Plenum Press, New York.
- Cork S.J. (1995). Life in a salad bowl. *Nature Australia*. **Spring**: 32-7.
- Cork S.J. & Braithwaite L.W. (1996). Resource availability, eucalypt chemical defences, and habitat quality for leaf-eating marsupials. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 9-16. World Koala Research Inc. Brisbane.
- Cork S.J. & Foley W.J. (1991). Digestive and metabolic strategies of arboreal mammalian folivores in relation to chemical defenses in temperate and tropical forests. In: *Plant Defenses Against Mammalian Herbivory*, Eds. R.T. Palo and C.T. Robbins, pp. 133-66. CRC Press, Boca Raton, Florida.
- Cork S.J. & Pahl L. (1984). The possible influence of nutritional factors on diet and habitat selection by the ringtail possum (*Pseudocheirus peregrinus*). In: *Possums and Gliders*, Eds. A. Smith and I. Hume, pp. 269-76. Australian Mammal Society, Sydney.
- Cork S.J. & Sanson G.D. (1990). Digestion and nutrition in the koala: a review. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 129-44. Surrey Beatty and Sons, Chipping Norton.
- Cork S.J., Margules C.R. & Braithwaite L.W. (1988). A survey of koalas and their habitat near Wedderburn NSW, suggestions for management and an assessment of the potential effects of a proposed subdivision of four hectare lots. (A report for Campbelltown City Council). CSIRO Div. of Wildlife and Ecology, Canberra.
- Cork S.J., Margules C.R. & Braithwaite L.W. (1990). Implications of koala nutrition and the ecology of other arboreal marsupials in south-eastern New South Wales for the conservation management of Koalas. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 48-58. NSW National Parks and Wildlife Service, Sydney.
- Coulson G. (1997). Male bias in road-kills of macropods. *Wildl. Res.* **24**: 21-5.
- Crow J.F. & Kimura M. (1970). *An Introduction to Population Genetics Theory*. Harper & Row, New York.

- CSIRO (1997). Koala Literature Review: Prepared for State Forests of NSW. Applied Resource Ecology Program: CSIRO Division of Wildlife and Ecology, Canberra.
- Currans B., Ryan T. & Gray I. (1990). Initial investigations of koala distribution in the Upper Nepean Catchment area. (Water Board, Sydney). In: *Environmental Science Studies in Ecology*, Eds. R. Whelan and A. Davis, pp. 1-29. Biology Department, University of Wollongong, Wollongong.
- Curtin A. & Lunney D. (1995a). A comparison of community-based survey and field-based survey for koalas in a large reserve system on the outskirts of Sydney, New South Wales. In: *Proceedings on a conference on the status of the koala in 1995*, pp. 186-8. Australian Koala Foundation, Brisbane.
- Curtin A. & Lunney D. (1995b). Rare and endangered fauna survey of Yengo National Park and Parr State Recreation Area: The koala *Phascolarctos cinereus*. NSW National Parks and Wildlife, Hurstville.
- Curtin A., Lunney D. & Matthews A. (2002). A survey of a low-density koala population in a major reserve system, near Sydney, New South Wales. *Aust. Mammal*, **23**: 135-44.
- Davies N.B. & Hartley I.R. (1996). Food patchiness, territory overlap and social systems: an experiment with dunnocks *Prunella modularis*. *Journal of Animal Ecology*. **65**: 837-46.
- Degabriele R. (1980). The physiology of the koala. *Scientific American*. **243**: 111-7.
- Degabriele R. (1981). A relative shortage of nitrogenous food in the ecology of the koala (*Phascolarctos cinereus*). *Aust. J. Ecol.* **6**: 139-41.
- Degabriele R. (1989). Wasting disease in the koala, *Phascolarctos cinereus*. *Perspectives in Biology and Medicine*. **32**: 414-8.
- Degabriele R. & Dawson T.J. (1979). Metabolism and heat balance in an arboreal marsupial, the koala (*Phascolarctos cinereus*). *J. Comp. Physiol.* **134**: 293-301.
- Dement W.A. & Mooney H.A. (1974). Seasonal variation in the production of tannins and cyanogenic glucosides in the chaparral shrub, *Heteromeles arbutifolia*. *Oecologia*. **15**: 65-76.
- Dixon K.R. & Chapman J.A. (1980). Harmonic mean measure of animal activity areas. *Ecology*. **61**: 1040-4.
- Dobson S. (1989). Unpublished letter from Sue Dobson, chairperson of the Campbelltown Koala Association, to John Kerin, 8th September 1989.
- Dobson S. (1990). Can you help us save the koalas at Wedderburn? In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, p. 178. NSW National Parks and Wildlife Service, Sydney.
- Downes S.J., Handasyde K.A. & Elgar M.A. (1997). The use of corridors by mammals in fragmented Australian eucalypt forests. *Conservation Biology*. **11**: 718-26.
- Eberhard I.H. (1978). Ecology of the koala, *Phascolarctos cinereus* (Goldfuss) Marsupialia: Phascolarctidae, in Australia. In: *The ecology of arboreal folivores*, Ed. G.G. Montgomery, pp. 315-27. Smithsonian Institution Press, Washington, D.C.
- Eberhard I.H., McNamara J., Pearse R.J. & Southwell I.A. (1975). Ingestion and excretion of *Eucalyptus punctata* D.C. and its essential oil by the koala, *Phascolarctos cinereus* (Goldfuss). *Aust. J. Zool.* **23**: 169-79.
- Ellis B., Close R.L. & Ward S. (1997). Identification of leaf fragments in koala faecal pellets. In: *A conference on the status of the koala in 1997: incorporating the sixth national carer's conference*, pp. 68-72. Australian Koala Foundation, Brisbane.

- Ellis W., Carrick F., Lundgren P., Veary A. & Cohen B. (1999). The use of faecal cuticle examination to determine the dietary composition of koalas. *Australian Zoologist*. **31**: 127-33.
- Ellis W.A.H. & Carrick F.N. (1992). Total body water and estimation of fat in the koala (*Phascolarctos cinereus*). *Aust. Vet. J.* **69**: 229-31.
- Ellis W.A.H., Hale P.T. & Carrick F. (2002). Breeding dynamics of koalas in open woodlands. *Wildl. Res.* **29**: 19-25.
- Ellis W.A.H., Meizer A., Green B., Newgrain K., Hindell M.A. & Carrick F.N. (1995). Seasonal variation in water flux, field metabolic rate and food consumption of free-ranging koalas (*Phascolarctos cinereus*). *Aust. J. Zool.* **43**: 59-68.
- Ellis W.A.H., Sullivan B.J., Lisle A.T. & Carrick F.N. (1998). The spatial and temporal distribution of koala faecal pellets. *Wildl. Res.* **25**: 663-8.
- Emmins J.J., Sofronidis G., Temple-Smith P.D. & Boyd R. (1996). The genetic status of South-eastern Australia's koalas. In: *A conference on the status of the koala in 1996 incorporating the fifth national carers conference*, pp. 19-29. Australian Koala Foundation, Brisbane.
- Everett K.D.E., Bush R.M. & Andersen A.A. (1999). Emended description of the order *Chlamydiales*, proposal of *Parachlamydiaceae* fam. nov. and *Simkaniaceae* fam. nov., each containing one monotypic genus, revised taxonomy of the family *Chlamydiaceae*, including a new genus and five new species, and standards for the identification of organisms. *Int. J. Syst. Bacteriol.* **49**: 415-40.
- Every K.R. (1986). Evaluation of a decline in population of the koala, *Phascolarctos cinereus* (Goldfuss) in Ventnor Reserve, Phillip I., Vic., by means of a triple-count technique. *Aust. Wildl. Res.* **13**: 517-25.
- Faulks J.A. (1990). The ranging behaviour of koalas. Honours Thesis, Southern Cross University.
- Faulks J.A. (1991). A preliminary investigation of the distribution of koalas and their potential habitat in the Tweed Shire, and implications for management. *Australian Zoologist*. **27**: 1-13.
- Fensham R.J. (1992). The management implications of fine fuel dynamics in bushlands surrounding Hobart, Tasmania. *J. Environ. Manage.* **36**: 301-20.
- Finch G. (2000). Critter crossings. *Public Roads*. **March/April 2000**: 35-9.
- Flannery T. (1990). Re-arranging conservation and research priorities: a view from a devil's advocate. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 174-8. NSW National Parks and Wildlife Service, Sydney.
- Foley W.J., Lassak E.V. & Brophy J. (1987). Digestion and absorption of *Eucalyptus* essential oils in greater glider (*Petauroides volans*) and brushtail possum (*Trichosurus vulpecula*). *J. Chem. Ecol.* **13**: 2115-30.
- Forbes G. (1926). *History of Sydney*. William Brooks & Co. Ltd. Sydney.
- Fox M.D. (1988). Understorey changes following fire at Myall Lakes, New South Wales. *Cunninghamia*. **2**: 85-94.
- Frankham R. (1995). Effective population size/adult population size ratios in wildlife: a review. *Gen. Res.* **66**: 95-107.
- Frankham R. (1996). Relationship of genetic variation to population size in wildlife. *Conservation Biology*. **10**: 1500-8.
- Franklin I.R. (1980). Evolutionary change in small populations. In: *Conservation Biology: An Evolutionary-Ecological Perspective*, Eds. M.E. Soulé and B.A. Wilcox, pp. 135-49. Sinauer Associates Inc. Massachusetts.

- Franklin I.R. & Frankham R. (1998). How large must populations be to retain evolutionary potential? *Animal Conservation*. **1**: 69-73.
- Frith H.J. (1973). *Wildlife Conservation*. Angus and Robertson Pty Ltd, Sydney.
- Gale B., Hoeben P. & Timms P. (1995). Genetic analysis of koala populations. In: *Proceedings on a conference on the status of the koala in 1995*, p. 47. Australian Koala Foundation, Brisbane.
- Gall B.C. (1980). Aspects of the ecology of the koala, *Phascolarctos cinereus* (Goldfuss), in Tucki Tucki nature reserve, New South Wales. *Aust. Wildl. Res.* **7**: 167-76.
- Gall B. & Rohan-Jones W. (1978). Koala survey. *Parks and Wildlife*. **2**: 64-7.
- Girjes A.A., Hugall A.F., Timms P. & Lavin M.F. (1988). Two distinct forms of *Chlamydia psittaci* associated with disease and infertility in *Phascolarctos cinereus* (koala). *Infect. Immun.* **56**: 1897-900.
- Glanzig A. (1995). *Native vegetation clearance, habitat loss and biodiversity decline: an overview of recent native vegetation clearance in Australia and its implications for biodiversity*. Biodiversity series, paper 6. Biodiversity Unit, Environment Australia, Canberra.
- Glassick T., Giffard P. & Timms P. (1995). Chlamydial infections in koalas: gene sequencing indicates that two separate chlamydial species are involved, *Chlamydia pecorum* and *Chlamydia pneumoniae*. In: *Proceedings on a conference on the status of the koala in 1995*, pp. 154-62. Australian Koala Foundation, Brisbane.
- Glassick T., Giffard P. & Timms P. (1996). Outer membrane protein 2 gene sequences indicate that *Chlamydia pecorum* and *Chlamydia pneumoniae* cause infections in koalas. *System. Appl. Microbiol.* **19**: 457-64.
- Goldingay R.L. & Kavanagh R.P. (1993). Home-range estimates and habitat of the yellow-bellied glider (*Petaurus australis*) at Waratah Creek, New South Wales. *Wildl. Res.* **20**: 387-404.
- Good R.B. (1981). The role of fire in conservation reserves. In: *Fire and the Australian Biota*, Eds. A.M. Gill, R.H. Groves and I.R. Noble, pp. 529-49. Griffin Press Limited, Australia.
- Gordon G., Brown A.S. & Pulsford T. (1988). A koala (*Phascolarctos cinereus* Goldfuss) population crash during drought and heatwave conditions in south-western Queensland. *Aust. J. Ecol.* **13**: 451-61.
- Gordon G., McGreevy D.G. & Lawrie B.C. (1990a). Koala population turnover and male social organization. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 189-92. Surrey Beatty and Sons, Chipping Norton.
- Gordon G., McGreevy D.G. & Lawrie B.C. (1990b). Koala populations in Queensland: major limiting factors. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 85-95. Surrey Beatty and Sons, Chipping Norton.
- Gould J. (1863). *The Mammals of Australia*. London.
- Graetz R.D., Wilson M.A. & Campbell S.K. (1995). *Landcover disturbance over the Australian continent: a contemporary assessment*. Biodiversity Unit, Environment Australia, Canberra.
- Grey P., Edelmann K. & Dwyer L. (1991). *Tourism in Australia: Challenges and Opportunities*. Longman Cheshire, Melbourne.
- Hansteen T.L., Andreassen H.P. & Ims R.A. (1997). Effects of spatiotemporal scale on autocorrelation and home range estimators. *J. Wildl. Manage.* **61**: 289-90.
- Harris J. (1999a). *A critical review of the techniques employed in field survey for the koala*. Unpublished report, Southern Cross University.

- Harris J. (1999b). A foundation for the development of a koala management plan for the Lismore local government area. Honours Thesis, Southern Cross University.
- Harris S., Cresswell W.J., Forde P.G., Trehwella W.J., Woolford T. & Wray S. (1990). Home-range analysis using radio-tracking data - a review of problems and techniques particularly as applied to the study of mammals. *Mammal Rev.* **20**: 97-123.
- Harrop C.J. & Degabriele R. (1978). Food and water requirements of the koala in captivity. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 45-61. The Zoological Parks Board of N.S.W. Sydney.
- Hasegawa M. (1995). Habitat utilisation by koalas (*Phascolarctos cinereus*) at Point Halloran, Queensland. Masters Thesis, University of Queensland.
- Hasegawa M. & Carrick F.N. (1995). First catch your koala! Use of a trap to capture koalas *Phascolarctos cinereus* for ecological studies. *Australian Zoologist*. **30**: 68-70.
- Hawe P., Degeling D., Hall J. & Brierley A. (1990). *Evaluating health promotion: A health worker's guide*. MacLennan and Petty Pty Ltd. Sydney.
- Hillis W.E. (1966). Variation in polyphenol composition within species of *Eucalyptus* L'Herit. *Phytochemistry*. **5**: 541-56.
- Hindell M.A. (1984). The feeding ecology of the koala, *Phascolarctos cinereus*, in a mixed Eucalyptus forest. Masters Thesis, Monash University.
- Hindell M.A. & Lee A.K. (1987). Habitat use and tree preferences of koalas in a mixed eucalypt forest. *Aust. Wildl. Res.* **14**: 349-60.
- Hindell M.A. & Lee A.K. (1990). Tree preferences of the koala. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 117-21. Surrey Beatty and Sons, Chipping Norton.
- Hindell M.A., Handasyde K.A. & Lee A.K. (1985). Tree species selection by free-ranging koala populations in Victoria. *Aust. Wildl. Res.* **12**: 137-44.
- Hobbs R.J. (1998). Ecologists in public. In: *Ecology for Everyone: Communicating Ecology to the Scientists, the Public and the Politicians*, Eds. R.T. Wills and R.J. Hobbs, pp. 20-5. Surrey Beatty & Sons, Chipping Norton.
- Home E. (1808). An account of some peculiarities in the anatomical structure of the wombat. *Philosophical Transactions of the Royal Society of London*: 308-12.
- Houlden B.A., Costello B.H., Sharkey D., Fowler E.V., Melzer A., Ellis W., Carrick F., Baverstock P.R. & Elphinstone M.S. (1999). Phylogeographic differentiation in the mitochondrial control region in the koala, *Phascolarctos cinereus* (Goldfuss 1817). *Molecular Ecology*. **8**: 999-1011.
- Houlden B.A., Greville W.D. & Sherwin W.B. (1995). Genetic assistance with wild and captive koala management. In: *Proceedings on a conference on the status of the koala in 1995*, pp. 43-6. Australian Koala Foundation, Brisbane.
- Hubbs A.H. & Boonstra R. (1998). Effects of food and predators on the home-range sizes of Arctic ground squirrels (*Spermophilus parryii*). *Canadian Journal of Zoology*. **76**: 592-6.
- Hugo G. (1992). *Atlas of the Australian People, New South Wales: 1986 Census*. Australian Government Publishing Service, Canberra.
- Hulbert I.A.R. & French J. (2001). The accuracy of GPS for wildlife telemetry and habitat mapping. *J. App. Ecol.* **38**: 869-78.

- Hull G. (1985). The utilization of residential areas by the koala, *Phascolarctos cinereus* Goldfuss, in Ballarat, Victoria. 3rd year Thesis, University of Ballarat.
- Hume I.D. (1990). Biological basis for the vulnerability of koalas to habitat fragmentation. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 32-6. NSW National Parks and Wildlife Service, Sydney.
- Hume I.D. (1993). Artificial diets for koalas. In: *Proceedings from the conference on the status of the koala in 1993*, pp. 91-4. Australian Koala Foundation, Brisbane.
- Hume I.D. (1995). The mystery of koala food choice. In: *Proceedings on a conference on the status of the koala in 1995*, pp. 55-64. Australian Koala Foundation, Brisbane.
- Hume I.D. (1997). *Marsupial Nutrition*. Cambridge University Press, Cambridge.
- Hume I.D. & Esson C. (1993). Nutrients, antinutrients and leaf selection by captive koalas (*Phascolarctos cinereus*). *Aust. J. Zool.* **41**: 379-92.
- Hundloe T. & Hamilton C. (1997). *Koalas and Tourism: An Economic Evaluation*. Australian Koala Foundation, Brisbane.
- Jackson M., Giffard P. & Timms P. (1997). Outer membrane protein A gene sequencing demonstrates the polyphyletic nature of koala *Chlamydia pecorum* isolates. *System. Appl. Microbiol.* **20**: 187-200.
- Jurskis V. & Potter M. (1997). Koala surveys, ecology and conservation at Eden. State Forests of New South Wales, Sydney.
- Kaufmann K.W. (1981). Fitting and using growth curves. *Oecologia.* **49**: 293-9.
- Kavanagh R.P. & Lambert M.J. (1990). Food selection by the greater glider, *Petauroides volans*: is foliar nitrogen a determinant of habitat quality? *Aust. Wildl. Res.* **17**: 285-99.
- Keith D. (1994). Floristics, structure and diversity of natural vegetation in the O'Hares Creek catchment, south of Sydney. *Cunninghamia.* **3**: 543-95.
- Kenward R.E. & Hodder K.H. (1996). *Ranges V: an analysis system for biological location data*. Institute of Terrestrial Ecology, Dorset.
- Kohen J. (1995). *Aboriginal Environmental Impacts*. University of NSW Press, Sydney.
- Koosmen A., Carey A. & Roe R. (1997). 554 koalas tell a story. In: *A conference on the status of the koala in 1997: incorporating the sixth national carer's conference*, pp. 75-96. Australian Koala Foundation, Brisbane.
- Krockenberger A.K. (1993a). Energetics and nutrition during lactation in the koala, *Phascolarctos cinereus*: how does an arboreal folivore meet its energy requirements for reproduction? Ph.D. Thesis, University of Sydney.
- Krockenberger A. (1993b). Requirements of reproduction in koalas: use of habitat. In: *Proceedings from the conference on the status of the koala in 1993*, p. 40. Australian Koala Foundation, Brisbane.
- Labisky R.F. & Fritzen D.E. (1998). Spatial mobility of breeding female white-tailed deer in a low-density population. *J. Wildl. Manage.* **62**: 1329-34.
- Lake P.S. (2001). On the maturing of restoration: Linking ecological research and restoration. *Ecological Management & Restoration.* **2**: 110-5.
- Lande R. (1993). Risks of population extinction from demographic and environmental stochasticity and random catastrophes. *Am. Nat.* **142**: 911-27.

- Lande R. (1995). Mutation and Conservation. *Conservation Biology*. **9**: 782-91.
- Landsberg J. (1987). Feeding preferences of common brushtail possums, *Trichosurus vulpecula*, on seedlings of a woodland habitat. *Aust. Wildl. Res.* **14**: 361-9.
- Landsberg J. (1990a). Dieback of rural eucalypts: does insect herbivory relate to dietary quality of tree foliage? *Aust. J. Ecol.* **15**: 73-87.
- Landsberg J. (1990b). Dieback of rural eucalypts: the effect of stress on the nutritional quality of foliage. *Aust. J. Ecol.* **15**: 97-107.
- Larkin R.P. & Halkin D. (1994). A review of software packages for estimating animal home ranges. *Wildl. Soc. Bull.* **22**: 274-87.
- Lawler I.R., Foley W.J., Eschler B.M., Pass D.M. & Handasyde K. (1998). Intraspecific variation in *Eucalyptus* secondary metabolites determines food intake by folivorous marsupials. *Oecologia*. **116**: 160-9.
- Lawson E.J.G. & Rodgers A.R. (1997). Differences in home-range size computed in commonly used software programs. *Wildl. Soc. Bull.* **25**: 721-9.
- Le Page C. (1993). Koala preservation society of NSW Inc. report. In: *Proceedings from the conference on the status of the koala in 1993*, pp. 73-4. Australian Koala Foundation, Brisbane.
- Lee A. & Martin R. (1988). *The koala. A natural history*. NSW University Press, Sydney.
- Lee A.K. & Cockburn A. (1985). *Evolutionary ecology of marsupials*. Cambridge University Press, Cambridge.
- Lidicker W.Z. & Ostfeld R.S. (1991). Extra-large body size in California voles: causes and fitness consequences. *Oikos*. **61**: 108-21.
- Liston C. (1988). *Campbelltown: The Bicentennial History*. Allen and Unwin, North Sydney.
- Lundie-Jenkins G. (2000). *Proserpine Rock-wallaby Recovery Program: Project Review*. Unpublished report produced for Queensland Parks and Wildlife Service.
- Lunney D., Curtin A. & Matthews A. (1995). The status of koalas in NSW. In: *Proceedings on a conference on the status of the koala in 1995*, pp. 73-8. Australian Koala Foundation, Brisbane.
- Lunney D., Esson C., Moon C., Ellis M. & Matthews A. (1997). A community-based survey of the koala, *Phascolarctos cinereus*, in the Eden region of south-eastern New South Wales. *Wildl. Res.* **24**: 111-28.
- Lunney D., Moon C. & Matthews A. (1996). A 1990 survey of the koala *Phascolarctos cinereus* population at Iluka in northern New South Wales. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 102-22. World Koala Research Inc. Brisbane.
- Lunney D., O'Neill L., Matthews A. & Coburn D. (2000). Contribution of community knowledge of vertebrate fauna to management and planning: A case study on the Iluka Peninsula, north coast New South Wales. *Ecological Management & Restoration*. **1**: 175-84.
- Lunney D., Phillips S., Callaghan J. & Coburn D. (1998). Determining the distribution of koala habitat across a shire as a basis for conservation: a case study from Port Stephens, New South Wales. *Pac. Cons. Biol.* **4**: 186-96.
- Majer J.D., Recher H.F. & Ganeshanandam S. (1992). Variation in foliar nutrients in *Eucalyptus* trees in eastern and Western Australia. *Aust. J. Ecol.* **17**: 383-93.

- Martin R. (1989). Draft management plan for the conservation of the koala (*Phascolarctos cinereus*) in Victoria. Technical Report Series No. 99. Arthur Rylah Institute for Environmental Research, Melbourne.
- Martin R. & Handasyde K.A. (1990a). Population dynamics of the koala (*Phascolarctos cinereus*) in south-eastern Australia. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 75-84. Surrey Beatty and Sons, Chipping Norton.
- Martin R. & Handasyde K.A. (1990b). Translocations and the re-establishment of koala populations in Victoria (1944-1988): the implications for NSW. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 58-67. NSW National Parks and Wildlife Research Service, Sydney.
- Martin R. & Handasyde K. (1999). *The koala: natural history, conservation and management*. NSW University Press, Sydney.
- Martin R.W. (1981). Age-specific fertility in three populations of the koala, *Phascolarctos cinereus* Goldfuss, in Victoria. *Aust. Wildl. Res.* **8**: 275-83.
- Martin R.W. (1983). Food preference, defoliation and population decline in a population of the koala, *Phascolarctos cinereus*, at Walkerville, Victoria. M.Sc. thesis, Monash University, Melbourne.
- Martin R.W. (1985a). Overbrowsing, and decline of a population of the koala, *Phascolarctos cinereus*, in Victoria II. Population condition. *Aust. Wildl. Res.* **12**: 367-75.
- Martin R.W. (1985b). Overbrowsing, and decline of a population of the koala, *Phascolarctos cinereus*, in Victoria III. Population dynamics. *Aust. Wildl. Res.* **12**: 377-85.
- Martin R.W. & Lee A. (1984). The koala, *Phascolarctos cinereus*, the largest marsupial folivore. In: *Possums and Gliders*, Eds. A. Smith and I. Hume, pp. 463-7. Australian Mammal Society, Sydney.
- McArthur C. & Sanson G.D. (1993). Nutritional effects and costs of a tannin in two marsupial folivores. *Functional Ecology*. **7**: 697-703.
- McGill J. (1999). *Campbelltown: A Modern History 1960 - 1999*. Campbelltown and Airs Historical Society, Campbelltown.
- Melzer A. (1994). Aspects of the ecology of the koala, *Phascolarctos cinereus* (Goldfuss, 1817), in the sub-humid woodlands of central Queensland. Ph.D. Thesis, University Of Queensland.
- Melzer A. & Lamb D. (1994). Low density populations of the koala (*Phascolarctos cinereus*) in central Queensland. *Proc. R. Soc. Qld.* **104**: 89-93.
- Melzer A., Carrick F., Menkhorst P., Lunney D. & John B.S. (2000). Overview, critical assessment, and conservation implications of koala distribution and abundance. *Conservation Biology*. **14**: 619-28.
- Mitchell P. (1990a). Social behaviour and communication of koalas. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 151-70. Surrey Beatty and Sons, Chipping Norton.
- Mitchell P. (1990b). The home ranges and social activity of koalas - a quantitative analysis. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 171-87. Surrey Beatty and Sons, Chipping Norton.
- Mitchell P. & Martin R. (1990). The structure and dynamics of koala population - French Island in perspective. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 97-108. Surrey Beatty and Sons, Chipping Norton.
- Mitchell P.J., Bilney R. & Martin R.W. (1988). Population structure and reproductive status of koalas on Raymond Island, Victoria. *Aust. Wildl. Res.* **15**: 511-4.

- Montgomery M.E., Costello B.H., Ihle S., Ward S., Close R., & Houlden B.A. (in prep.). Conservation Genetics of the Koala in New South Wales.
- Montgomery M., Houlden B., & Taggart D. (2000). The incidence and consequences of testicular aplasia in koala populations in eastern Australia. In: *Australian Mammal Society 2000 conference: program and abstracts*. Australian Mammal Society.
- Moon C. (1990). Koala corridors: a case study from Lismore. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 87-93. NSW National Parks and Wildlife Service, Sydney.
- Moon C. (1995). W.I.R.E.S. koalas tell a story. In: *Proceedings on a conference on the status of the koala in 1995*, pp. 49-54. Australian Koala Foundation, Brisbane.
- Nagy K.A. & Martin R.W. (1985). Field metabolic rate, water flux, food consumption and time budget for koalas, *Phascolarctos cinereus* (Marsupialia: Phascolarctidae) in Victoria. *Aust. J. Zool.* **33**: 655-65.
- Natrass A.E.O. & Fiedler K.B. (1996). Koala rescue - the perception and the reality. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 129-36. World Koala Research Inc. Brisbane.
- New T.R. (2000). *Conservation Biology: An Introduction for Southern Australia*. Oxford University Press, Melbourne.
- NSW National Parks and Wildlife (2000). *Biodiversity study for the Georges River Catchment. Volume 1: Native vegetation*. NSW National Parks and Wildlife, Sydney.
- Obendorf D.L. & Handasyde K.A. (1990). Pathology of chlamydial infection in the reproductive tract of the female koala (*Phascolarctos cinereus*). In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 255-9. Surrey Beatty and Sons, Chipping Norton.
- Osawa R., Mizuno S., Takashima I. & Hashimoto N. (1996). Complement fixation tests to detect anti chlamydial antibody in koalas (*Phascolarctos cinereus*), using different antigens. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 53-5. World Koala Research Inc. Brisbane.
- Pahl L. & Staines D.L. (1993). Final report joint regional koala habitat project.
- Pahl L.I. & Hume I.D. (1990). Preferences for *Eucalyptus* species of the New England Tablelands and initial development of an artificial diet for koalas. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 123-8. Surrey Beatty and Sons, Chipping Norton.
- Pahl L., Wylie F.R. & Fisher R. (1990). Koala population decline associated with loss of habitat and suggested remedial strategies. In: *Koala summit. Managing Koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 39-48. NSW National Parks and Wildlife Service, Sydney.
- Patterson R. (1996). The distribution of koalas in Queensland - 1986 to 1989. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 75-81. World Koala Research Inc. Brisbane.
- Pearse R.J. & Eberhard I.H. (1978). Conservation of koalas. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 213-22. Zoological Parks Board of NSW, Sydney.
- Pettersson B., Andersson A., Leitner T., Olsvik O., Uhlen M., Storey C. & Black C.M. (1997). Evolutionary relationships among members of the genus *Chlamydia* based on 16S ribosomal DNA analysis. *J. Bacteriol.* **179**: 4195-205.
- Phillips B. (1990). *Koalas: The little Australians we'd all hate to lose*. Aust. Govt. Print. Serv., Canberra.

- Phillips S. (1995). Planning for the effective conservation of koalas - a case study from north-eastern New South Wales. In: *Proceedings on a conference on the status of the koala in 1995*, p. 164. Australian Koala Foundation, Brisbane.
- Phillips S. (1999). Report on fauna measures associated with the Yelgun to Chinderah upgrade. Unpublished report prepared for Maunsell McIntyre Pty Ltd.
- Phillips S.S. (2000). Population trends and the koala conservation debate. *Conservation Biology*. **14**: 650-9.
- Phillips S. & Callaghan J. (1996). Koala Habitat Atlas Project No. 5: Campbelltown Local Government Area. Draft. Australian Koala Foundation, Brisbane.
- Phillips S. & Callaghan J. (2000). Tree species preferences of koalas (*Phascolarctos cinereus*) in the Campbelltown area south-west of Sydney, New South Wales. *Wildl. Res.* **27**: 509-16.
- Phillips S., Callaghan J., Parnaby H. & Fitzgerald M. (1996). Wedderburn Fauna Planning Study. Australian Koala Foundation, Brisbane.
- Phillips S., Callaghan J. & Staines D.L. (1996). The koala habitat atlas - field survey guidelines, data analysis and habitat modelling details. In: *A conference on the status of the koala in 1996 incorporating the fifth national carers conference*, pp. 63-7. Australian Koala Foundation, Brisbane.
- Prevett P.T. (1991). Movement paths of koalas in the urban-rural fringes of Ballarat, Victoria: implications for management. In: *Nature Conservation 2: the role of corridors*, Eds. D.A. Saunders and R.J. Hobbs, pp. 259-72. Surrey Beatty & Sons, Chipping Norton.
- Prevett P. (1993). Koala "blackspots" on major highways. In: *Proceedings from the conference on the status of the koala in 1993*, pp. 88-91. Australian Koala Foundation, Brisbane.
- Pudjiatmoko H.F., Ochiai Y., Yamaguchi T. & Hiraj K. (1997). Phylogenetic analysis of the genus *Chlamydia* based on 16S rRNA gene sequences. *Int. J. Syst. Bacteriol.* **47**: 425-31.
- Ramsay S. (1999). The ecology and dispersal patterns of juvenile koalas, *Phascolarctos cinereus*, in fragmented habitat. Ph.D. Thesis, University of Sydney.
- Ramsay S., Hume I.D. & Cork S.J. (1997). Dispersal patterns of juvenile koalas. In: *A conference on the status of the koala in 1997: incorporating the sixth national carer's conference*, pp. 100-5. Australian Koala Foundation, Brisbane.
- Recher H.F. (1998). Public and political: the challenge for ecologists. In: *Ecology for Everyone: Communicating Ecology to the Scientists, the Public and the Politicians*, Eds. R.T. Wills and R.J. Hobbs, pp. 9-15. Surrey Beatty & Sons, Chipping Norton.
- Recher H.F. & Christensen P.E. (1981). Fire and the evolution of the Australian biota. In: *Ecological biogeography of Australia*, Ed. A. Keast, pp. 137-63. Junk, The Hague.
- Reed P.C. & Lunney D. (1990). Habitat loss: the key problem for the long term survival of koalas in New South Wales. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 9-32. NSW National Parks and Wildlife Service, Sydney.
- Reed P.C., Lunney D. & Walker P. (1990). A 1986-87 survey of the koala *Phascolarctos cinereus* (Goldfuss) in New South Wales and an ecological interpretation of its distribution. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 55-74. Surrey Beatty and Sons, Chipping Norton.
- Ridley D. (1993). Koala management in logging areas - an optional managers perspective with reference to Yurammie west forest, Eden district. In: *Proceedings from the conference on the status of the koala in 1993*, pp. 55-73. Australian Koala Foundation, Brisbane.

- Robbins M. & Russell E. (1978). Observations on movements and feeding activity of the koala in a semi-natural situation. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 29-41. Zoological Parks Board of NSW, Sydney.
- Robertson P.A., Aebischer N.J., Kenward R.E., Hanski I.K. & Williams N.P. (1998). Simulation and jack-knifing assessment of home-range indices based on underlying trajectories. *J. App. Ecol.* **35**: 928-40.
- Robinson A.C. (1978). The koala in South Australia. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 132-43. Zoological Parks Board of NSW, Sydney.
- Robinson A.C., Spark R. & Halstead C. (1989). The distribution and management of the koala (*Phascolarctos cinereus*) in South Australia. *South Australian Naturalist.* **64**: 4-24.
- Robinson N.H. (1985). Mammals of the metropolitan water, sewerage and drainage board catchments. University of Wollongong, Department of Biology, Wollongong.
- Sarre A. (1999). Caught in the crossfire. *Ecos.* : 9-14.
- Schoener T.W. (1981). An empirically based estimate of home range. *Theoretical Population Biology.* **20**: 281-325.
- Shaffer M.L. (1981). Minimum population sizes for species conservation. *BioScience.* **31**: 131-4.
- Sharpe L.L. (1980). Behaviour of the koala, *Phascolarctos cinereus* (Goldfuss). Honours Thesis, Monash University.
- Sheppard J. (1990). The Wedderburn koala colony. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 70-3. NSW National Parks and Wildlife Service, Sydney.
- Sherwin W.B. & Murray N.D. (1990). Population and conservation genetics of marsupials. *Aust. J. Zool.* **37**: 161-80.
- Sherwin W.B., Timms P., Wilcken J. & Houlden B.A. (2000). Analysis and conservation implications of koala genetics. *Conservation Biology.* **14**: 639-49.
- Simberloff D. (1988). The contribution of population and community biology to conservation science. *Ann. Rev. Ecol. Sys.* **19**: 473-511.
- Sluiter A.F. (2000). Determination of preferential consumption of tree species by the koala, *Phascolarctos cinereus*, using faecal pellet analysis. Honours Thesis, University of Western Sydney Macarthur.
- Sluiter A.F., Close R.L. & Ward S.J. (2002). Koala feeding and roosting in the Campbelltown area of New South Wales. *Aust. Mammal.* **23**: 173-5. (see Appendix 3)
- Smith M. (1979). Behaviour of the koala, *Phascolarctos cinereus* Goldfuss, in captivity I. Non-social behaviour. *Aust. Wildl. Res.* **6**: 117-29.
- Smith M. (1980a). Behaviour of the koala, *Phascolarctos cinereus* Goldfuss, in captivity III. Vocalizations. *Aust. Wildl. Res.* **7**: 13-34.
- Smith M. (1980b). Behaviour of the koala, *Phascolarctos cinereus* Goldfuss, in captivity IV. Scent-marking. *Aust. Wildl. Res.* **7**: 35-40.
- Smith M. (1980c). Behaviour of the koala, *Phascolarctos cinereus* Goldfuss, in captivity V. Sexual behaviour. *Aust. Wildl. Res.* **7**: 41-51.

- Smith M. (1980d). Behaviour of the koala, *Phascolarctos cinereus* Goldfuss, in captivity VI. Aggression. *Aust. Wildl. Res.* 7: 177-90.
- Smith P. & Smith J. (1990). Decline of the urban koala (*Phascolarctos cinereus*) population in Warringah Shire, Sydney. *Australian Zoologist.* 26: 109-29.
- Soulé M.E. (1980). Thresholds for survival: maintaining fitness and evolutionary potential. In: *Conservation Biology: An Evolutionary-Ecological Perspective*, Eds. M.E. Soulé and B.A. Wilcox, pp. 151-69. Sinauer Associates Inc. Massachusetts.
- Soulé M.E. & Gilpin M.E. (1991). The theory of wildlife corridor capability. In: *Nature Conservation 2: The role of corridors*, Eds. D.A. Saunders and R.J. Hobbs, Surrey Beatty & Sons, Chipping Norton.
- Spencer A.J. & Canfield P.J. (1993). Haematological characterisation of heavy tick infestation in koalas (*Phascolarctos cinereus*). *Comp. Haematol. Int.* 3: 225-9.
- St John B. (1996). Perspectives on koala management in South Australia. In: *A conference on the status of the koala in 1996 incorporating the fifth national carers conference*, pp. 75-86. Australian Koala Foundation, Brisbane.
- Starr J. (1990). Management of koalas in an urban environment. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 319-21. Surrey Beatty and Sons PTY Limited, Sydney.
- Starr J., Moran E. & Whitehouse D. (1990). The Port Macquarie experience. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 67-8. NSW National Parks and Wildlife Service, Sydney.
- Stone B.F. & Carrick F.N. (1996). Some effects of ticks on koalas, especially tick paralysis. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 65-9. World Koala Research Inc. Brisbane.
- Stone C. & Bacon P.E. (1994). Relationships among moisture stress, insect herbivory, foliar cineole content and the growth of river red gum *Eucalyptus camaldulensis*. *J. App. Ecol.* 31: 604-12.
- Strahan R. & Martin R. (1982). The koala: little fact, much emotion. In: *Species at risk: research in Australia*, Eds. R.H. Groves and W.D.L. Ride, pp. 147-55. Australian Academy of Science, Canberra.
- Summerville K. (1990). Koalas in the Tweed shire. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 74-6. NSW National Parks and Wildlife Service, Sydney.
- Swihart R.K. & Slade N.A. (1985a). Influence of sampling interval on estimates of home-range size. *J. Wildl. Manage.* 49: 1019-25.
- Swihart R.K. & Slade N.A. (1985b). Testing for independence of observations in animal movements. *Ecology.* 66: 1176-84.
- Takami K., Yoshida M., Yamamoto Y., Harada M. & Furuyama J. (1998). Genetic variation of mitochondrial cytochrome *b* genes among the subspecies of koala, *Phascolarctos cinereus*. *J. Vet. Med. Sci.* 60: 1161-3.
- Talbot J. (1993). *Kruwinnus & Another vs Campbelltown City Council*. Case number 10585 of 1992, Land and Environment Court of New South Wales.
- Taylor A. (2000). Habitat utilisation and dietary preferences of koalas within the East Lismore and Goonellabah urban areas. Honours Thesis, Southern Cross University.
- Taylor A.C., Graves J.A.M., Murray N.D. & Sherwin W.B. (1991). Conservation genetics of the koala (*Phascolarctos cinereus*) II. Limited variability in minisatellite DNA sequences. *Biochemical Genetics.* 29: 355-64.

- Thompson V.D. & Fadem B.H. (1989). Scent marking in the koala (*Phascolarctos cinereus*): related behaviour and sex differences. *Zool. Garten N. E.* **59**: 157-65.
- Threatened Species Conservation Act (1995). New South Wales Act No 101, updated 13 July 2001. *Government Gazette*.
- Tilley D. & Uebel K. (1990). Observations of koala populations within the Sydney Water Board's Upper Nepean Region catchment area. In: *Koala summit. Managing koalas in New South Wales*, Eds. D. Lunney, C.A. Urquhart and P. Reed, pp. 81-4. NSW National Parks and Wildlife Service, Sydney.
- Timms P., Kato J., Maugeri M. & White N. (1993). DNA fingerprint analysis of a free-range koala population. *Biochemical Genetics*. **31**: 363-73.
- Tufto J., Anderson R. & Linnell J. (1996). Habitat use and ecological correlates of home range size in a small cervid: the roe deer. *Journal of Animal Ecology*. **65**: 715-24.
- Ullrey D.E., Robinson P.T. & Whetter P.A. (1981a). Composition of preferred and rejected Eucalyptus browse offered to captive koalas, *Phascolarctos cinereus* (Marsupialia). *Aust. J. Zool.* **29**: 847-52.
- Ullrey D.E., Robinson P.T. & Whetter P.A. (1981b). Eucalyptus digestibility and digestible energy requirements of adult male koalas, *Phascolarctos cinereus* (Marsupialia). *Aust. J. Zool.* **29**: 836-46.
- Ward S. (1994). Small mammals and wildfire: habitat use and condition. Honours Thesis, University of Wollongong.
- Ward S.J. & Close R.L. (1998). Community assistance with koala *Phascolarctos cinereus* sightings from a low density population in the south-west Sydney region. In: *Ecology for Everyone: Communicating Ecology to the Scientists, the Public and the Politicians*, Eds. R.T. Wills and R.J. Hobbs, pp. 97-102. Surrey Beatty & Sons, Chipping Norton. (see Appendix 2).
- Ward S. & Close R.L. (1999). *Koala Tales: koalas in southern Sydney*. Video. University of Western Sydney Macarthur, Sydney.
- Ward S.J. & Close R.L. (2000). Postal survey of Southern Sydney community in October / November 1999 for koala and other wildlife sightings: Report on koala sightings and conservation attitudes. Unpublished report to the Georges and Hacking River Catchment Management Committees. University of Western Sydney, Campbelltown. (see Appendix 1).
- Wardrop S., Fowler A., O'Callaghan P.G., Giffard P. & Timms P. (1999). Characterization of the koala biovar of *Chlamydia pneumoniae* at four gene loci -ompAVD4, ompB, 16S rRNA, groESL spacer region. *System. Appl. Microbiol.* **22**: 22-7.
- Ware R. (1993). Criteria for Wildlife Corridors: a case study of Bargo River gorge in the Nattai/Upper Nepean region. Honours Thesis, University of Western Sydney Macarthur.
- Whelan R.J. (1995). *The Ecology of Fire*. Cambridge University Press, Cambridge.
- White G.C. & Garrott R.A. (1990). *Analysis of wildlife radio-tracking data*. Academic Press, London.
- White N.A. (1994). Habitat utilisation and population dynamics of the koala (*Phascolarctos cinereus*) in the Bremner River catchment, south-east Queensland. Ph.D. Thesis, University of Queensland.
- White N.A. (1999). Ecology of the koala (*Phascolarctos cinereus*) in rural south-east Queensland, Australia. *Wildl. Res.* **26**: 731-44.
- White N.A. & Kunst N.D. (1988). A report on ecological research on population and habitat features of the koala in the key sites in south eastern Queensland and recommendations for management. Queensland National Parks and Wildlife Service.

White N.A. & Kunst N.D. (1990). Aspects of the koala ecology of the koala in southeastern Queensland. In: *Biology of the Koala*, Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson, pp. 109-16. Surrey Beatty and Sons, Chipping Norton.

Wiggers E.P. & Beckerman S.F. (1993). Use of thermal infrared sensing to survey white-tailed deer populations. *Wildl. Soc. Bull.* **21**: 263-8.

Williams D. (1983). Basic fire behaviour. What is fire? *Trees and Victoria's Resources.* **25**: 6-7.

Wood A.D. (1978). The diseases of the captive koala. In: *The Koala: Proceedings of the Taronga symposium on koala biology, management and medicine, Sydney 11th and 12th March 1976*, Ed. T.J. Bergin, pp. 158-65. The Zoological Parks Board of N.S.W. Sydney.

Wood M.M. & Timms P. (1992). Comparison of nine antigen detection kits for diagnosis of urogenital infections due to *Chlamydia psittaci* in koalas. *Journal of Clinical Microbiology.* **30**: 3200-5.

Worthington Wilmer J.M., Melzer A., Carrick F. & Moritz C. (1993). Low genetic diversity and inbreeding depression in Queensland koalas. *Wildl. Res.* **20**: 177-88.

Young W.G., Lam C.W., Douglas W.H. & Pintado M.R. (1996). Some approaches to koala age estimation from teeth. In: *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*, Ed. G. Gordon, pp. 29-36. World Koala Research Inc. Brisbane.

Appendix 1.

Report on the Sutherland Postal Survey.

Postal survey of Southern Sydney community in October / November 1999 for koala and other wildlife sightings: report on koala sightings and conservation attitudes.

Report to the Georges and Hacking River Catchment Management Committees, March 2000.

Steven Ward and Robert Close*.

Department of Biological Sciences, Faculty of Informatics, Science and Technology, University of Western Sydney Macarthur, PO Box 555 Campbelltown, 2560.

* E-mail: r.close@uws.edu.au, Ph: (02) 4620 3203, Fax: (02) 4620 3025.

EXECUTIVE SUMMARY

In October and November of 1999 a postal survey was conducted in the Sutherland, Liverpool and Illawarra shires, concentrating on the Sutherland region. 2676 responses were received from 25 925 surveys which were distributed, a response rate of 10.3%.

Few respondents (5.9%) reported sighting a koala, but many new sightings, including 10 reports of koalas with young, were obtained. Previously, breeding females have only been reported from the Campbelltown area. There was insufficient evidence to support the conclusion that breeding groups of koalas exist to the north or east of the Holsworthy Army Range, but the possibility remains that breeding groups may exist and remain unknown to the wider community at Darkes Forest, Heathcote NP, and Helensburgh. Some evidence suggests that low density breeding group(s) of koalas may have existed along the Woronora River in the Engadine, Barden Ridge and Woronora suburbs, prior to housing development. However, most koala sightings appear to be of dispersing male koalas, probably from the known breeding groups at Campbelltown.

From a management perspective we suggest that the most important issue is to maintain and / or construct new corridors to the Royal National Park and remnant bushland along the Woronora River and its tributaries. Measures to minimise koala deaths along Heathcote Road, the Princes Highway and Sydney to Wollongong rail line would also be advantageous.

INTRODUCTION

Background

From community reports of koala sightings previously collected by the University of Western Sydney Macarthur (UWSM) it was known that koalas were present in the Sutherland, southwestern Liverpool, and northern Illawarra shire areas. It was also known that koalas occurred at low population densities, and that breeding animals existed to the east of the Campbelltown Local Government Area, along the Georges River or its tributaries in the suburbs of Kentlyn and Wedderburn.

It was not clear, however, whether or not koalas were breeding in the Sutherland, Liverpool or Illawarra shires. Because virtually all roadkills, captures, or sightings, where the sex of the animal could be determined, were of male koalas it was thought most probable that koalas were not breeding in the Sutherland, Liverpool or Illawarra

shires and that the sighted animals were dispersing, and predominantly male. However, due to the koalas' cryptic nature it was considered possible that as yet unknown breeding aggregations could exist within these shires. In fact, the presence of a breeding colony of koalas at Wedderburn was not widely known 1986 (Brett 1989, Cork *et al.* 1988, Close 1993, Sheppard 1990).

In mid-1995, Steven Ward commenced a PhD investigating the life strategies of koalas in areas of Sydney Sandstone. A local Fairfax paper, the *Macarthur Advertiser*, and UWSM provided funds for a scholarship and the Australian Koala Foundation provided \$5000 running costs per year for 3 years.

Several techniques were considered or trialed for the investigation of the koala colony. The primary technique used to locate koalas was the collation of community reports of koala sightings (hence the knowledge about koala sightings in the Sutherland shire). Community reports also permitted some opportunistic captures of koalas and subsequent data collection. Some publicity was obtained in the Sutherland region, resulting in a number of reports of koala sightings and some captures (Ward and Close, 1998). However, the level of publicity obtained in the Sutherland, Liverpool and Illawarra shires was much less than that at Campbelltown. The paucity of reports, therefore, in the former shires, may have been due to that lack of publicity rather than a low koala density.

The main objectives of the postal survey were to:

1. Obtain information about koala sightings from the community.
2. Determine if koalas were breeding in the Sutherland, Liverpool or Illawarra shires.
3. Obtain information on sightings of other animal species, both native animals and feral pests.

Concerns and Problems associated with Community Reports

The use of community reports is not without problems and bias. There are two major concerns. Firstly, the public must be informed that sightings should be reported and who to contact. Secondly, the areas surveyed are highly biased towards those where people spend most of their time ie. the human / bush interface.

Other problems exist, such as misidentification of animals, misreporting (eg. hoaxes) and unwillingness to pass on information. The latter is usually because of concerns as to how the information will be used. Misidentification and misreporting of koalas occurs infrequently. Descriptions and sketches of the other animal species were provided in the survey to minimise misidentification of these species.

In southern Sydney the second problem is extremely difficult to overcome due to the restricted access to the large area of the Holsworthy Military Range. Since few members of the public venture into the Army Reserve, the distribution of koalas within the army range is still poorly understood, although studies have documented some sightings (Axis Environmental and AMBS Consulting 1996). Information and co-operation from the Australian Army has also been of assistance.

The problem of communication with the community was addressed through obtaining as much publicity in local media as possible. In particular a weekly column in the *Macarthur Advertiser* which provided a number to report koala sightings has been

particularly useful. In addition there have been talks to schools and community groups, displays at fairs and fetes and publicity in other media. Because most publicity was obtained in the Campbelltown shire region it is not surprising that most reports of koala sightings have been from this area. Shires in the southern Sydney area in which there has been a lesser amount of publicity and from which less information have been obtained are: Liverpool, Sutherland, Illawarra, Wollondilly and Wingecarribee. The primary aim of this postal survey was obtain information from residents about koalas, and also other animals, primarily within the Sutherland shire region, but also from the Liverpool and Illawarra shires. As available funds limited the number of households to which surveys could be distributed those surveys closest to bushland areas were selected as being most likely to produce relevant information.

METHODS

Funding of \$2968.20 From the Hacking River Catchment Management Committee (CMC) and \$4982.00 from the Georges River CMC was obtained. After the design of the survey was completed, costs for printing and distribution of the surveys were cheaper than anticipated, so after liaising with the CMC's the total number of postal surveys distributed was increased from 18 150 to 25925. These surveys were hand delivered in October and early November to the following suburbs: Alford's Point, Bangor, Bundeena, Darkes Forest, Engadine, Grays Point, Kirrawee, Heathcote, Helensburgh, Illawong, Lucas Heights, Maianbar, Menai, Otford, Sandy Point, Stanwell Park, Stanwell Tops, Waterfall, Woronora, Woronora Heights and Yarrowarrah (Figure 1). A batch of 8000 surveys was printed and distributed after the first run of 18 000. Some of these surveys arrived after the "due-by" date for respondents to return the surveys.

The survey questions and design were based on a koala postal survey conducted in Port Stephens (Callaghan *et al.* 1994) with modifications (see attachment 1). Publicity was obtained in the *Sutherland Shire Leader* announcing the survey and explaining the reasons for it. Articles were published soon after distribution of the surveys and another approximately two weeks after the requested return date. Copies of these articles have not been obtained by UWS at this stage and so are currently unavailable.

The data provided in the survey responses were entered into a Microsoft Access database. Reported koala sightings were then compared to previous reports of sightings. Where sufficient information was provided (eg. location and date) for some sightings it was possible to pinpoint multiple reports of the same sighting. Where possible those respondents that gave permission to be contacted were telephoned to clarify the details provided in the survey response (this process is yet to be completed as of 8/3/2000). Unfortunately, some respondents indicated sighting a koala at question 3 or 6 but did not provide location(s) or contact details.

Some respondents indicated having never seen a koala at question 3, but also indicated that they had seen a dead koala. These respondents were also contacted where possible. The total number of respondents reporting that they had sighted a koala included both those answering affirmatively to question 3, and those who indicated sighting a dead koala at question 6.

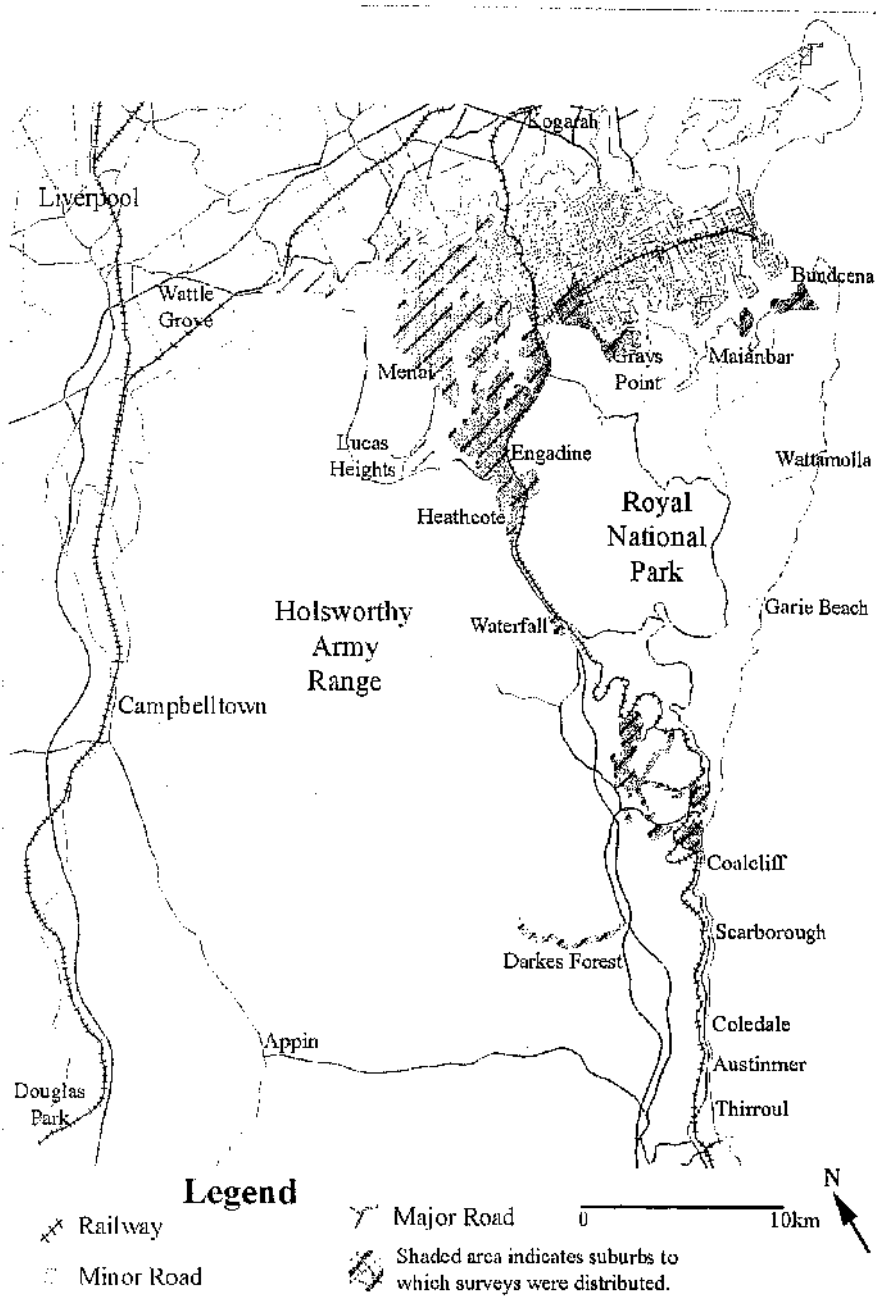


Figure 1. Areas to which 25 925 postal surveys were distributed.

Reports of sightings were placed into two categories: confirmed and unconfirmed. Confirmed sightings were those where the respondent was contacted and a fairly accurate location, and preferably date, was established. Unconfirmed sightings were those where the respondent could not be contacted or where the location was uncertain. Reports of sightings of dead koalas were also placed in the unconfirmed category unless the corpse had been checked to verify that it was a koala. This was because most reports of dead animals were of roadkills and these are very easy to misidentify unless the motorist stops to verify the identity of the roadkill. Confirmed and unconfirmed sightings were then mapped (Fig 2) together with non-survey sightings reported to UWS. Where multiple reports of sightings were identified these were noted, and mapped as only one sighting.

Sightings of koalas with young were also mapped separately (Fig 3) to view these clearly.

For question 9, part 1 to 5, unless the respondent clearly indicated that they supported the proposed action, including blank surveys that were returned, their response was put down as a "no". Thus the support for these possible actions can be considered to be a conservative underestimate of the respondents' viewpoints.

A number of respondents also provided viewpoints that were not solicited, for example the comment "and cats" was relatively common for Q9, part 2 (dog restrictions). A number of extra categories were placed in the database and a positive response entered if the respondent indicated this viewpoint.

RESULTS

a) Response rate and respondent data

2676 returns were received by 1st March 2000, which is a response rate of 10.32%.

Respondents to the survey varied widely in their ages (although 1368 respondents did not answer this optional question), ranging from 10 to 90 years old, with the average being 47.05 years. Many more people supplied information on how long they had lived in southern Sydney, with only 27 respondents not answering this question. The average time lived in southern Sydney was 22.41 years, which is much lower than the average age. 82 years was the longest reported time living in southern Sydney.

b) Koala sightings

158 respondents, or 5.9% reported having sighted a koala, or having seen a dead koala. Of those reporting having sighted a koala, two respondents indicated that these sightings were at Symbio Wildlife Gardens which is based at Helensburgh and where captive koalas are kept.

Many new koala sightings were obtained through the survey (Fig. 2) particularly along Heathcote Road, which runs from Engadine looping around towards Liverpool. These sightings include many roadkills. If the unconfirmed roadkill sightings are ignored, there are far fewer sightings along Heathcote Road. However, a high concentration of sightings remains where Heathcote Rd crosses Deadmans Creek at Sandy Point, and also to a lesser extent around the Lucas Heights nuclear reactor (ANSTO) and where the Heathcote Rd crosses the Woronora River. Most of these sightings also appear to be quite recent, with the majority being in the 1990's.

Most of the sightings in the urban area around Sutherland, mainly around the Woronora River and its tributaries, were previously unknown to UWS. Some of these sightings were some time ago, with the oldest being 1929, 1931, 1940 (two sightings), 1969, and four sightings in the 1970's. There are also many reports of more recent sightings.

Sightings in the Royal National Park and in the suburbs to the north are much more scattered. There is a cluster of sightings around the Hacking River at Audley. The other sightings in these areas appear to be scattered with no clear patterns evident, except that many of these sightings occurred close to waterways. The sightings to the north of Port Hacking were also a surprise, but the only sighting for which a date is available occurred in 1977.

Figure 2. Koala sightings to the north and east of the Holsworthy Army Range.

Note that circular symbols indicate a sighting of a live koala, triangles represent a sighting of a dead koala, and stars indicate a sighting of a female with young. Red indicates that the koala was sighted by Steven Ward or A. Paul Robert Close. Orange sightings indicate sightings where the details of the sighting were confirmed by the respondent via telephone. Green symbols represent sightings where the respondent could not be contacted, or where an accurate location could not be established. Dates are also included for sightings where available. Where symbols are crowded the date may be linked to the symbol by a thin line of the same colour. "Sick" indicates that the koala was reported as being sick. Arrows indicate movements of tagged koalas and dashed arrows indicate that the koala was moved prior to release due to threats at the capture site. Names next to sightings are nicknames given to some animals (see report for further details). Sightings where the koala was not seen by the respondent (ie. sighted by a friend) are not mapped.

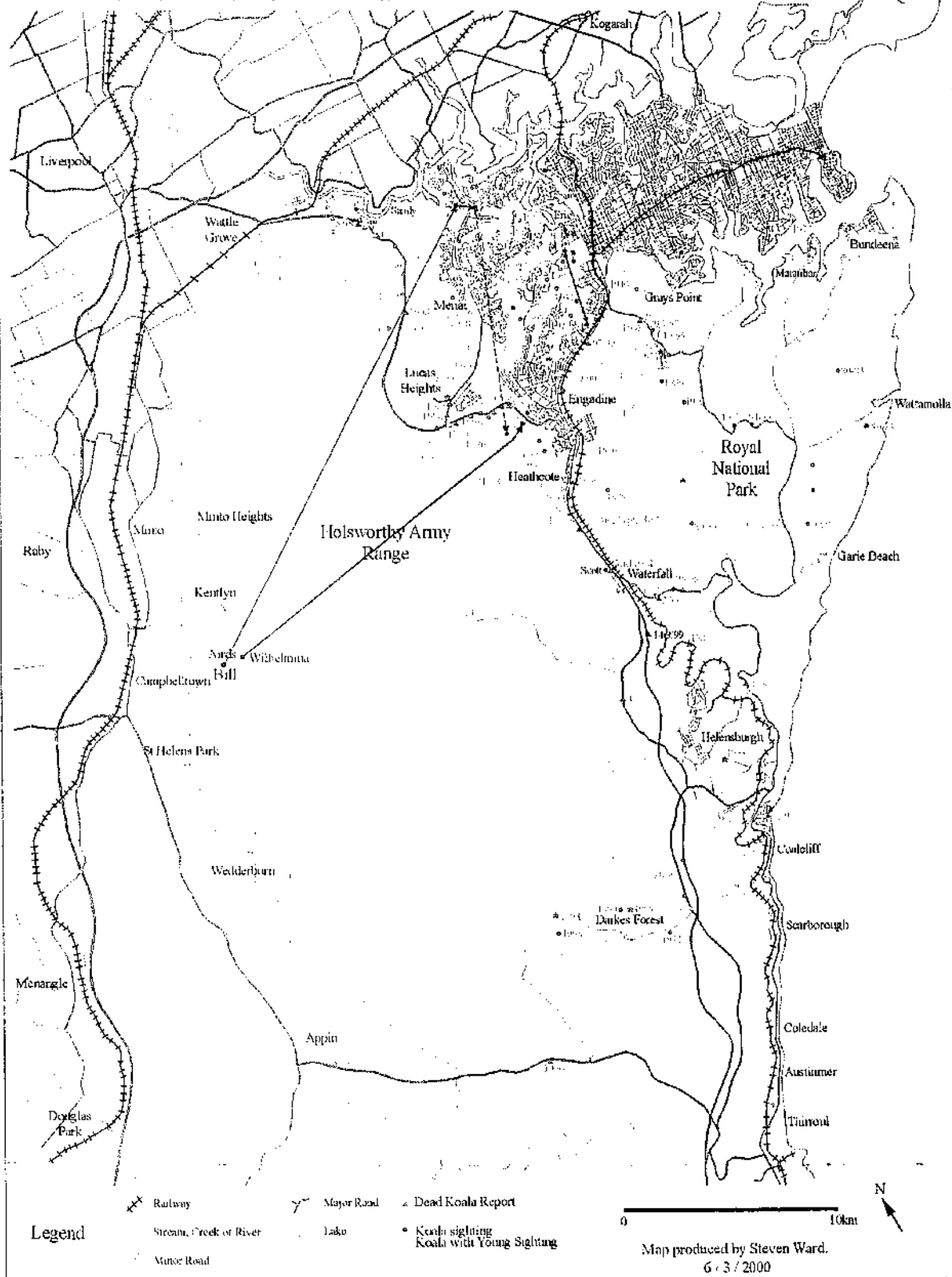
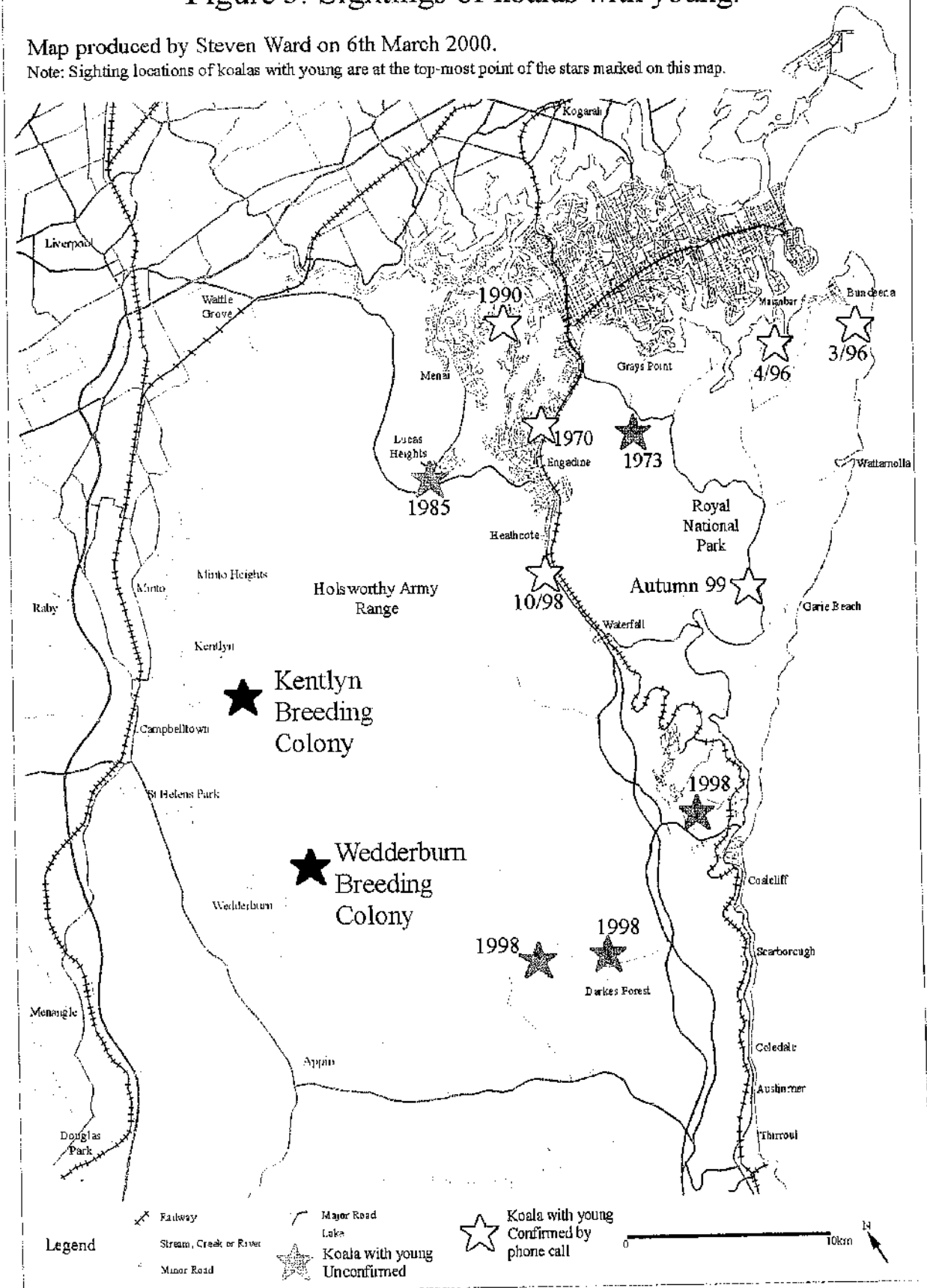


Figure 3. Sightings of koalas with young.

Map produced by Steven Ward on 6th March 2000.

Note: Sighting locations of koalas with young are at the top-most point of the stars marked on this map.



From Helensburgh to the northern Illawarra region a number of scattered sightings were reported, and there also appears to be a cluster of sightings at Darkes Forest. Surprising sightings included one almost on the beach at Stanwell Park and a report of sightings at Thirroul.

A number of koalas had either been captured or the corpse collected prior to the postal survey, and for some their movements were known because the animal was tagged. Most of these animals are marked in red on Figure 2.

Koalas captured and corpses collected by UWS

Wilhelmina is a female koala that was captured in Kentlyn (a suburb of Campbelltown), and later sighted on 8/12/93 at Goburra Pool, in the Heathcote National Park.

Bill is a male koala, and was first captured as a one-year old in late 1996 with his mother Shirley, at Kentlyn. He turned up approximately one year later after the 1997 bushfires in the Menai area in a tree in a resident's front garden on Coachwood Crescent, Alford's Point. He was again captured by UWS, examined and then released into a small patch of unburnt bushland in the Georges River National Park, as close to the capture point as possible. He then turned up in a small tree on the following day (31/12/97) by the roundabout at the junction of Brushwood Dr, Fowler Rd and Old Illawarra Rd, Illawong. It is unknown how Bill crossed Alford's Point Rd. It was decided not to recapture Bill and those calling the UWS koala hotline (five reports) were advised to let him move on when he was ready to do so. During the night a resident saw Bill cross Fowler Rd and called AWARE, an animal care group, and reported that Bill had "limped" across the road. Bill was subsequently captured by AWARE later that evening. UWS was contacted the following morning and Bill was taken for a veterinary inspection. He was found to have a more muscle on his right hindleg (which may have caused a gait that could look similar to a limp). There were no signs, however, that Bill had been hit by a vehicle. After discussions with NPWS it was decided to release Bill into the Heathcote National Park, and no further reports of Bill have been received.

Two sightings in August and September 1998 were reported around the eastern boundary of the Woronora cemetery. A 7.6kg male koala, nicknamed Eric, was later caught on 15/12/98 in a property on Prince Edward Park Rd, ~200m south of the intersection with the River Rd. It is unknown if this animal is the same one for the two earlier sightings, but given the closeness of the localities and dates it seems quite probable. Eric was released in Prince Edward Park, near the water pipeline. A sighting where the eartag description matched those given to Eric was later reported in Fahy Creek, Yarrawarra.

A 6.7kg male, around three to four years old, was caught on 13/9/97 just north of Waterfall, and was nicknamed Scott. No subsequent reports of this koala have been received.

On 8/6/98 a 6.6kg male, nicknamed Sandy, was caught on St Georges Crescent, Sandy Point, opposite the fire station. This animal was released the following day following a veterinary inspection at Elizabeth Macarthur Agricultural Institute.

A 8.5kg male koala corpse was collected from the Casula Vet Hospital on 10/5/98. This animal was brought in by a member of the public who reported that they had found the animal injured by the side of Heathcote Road, with St George Crescent being the closest crossroad. The animal was euthanased because its injuries were too severe. No contact details were available for the member of the public who brought in the koala.

On 14/9/99 a 6.2kg male koala corpse was collected from near the toll gates, south of Waterfall, by National Parks and Wildlife ranger Tony Dowd and then past on to UWS.

c) Koalas with young

A total of 10 reports of koalas with young was received (Fig 3), all of which were new to UWS. These sightings were generally quite recent with eight of the ten sightings being in the 1990's, and the oldest being in 1973. These sightings also appeared to be widely scattered, although two sightings occurred in the Darkes Forest area. These two sightings, however, may be independent reports of the same animal as both sightings occurred in 1998.

d) Change over time and old records

Eight respondents indicated that they believed that the number of koalas had increased and 33 that they believed that the number of koalas had decreased. Many of these persons did not give a year when they had noticed this change and no consistent trends were evident for those who did give a year. The majority of respondents either did not answer this question or answered that they didn't know. This result is unsurprising given the low number of koala sightings.

Some respondents gave details of sightings by persons other than themselves. These sightings were not mapped because they were not being reported by persons who had sighted the koalas directly. Where possible these reports are being followed up.

Of particular interest was that some respondents who were contacted stated that a "Mr Hicks" had been breeding koalas in the Oatley area in the 1970's. These reports will be investigated further but details are unclear at this stage.

e) Support for conservation actions and extra comments

The greatest support was for tree planting programs at 2301 of respondents (85.99%). This was closely followed by environment protection zones, which 2255 (84.27%) and restriction on dogs, which 2209 (82.55%) of respondents supported. 1897 (70.89%) supported traffic restriction in koala blackspots and 1754 (65.55%) supported using public money from rates or taxes to buy land from koala reserves.

Many respondents made unsolicited comments in the space provided at question 13. The most common comments were that they (the respondents) supported the survey, that they would support controls on cats, that they walked a lot in the area (often with the comment that they had never seen a koala despite lots of walking) and that they would like to see more koalas or other wildlife.

Some respondents also expressed concern about overdevelopment in their area. A number of respondents requested further information or offered their help as volunteers. Some also commented that they believed that koalas should be released in

the area and others that the rusa deer should be removed from the area, and in particular from the National Park(s).

DISCUSSION

a) Response rate and respondent data

The response rate to this survey (10.3%) was identical to the return rate for the Eden koala survey (Lunney *et al.* 1997) although lower than the >18% return rate for the Port Stephens koala survey (Callaghan *et al.* 1994). The higher return rate for the Port Stephens survey can probably be attributed to more effort, particularly through schools, being invested in encouraging returns and the greater koala population in the area (ie. members of the public would be more likely to have sighted a koala, and because they had something to report, more likely to return the survey). Time constraints did not permit a greater investment in encouraging returns for this survey, although the publicity in the *Sutherland Shire Leader* would have helped to inform the community about the purpose of the survey and to encourage replies.

Respondents varied widely in their age, and length of time living in the shire, which indicates that koalas attract attention from many different groups in the community. From conversations with respondents the quality of information reported about koala sightings appeared to be independent of the respondent's age. That is, some respondents, both young and old, could supply quite specific information, whereas others were vague.

b) Koala sightings

57% of respondents to the Port Stephens (Callaghan *et al.* 1994), 16.1% for the Campbelltown (Callaghan *et al.* 1998), and 8% of respondents for the Eden survey (Lunney *et al.* 1997) reported that they had sighted a koala in the local area. For this survey only 5.9% of respondents reported sighting a koala in the southern Sydney region.

Two possibilities may account for the low rate of koala sightings. Firstly, both the Port Stephens and Eden surveys were distributed to all households in the shires, and for both, the urban areas were much smaller than for this study. The Campbelltown survey also strongly targeted residents living close to koala habitat. Many residents reached by this survey live in an urban environment. Thus the majority of people reached by this survey would likely have little day-to-day contact with bushland, and hence are much less likely to encounter koalas.

Secondly, it is recognised that the Eden area has a low koala density and the fact that fewer respondents to this survey reported sighting koalas than for the Eden survey is consistent with our belief that koalas occur at low densities within the area surveyed.

The authenticity of sightings was confirmed wherever possible by contacting the respondent, although this process is yet to conclude. Furthermore, the effect of misreporting was limited through the use of the "unconfirmed" category of sightings, and a map was produced with the lowest confidence sightings eliminated.

c) Koalas with young

The wide distribution of sightings of koalas with young makes these data hard to interpret. The low number of sightings of koalas with young, relative to reports of other koala sightings, suggests that these breeding females are isolated individuals breeding

on their own. The results from this survey suggest that male koalas disperse to the north and east of the Holsworthy army Range from known, or unknown, breeding aggregations more frequently than females, but with the occasional female dispersing and surviving to breed in a new area. However, this idea is contrary to the generally accepted idea that koalas breed in certain areas, or pockets, of suitable habitat. To test this hypothesis it would be necessary to survey the areas in which females with young were reported. Unfortunately the cryptic nature of the koala would make it difficult to reject that there were no breeding koalas in locations surveyed, but in any event, was beyond the scope of this study.

Another possible explanation is that the female sightings may have been reported inaccurately, or that the respondents may have been mistaken with their sightings. However, it seems unlikely that all 10 sightings of females with young could be attributed to these causes.

These female sightings could also indicate the presence of as yet undiscovered breeding groups of koalas. The most feasible location for a breeding colony of koalas ANSTO would be at Darkes Forest, followed by the Heathcote National Park and / or Holsworthy Army range and less likely at Helensburgh. Other breeding groups (rather than individual animals) in the Sutherland suburbs or the Royal National Park seem improbable because of the frequency of their use by humans (ie. more sightings of koalas with young would be expected). The Royal National Park, due to its proximity to Sydney, has many visitors and walkers, whereas many areas of the Heathcote National Park are less accessible, and should be surveyed.

Thus, this survey was unable to establish the presence of any new breeding groups of koalas. However, it seems likely that isolated female koalas are breeding, which has not been previously recorded for koalas. This survey also provided evidence supporting further investigation of Darkes Forest, and to a lesser extent the Heathcote National Park and Helensburgh, for breeding colonies of koalas.

d) Change over time and old records

No trends in changes of koala populations over time were discernable from the responses to question four. Also, there were insufficient reported sightings of koalas with young to support the concept that koalas have breeding consistently in same location over a period of time (see section c). However some respondents indicated during telephone discussions that they had consistently sighted koalas (either the same animals or different ones) in the same location over a period of time. Generally the respondent also indicated during these discussions that there had been some event since that time (for example houses had been built in the area) and they had not seen koalas there after that event.

Two respondents indicated that koalas had been consistently sighted at, or near, Shackles Estate (to the east of Barden Ridge off David and Allies Rd) in the 1970's or early 1980's. One of these respondents had not sighted the koalas directly, however. These respondents indicated that houses had been built and that they had either not sighted, or not heard of, koala sightings since then.

Another respondent also described sighting four koalas at "The Needles" (approximately 2km upstream along the Woronora River from Shackles Estate) in 1940. Two of these koalas were described as being adults in the same tree, with two

that appeared to be juveniles in another tree close by. Other respondents also indicated that their parents had worked in the area (for example on the Water pipeline which runs to the east of the Woronora River) and they knew of koala populations in these areas in the early nineteen hundred's and took them to see one or more of these animals when they were children.

These reports indicate that there may have been a breeding population of koalas along the Woronora River or its tributaries in the Barden Ridge, Engadine, and Woronora suburbs, but there is presumably insufficient habitat now left to support a breeding population because of subsequent housing development.

The reports of a "Mr Hicks" who was apparently breeding koalas in the Oatley area warrant further investigation. It is unclear what activities Mr Hicks was undertaking and what happened to the animals that he dealt with. Some respondents indicated that they believed that he was releasing koalas back into the wild. If true, this could impact upon the genetic makeup of koala populations in the southern Sydney area, especially if some of these koalas came from other areas. However, there are insufficient details at this stage to comment further.

e) Support for conservation actions and extra comments

Support amongst respondents for conservation actions (question 9) was quite high, although lower than support for similar actions proposed in the Port Stephens survey for which support ranged from 75-98%. There was particularly high support for: tree planting programs, environment protection zones, and restrictions on dogs, despite a low percentage of respondents reporting having personally sighted koalas in the area. Probably these three actions were seen as having other benefits, even if respondent did not believe koalas to be present in their local area.

Management Issues

Koala roadkills were primarily reported along Heathcote Rd and the Princes Highway. The worst "blackspot" for koala roadkills is where Heathcote Rd crosses Deadmans Creek at Sandy Point. Lowering the speed limit through the Deadmans Creek gorge could reduce koala roadkills, as could construction of a bridge spanning the gorge (although this option would be expensive). The Roads and Traffic Authority (RTA) has already erected koala roadsigns along Heathcote Road.

Other roadkills were also reported scattered along Heathcote Rd, but with another cluster at the Woronora River crossing where New Illawarra Road joins Heathcote Rd. Koala roadkills may occur more frequently in these areas when the upgrading of Heathcote Rd is finished.

A study in Queensland (Natrass and Fiedler 1996) found that road purpose, speed limit, overhead lighting, width and volume of traffic were the major influences for determining the risk of mortality for wild koalas. Natrass and Fiedler (1996) also found that risks to koalas in 60km/hr zones was low to negligible, increased for 70km/hr zones (22% of road fatalities) and was highest for 80km/hr zones (74%), the maximum legal speed limit in the study area. They also found that good lighting for motorists lowered risks to koalas. Thus, although koala fatalities are infrequent, a combination of improved lighting and a lowered speed limit would help to lower koala roadkills, particularly where Heathcote Rd crosses Deadmans Creek.

Several koalas were sighted around the Woronora river area and in Royal National Park. Corridors should be maintained to allow koalas access to remnant bushland, whilst avoiding, where possible, roads and other threats. The route that koalas use to move into or out of Royal National Park is unknown, but the Princes Highway and railway line pose significant barriers. Our research (unpub. data) suggests that koalas in the southern Sydney area travel along or beside waterways and gorges and thus culverts or bridges which koalas can pass under are probably the most effective way of maintaining corridors. It appears likely that the Woronora River valley has allowed koalas continued access to the Sutherland region, but there would currently be few locations where koalas could cross unhindered into Royal National Park. Future planning for both the Princes highway and the rail line should examine the possibility of building culverts, or otherwise facilitating animal movements across both transport links. These corridors would be most effective if they were built so that animals could quickly pass under both the highway and the rail line, rather than getting stuck inbetween.

Some residents expressed concern over the proposal to develop the fire trail linking Prince Edward Park Rd in Woronora and Bundanoon Rd in Woronora Heights. It is difficult to fully anticipate what the effect of this may be upon koalas. However, it is possible that an increased traffic load could lead to koalas being hit by vehicles.

Thus we believe that the main aims of this survey: to record koala sightings, to determine if koalas were breeding in the Sutherland, Liverpool or Illawarra shires and to obtain information on sightings of other animal species have been successful. The analysis of sightings of other animal species has not been addressed in this report but much information has been gathered which could be utilised by councils or community or management authorities. Further, we suggest that evidence does not currently exist to support the supposition that breeding concentrations of koalas exist in the Sutherland, Liverpool or Illawarra shires, but that individual female koalas may be breeding in widely scattered locations. However, breeding groups of koalas may exist but remain unknown to the wider community. Possible locations of breeding groups of koalas are Darkes Forest, Heathcote National Park, and Helensburgh.

ACKNOWLEDGEMENTS

We wish to thank the Hacking River and Georges River Catchment Management Committees for their funding of this project; Gary Schoer for advice, Simone Kleyn, and Robyn Wosinki for help with the data entry, Lynn Coxall for help with determining grid co-ordinates of reported sightings and for confirming details of koala sightings with respondents who gave permission to be contacted, Ian Drinnan, Sutherland Shire Council and Patricia Nagle, National Parks and Wildlife Service for help in trying to find a suitable map, Robert Close for proofreading, and, of course, all those who returned completed surveys.

REFERENCES

Axis Environmental and AMBS Consulting (1996). *Holsworthy Training Area Environmental Audit Main Report*. Unpublished report, Department of Defence.

Brett, D. (1989). Caring for Campbelltown's koalas. *Ecos* 60: 28-9.

Callaghan, J., Leathley, S., and Lunney, D. (1994). Port Stephens Koala management plan draft for public discussion. Unpublished report, Port Stephens Council.

Callaghan, J., Phillips, S., Thompson, J., and Curran, T. (1998). *Draft Comprehensive Koala Plan of Management: Campbelltown Local Government Area*. Australian Koala Foundation: Brisbane.

Close, R. L. (1993). Campbelltown's koalas: what is their future? *National Parks Journal* 37: 22-5.

Cork, S.J., Margules, C.R, and Braithwaite, L.W. (1988). A survey of koalas and their habitat near Wedderburn NSW, suggestions for management and an assessment of the potential effects of a proposed subdivision of four hectare lots. Unpublished report for Campbelltown City Council. CSIRO Div. Of Wildlife and Ecology: Canberra.

Lunney, D, Esson, C., Moon, C., Ellis, M., and Matthews, A. (1997). A community-based survey of the koala, *Phascolarctos cinereus*, in the Eden region of south-eastern New South Wales. *Wildl. Res.* 24: 111-128.

Nattrass, A.E.O. and Fiedler, K.B. (1996). *Koalas - Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990*. Ed. G. Gordon. pp 129-136. World Koala Research Inc., Brisbane.

Sheppard, J. (1990). The Wedderburn koala colony. Pp 70-4 in *Koala Summit: Managing koalas in New South Wales* ed by D. Lunney, C.A. Urquhart and P. Reed. NSW National Parks and Wildlife Service: Sydney.

Ward, S. J. and Close, R.L. (1998). Community assistance with koala (*Phascolarctus cinereus*) sightings from a low density population in the south-west Sydney region. pp 97-102 in *Ecology for Everyone*. Eds. R. Wills and R. Hobbs. Surrey Beatty and Sons Pty Ltd, Sydney.

Attachment 1.

Scanned copies of the Sutherland survey form are attached. All pages have been reduced from A3 to A4 size.

No postage stamp required if posted in Australia

To The Householder:

KOALA SURVEY



Please fold and return to:

University of Western Sydney Macarthur
Reply Paid 5
Associate Professor Robert Close
Faculty of Informatics, Science and Technology
PO Box 555
Campbelltown 2560

Dear Resident,

We are writing to ask for your co-operation in a koala survey being conducted by the University of Western Sydney Macarthur. The purpose of the survey is to obtain information on koalas in the Southern Sydney area and is funded by the Georges River and Hacking River Catchment Management Committees, and supported by Sutherland Shire Council.

We would like you to fill in this survey form **EVEN IF YOU HAVE NEVER SEEN ANY KOALAS**. A lack of sightings in an area will help us in building up a picture of koala distribution. We are also requested sightings for other animal species, including feral animals.

The information collected in this survey will utilised by Sutherland Council to assist in planning, and by the Georges and Hacking River Catchment Management Committees for biodiversity assessment. A report based on the results of the survey will be available on the Georges River Catchment Management Committee's website www.geocities.com/Rainforest/Vines/9737 or by contacting the Hacking River Catchment Management Committee co-ordinator, Libby Rawlingson, on (02) 9895 7769.

Associate Professor Robert Close from the University of Western Sydney Macarthur will continue to collect details of koala sightings in the future. **It should sight a koala, please call the University of Western Sydney Macarthur koala hotline on (02) 9962 9996 and we will return your call as soon as possible.**

Steven Ward and Robert Close
University of Western Sydney Macarthur, PO Box 555, Campbelltown 2560

Please circle the appropriate answer, or give details as requested.

1. What is your local area?
- | | | | |
|------------------|-------------------|-------------|--------------|
| a) Menai | b) Sutherland | c) Engadine | d) Heathcote |
| e) Lucas Heights | f) Pleasure Point | g) Woronora | h) Waterfall |
| i) other | | | |

2. How many years have you lived in southern Sydney?.....
3. How often do you see koalas in southern Sydney?
- | | | | |
|--------------|--------------|-----------|-----------------|
| a) Monthly | b) Quarterly | c) Yearly | d) Occasionally |
| e) Once only | f) Never | | |
4. In the time you have lived in southern Sydney has the number of koalas
- | | | | |
|--------------|--------------------|--------------|---------------|
| a) Increased | b) Stayed the same | c) Decreased | d) Don't Know |
|--------------|--------------------|--------------|---------------|
- If you have noticed a change, in what year did this begin?
5. Have you seen sick koalas in southern Sydney? (eg with infected eyes or a wet dirty tail). Yes / No
6. Have you ever seen any dead koalas in southern Sydney?..... Yes / No
- If yes, was the koala dead on a road..... Yes / No
7. Have you seen any koalas with young in southern Sydney..... Yes / No
8. Do you have any old records of historical information about koalas in the southern Sydney region? Please give details
9. Would you support any of the following actions to help koalas in southern Sydney (circle those you support).
- | | |
|---|--|
| (1) Traffic restrictions (eg speed limits in koala blackspots) | |
| (2) Restrictions on dogs (eg to stop dogs roaming at night) | |
| (3) Tree planting programs | |
| (4) Environmental Protection Zones (to control development in areas used by koalas) | |
| (5) Use public money (from rates or taxes) to buy land for koala reserves | |
10. Please mark the location of all your koala sightings on map 1 and sightings of other wildlife on map 2 (overleaf).
11. May we contact you for more details?..... Yes / No
12. OPTIONAL Name..... Age.....
Phone No.....
Address.....
13. Do you have any comments?

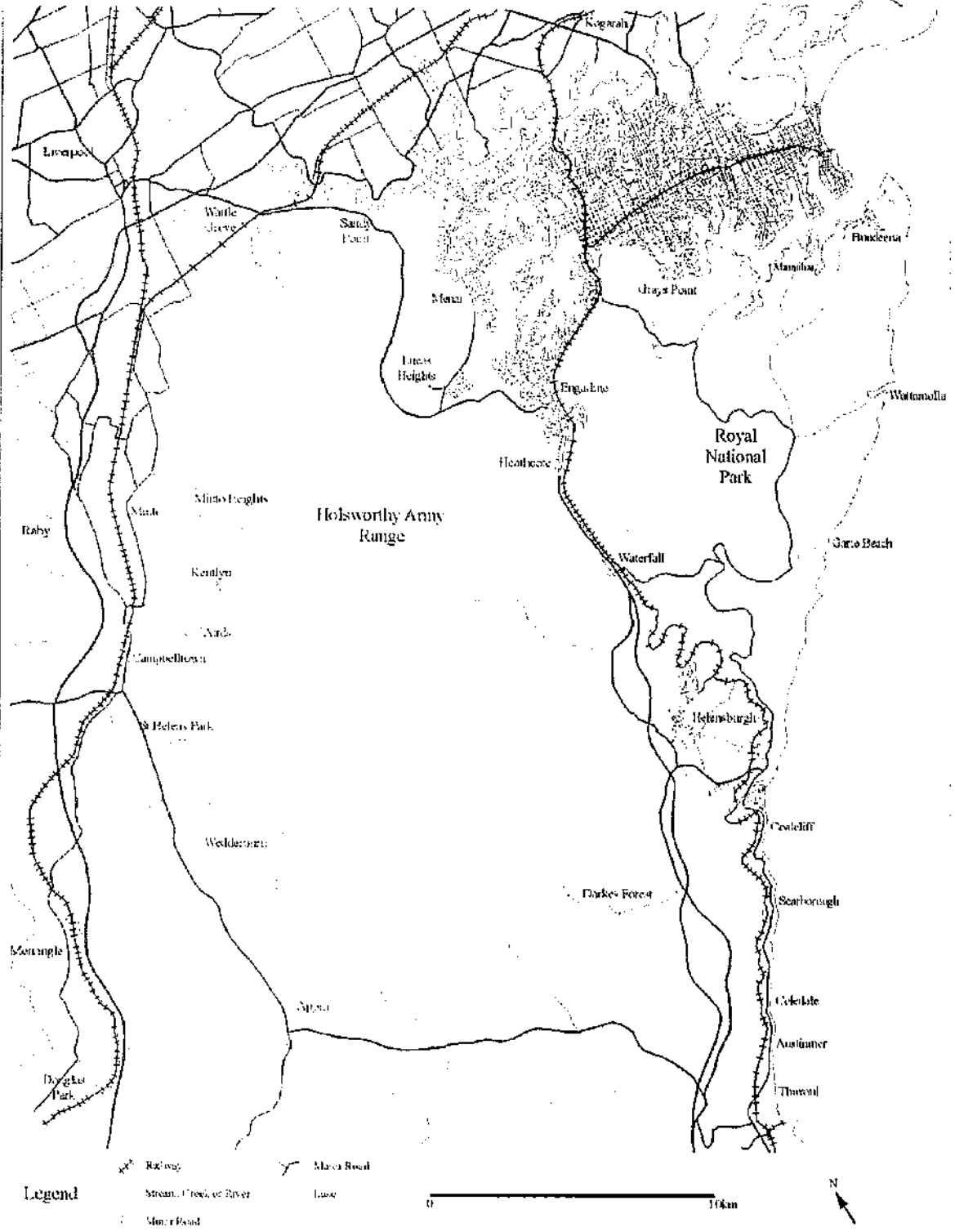
Please post your completed survey form (no stamp required) by 5th November 1999, or as soon as possible after this date.

NOTE: The ethical aspects of this study have been approved by the University of Western Sydney Macarthur Ethics Review Committee (Human Subjects). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Executive Officer, Claire Kaspara (tel: 02 4620 3641). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Map 1. Koala sightings.

With blue or red pen please mark with a cross (x) as accurately as possible, places where you have seen a koala. Please also indicate, next to the "x":

1. The year (and month if possible) of the sighting
2. Whether the koala was carrying a young (Y)
3. Whether the koala was sick (S) or dead (D)



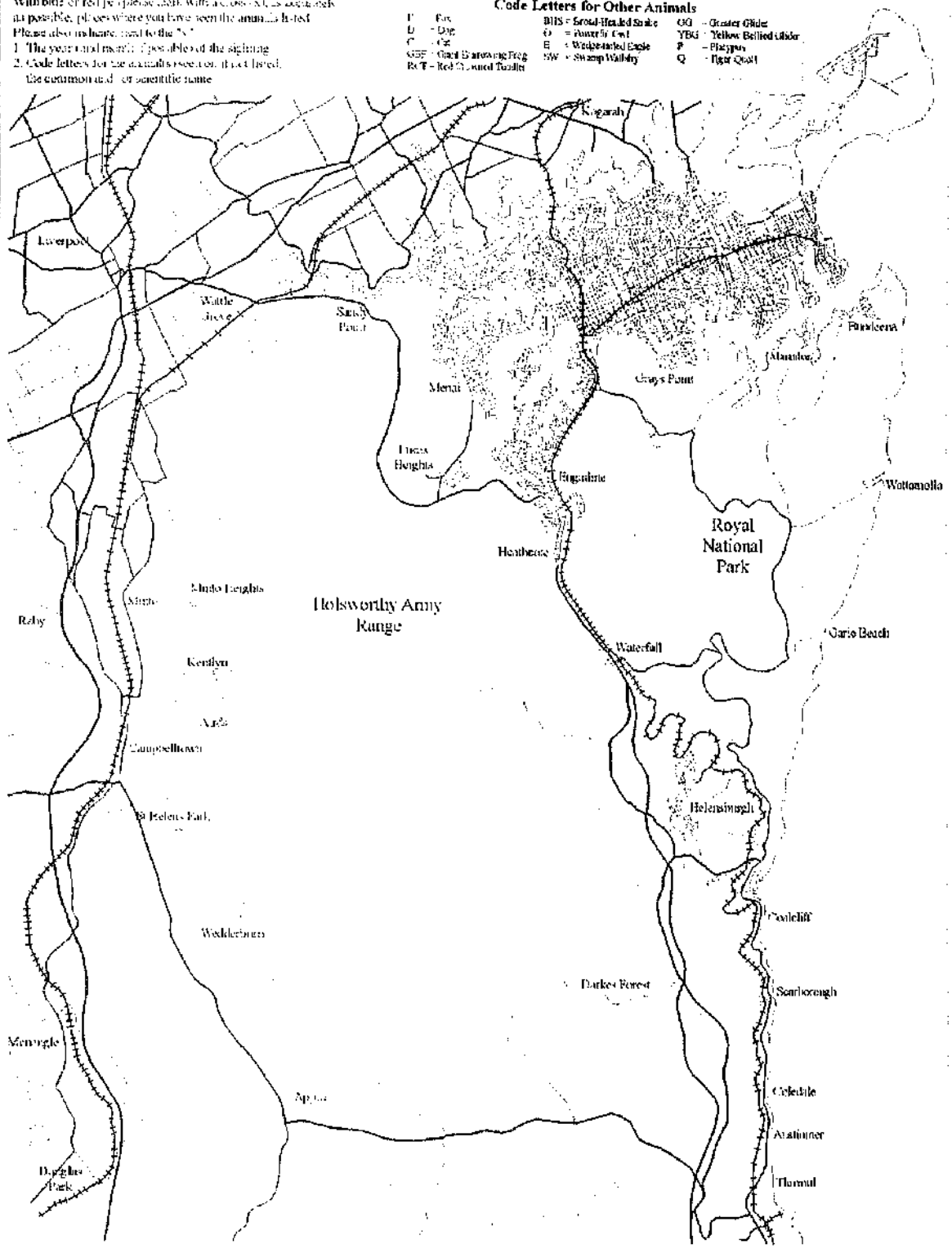
Map 2. Sightings of Other Animals.

With blue or red pen please mark with a cross (x) as appropriate, as possible, places where you have seen the animals listed. Please also include, next to the "x",

1. The year and month, if possible, of the sighting
2. Code letters for the animals (see code list below), the common and/or scientific name

Code Letters for Other Animals

F - Fox	BHS - Broad-headed Snake	GG - Greater Glider
D - Dog	G - Goatsuck	YBK - Yellow Bellied Kidder
C - Cat	E - Eastern Grey Kangaroo	P - Platypus
GEF - Great Eastern Frog	SW - Swamp Wallaby	Q - Tiger Quail
RT - Red Tailed Tazul		



Legend

- Railway
- Stream, Creek, or River
- Minor Road
- Major Road
- Lake

0 100km



Descriptions of Other Animal Species



Fox (*Vulpes vulpes*) Reddish brown with whitish chin, chest and belly. Large ears (~10cm).



Dog (*Canis familiaris*) Any type (breed) of dog roaming unattended in bushland areas.



Cat (*Felis catus*) Any cat seen in bushland areas.



Giant Burrowing Frog (*Heleioporus australiacus*) Adult frogs ~16cm long. Dark brown above with yellow spots along its sides. The tadpoles are large, up to 7cm. This species is similar in appearance to the Eastern Bango Frog. The call of the Giant Burrowing Frog is distinctive, however, and is a soft rapid 'hee-hee-hee' pulse 'hee-hee-hee', which is why this species is sometimes also called the owl frog. If you have heard this frog's call but have not observed it please mark the location with GBE + CALL.

Red-Crowned Toadlet (*Pseudophryne australis*) Adult frogs 5cm long. No diagram, but is dark brown with a distinct vertical orange crown patch on the head, a streak of the same colour in the tail base area, and a patch of a similar colour or whitish on the upper forearms. The call is a soft squeak like 'ceek-cek' repeated. If you have heard this frog's call but have not observed it please mark the location with RCT + CALL.



Broad-headed Snake (*Hoplocephalus banyatzenovi*) Adult snake up to 1m long. Broad, flat head. Black colour with yellow spots forming bands.



Powerful Owl (*Ninox strenua*) Head-body length up to 55cm, wing span up to 1.5m. Deep slow 'Woo-hoo' call. Upper part of body dark brown with white or pale brown horizontal bars. Whitish underneath with brown markings. Black bill (beak), yellow feet.



Wedge-tailed Eagle (*Aquila audax*) Very large, head-body length up to 90cm. Long, wedge shaped tail. Adult black with pale neck. Immature eagles are brown and a golden-brown neck. Bill blue-white with black tip. Toes whitish and legs feathered to toes.



Swamp Wallaby (*Wallabia bicolor*) Head-body length up to 85cm, and weight up to 20kg. Dark brown or black, light yellow or orange underneath. Tail straight out behind.



Greater Glider (*Petaurista volans*) Head-body length up to 45cm, tail up to 60cm long. Variable in colour, ranging from dark chocolate to cream above. Whitish below. Large ears which are furred.



Yellow-Bellied Glider (*Petaurus australis*) Head-body length up to 30cm, tail up to 48cm (one and half times bodylength) and fluffy. Grey and white to orange below. Gliding membrane (skin) between ankles and wrists. Large ears bare of fur.



Platypus (*Ornithorhynchus anatinus*) Head-body length (including bill) up to 50cm long. Duck-like bill, webbed feet, large flat tail.



Tiger Quoll (*Dasyurus maculatus*) Head-body length up to 75cm, tail up to 55cm. Rufous to dark brown with white spots of various sizes over the body and tail. Pale underneath.

Appendix 2.

Ward and Close 1998.

CHAPTER EIGHTEEN

Community assistance with koala *Phascolarctos cinereus* sightings from a low density population in the south-west Sydney region.

S. J. WARD¹ and R. L. CLOSE¹

Detecting koalas *Phascolarctos cinereus* (Goldfuss) in the Campbelltown region, south-west of Sydney, is difficult due to low densities of animals. Sightings by local residents provide valuable information and may lead to the capture of animals for the collection of morphometric data, attachment of ear-tags, and radio-collars. The *Macarthur Advertiser*, a local newspaper, has run a weekly column since October, 1995. This column includes a contact number to report sightings, and provides an avenue for education of the public on koala biology and related ecological issues. Sightings reported by the public have increased more than three-fold since publication of the column, compared to reports collected from 1990 to 1995. Sightings reported prior to publication of the column, observations by University personnel and members of the local National Parks Association tended to be concentrated in the same locations, but sightings reported after publication of the column were widespread. Community sightings have provided valuable information which otherwise would have required intensive search effort. Simultaneously, the programme has provided the community with information about ecological concepts.

INTRODUCTION

RESEARCH on koalas poses logistical problems due to the difficulty of detecting koalas, especially at low densities, and capturing animals in large trees located in rugged terrain. The koala population of south-west Sydney region has an estimated density of only one koala per 10 hectares (Close 1993), and animals often use steep, rocky gorges. This chapter reports the use of community responses to help study the ecology of koalas and overcome the difficulties of studying koalas under such conditions.

BACKGROUND

A number of researchers (Robinson 1978; Reed *et al.* 1990; Smith and Smith 1990; Le Page 1993; Leathley *et al.* 1993; Lunney and Moon 1993; Ridley 1993; Curtin and Lunney 1995; Leathley *et al.* 1995; Moon 1995; O'Brien 1995; Lunney *et al.* 1996; Natrass and Fiedler 1996; Patterson 1996) have used postal surveys or community reports to obtain information on koala populations (usually distribution data). Smith and Smith (1990) for example, concluded that the koala population in Warringah shire, Sydney, had declined, after reviewing reports of community sightings dating back to the 1940s. We believe, however, that the ongoing publicity for this research, and requests to report koala sightings, are a variation on previously used methods of

obtaining information from the community. The approach of using community koala sightings is facilitated by the readily identifiable nature of koalas.

The *Macarthur Advertiser* is a local Fairfax newspaper which is delivered to all homes from Wedderburn to Glenfield (Fig. 1). It has a Circulation Audit Bureau (CAB) distribution of 62 608 (at August 9, 1996). The newspaper is supporting the research through fundraising and a \$20,000 donation to provide Steven Ward with a scholarship, and by printing a weekly column written by the two authors. The column includes a contact number to report koala sightings, and provides an avenue for education of the public on koala biology. Not all columns are about koalas; some focus on other species or ecological concepts that are relevant to the south-west Sydney region.

The fundraising is being accomplished through the formation of "Mac's Koala Club" (Fig. 2), as a promotion to raise funds for Steven Ward's scholarship. As part of the promotion a "Mac the Koala" suit has also been created to promote both the Club and the newspaper. This is worn at various community events around the district. This campaign also increases community awareness of the local koala colony.

Prior to 1986 the presence of the koala colony in the area was unknown, except to a few individuals. This knowledge became more

¹Department of Biological Sciences, University of Western Sydney, Macarthur, P.O. Box 555, Campbelltown, New South Wales, Australia 2560.

Pp. 87-102 in *ECOLOGY FOR EVERYONE. COMMUNICATING ECOLOGY TO SCIENTISTS, THE PUBLIC AND THE POLITICIANS* ed by R. T. Wills and R. J. Hobbs. Surrey Beatty & Sons, 1988.

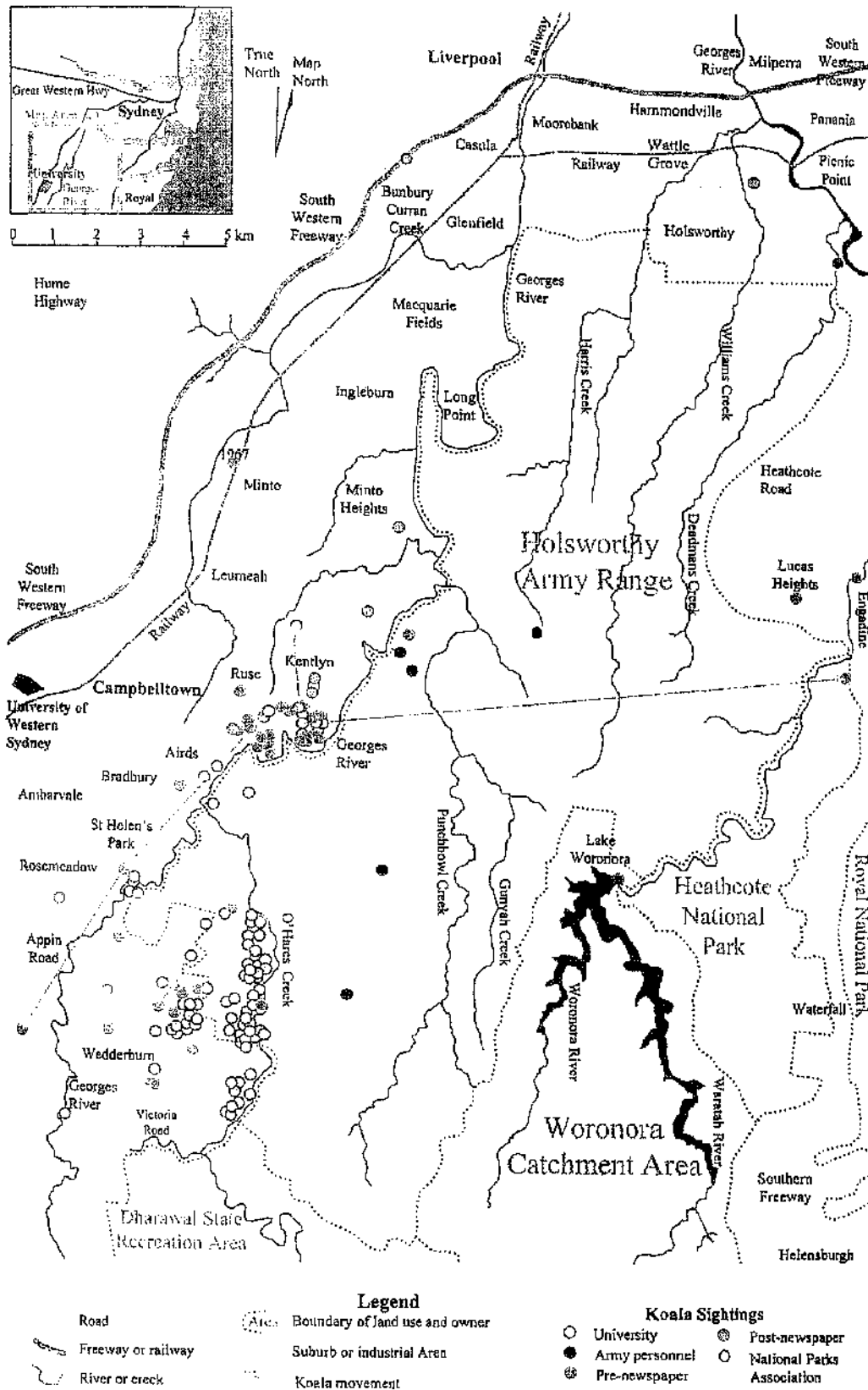
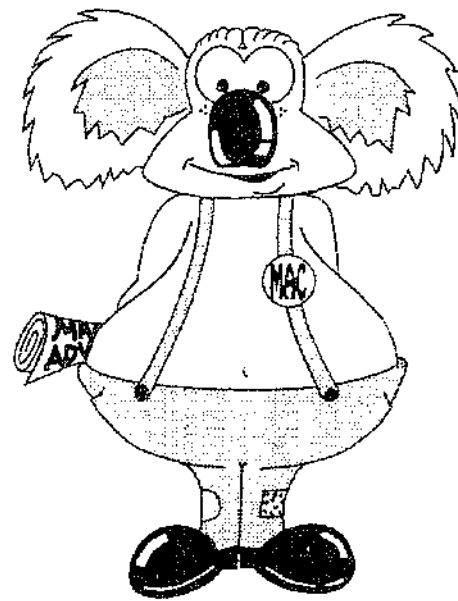


Fig. 1. Regional map (top left) showing area of interest, which is enlarged with koala sightings. Names of some roads, creeks, rivers, and suburbs are shown.



Why Not Join Mac's Koala Club

and help save the Koalas.

Membership costs just \$7⁰⁰ Children, \$10⁰⁰ Adult for 12 months and includes:-

- T-shirt ● Ruler & Gum Tree Tube ● Discount Voucher Booklet ● Ballons ● Stickers and more

MAC'S KOALA CLUB

Campbelltown P.O. Box 234

Date

Name

Address

Phone

Date of Birth

Sign

Parent/Guardian

Proudly sponsored by **Advertiser** (046) 40 5151

Fig. 2. Form to join Mac's Koala Club, which is published weekly in the *Macarthur Advertiser*. The form printed in the *Macarthur Advertiser* also includes names of members whose birthday occurs during that week.

widely known when a development was approved at the end of Victoria Road in Wedderburn, a suburb to the south of Campbelltown (Fig. 1), and there was considerable publicity about the koala colony at this time. From 1986 to 1990 the members of the Macarthur branch of the National Parks Association noted details of any koalas seen. A CSIRO study of the disputed area (Cork *et al.* 1988) used the sightings available at that time, vegetation data, and observations of pellets or scratches to provide an assessment of the impact of the development on the koala population. As a result of local opposition to the development (Dobson 1990; Sheppard

1990), the construction work was stopped and media attention subsided, although there were intermittent media stories until publication of the weekly column commenced.

Recently the Federal Government has proposed building the second international airport for Sydney in the Holsworthy army range. This area is currently undeveloped, and use of the range has almost exclusively been by army personnel. Shelling of the range, unexploded ordnance, fences, signs along the Georges River, and the rugged nature of the terrain effectively deter most trespassers. An exception is the section of the Holsworthy Army range to the west of O'Hares Creek, which has

not been shelled. Access is possible along a fire trail, although human impact so far is minimal.

The south-west Sydney region koala population faces strong pressures from urban expansion and the Holsworthy airport proposal, if it proceeds, is likely to have an exceptionally large impact. Basic ecological data coupled with community understanding of the value of bushland are required if the koala population is to be preserved. This study incorporates both needs.

METHODS

Koalas, when caught, have a coloured ear-tag placed in each ear, and each individual can be identified by its unique colour combination. In all of the *Macarthur Advertiser* columns, readers have been asked to report details of any koala seen and to look carefully for ear-tags; a telephone number is provided in each column.

Sightings for the south-west Sydney region (the area covered in Fig. 1) came from four sources. These sources were: University staff, students and volunteers; Corporal Robert Thompson (Australian Army); National Parks Association records; and public reports made to the University. Sightings reported by the public were classed as being either prior to publication of the newspaper column (pre-newspaper), or after publication (post-newspaper). Multiple sightings reported at the same time were classed as a single report, as were sightings thought to be of the same animal within a week of the first sighting. The time period for the pre-newspaper category was calculated from the first documented report to the day prior to the newspaper column publication, and from the day of publication to the last reported sighting for the post-newspaper category (Table 1). Where possible, sightings have been mapped, but it was not possible to display all sightings in the Wedderburn area (Fig. 1) because of the superposition of symbols.

RESULTS

The average number of sightings per year has increased more than three-fold since the first column was published (Table 1).

The sightings made by the National Parks Association members concentrated strongly in the Wedderburn area. In particular, many occurred near a fire trail extending from Victoria Road, running north near to O'Hares Creek (Fig. 1). The University sightings are also concentrated strongly in Wedderburn, near O'Hares Creek, but with some sightings occurring in Kentlyn (Fig. 1). The sightings reported by Corporal Thompson were few, but widespread within the western section of the Holsworthy Army range (Fig. 1). Pre-newspaper sightings are concentrated in the Ruse, Kentlyn and Wedderburn areas but with reports of sightings at Woronora Dam (to the east of Lake Woronora), the Lucas Heights and Engadine area, the crossing of Heathcote Road over Deadmans creek, and during 1967 in Minto (Fig. 1). Post-newspaper sightings have been widespread, with particularly notable sightings being those at Casula, and to the north-east of Holsworthy (Fig. 1).

Few sightings have been of ear-tagged animals (seven sightings of six koalas to date). Twenty-one koalas have been ear-tagged since 1992, with five of these koalas known to be dead (at August 9). However, three sightings reported prior to the publication of the newspaper column were of two animals which dispersed considerable distances (12.6 and 9.2 km, Fig. 1).

DISCUSSION

It was not possible to establish the veracity of most reported sightings. However, for all investigated sightings the animal was located, or evidence of a koala's presence was found (scratches or faecal pellets).

Following the start of the weekly newspaper column and promotion of Mac's Koala Club the

Table 1. Dates, number of reported koala sightings, and average number of sightings per year for National Parks Association, pre-newspaper (prior to publication of the weekly newspaper column) and post-newspaper (during the period of publication of the newspaper column) categories.

Category	Dates	Number of Reported Sightings	Average Number of Sightings per year
National Parks Association	May 31, 1986- May 4, 1990	66	16.80
Pre-newspaper	October 31, 1990- October 17, 1995	36	7.26
Post-newspaper	October 18, 1995- June 24, 1996	16	23.38

number of koala sightings reported to the University has increased and is probably due to the increased publicity. However, koalas may be coming into locations where people are present (i.e., the suburbs) more frequently, possibly due to development of residential areas, an increase in koala numbers, or a change in their behaviour. Koalas may also be attracted to watered and fertilized trees in suburban gardens, thus resulting in more sightings being reported.

The concentration of University, National Parks Association, and pre-newspaper sightings in the Wedderburn and Kentlyn areas probably reflects the location of most efforts to find koalas. Few sightings have come from the Holsworthy Army range. This probably reflects the small search effort, rather than the true koala distribution. Little work has been conducted to date in the suburbs north or east of the Holsworthy Army range, and the distribution area of the *Macarthur Advertiser* does not extend to these areas (Holsworthy, Moorebank, Wattle Grove).

Twenty-nine per cent of the koalas ear-tagged have been sighted. However, the ear-tags are difficult to see or people may forget to look for them. We hope to obtain more information on koala movements by ear-tagging more koalas, thus increasing the chances of sighting marked animals.

The publication of the column has drawbacks, mainly the time invested in writing. On rare occasions the column has not been printed because of technical difficulties. The Mac's Koala Club membership has steadily increased to over 350, although fundraising has been slow. It is not clear what educational impact the column and Mac's Koala Club have had, but we hope to assess this in the future.

Plans to further enhance the community response include production of a video for distribution to schools in the area, setting up a telephone line which provides a recording of a calling koala male (to allow the public to recognize these calls) and requesting historical sightings. Expansion of Mac's Koala Club to areas with potential koala populations which are served by other Fairfax newspapers is already underway.

This project is not only permitting the study of a species whose low population density would otherwise restrict ecological studies, but should increase the communities' knowledge, and presumably appreciation, of native local flora and fauna. This appreciation is currently being tested by a recent call for submissions concerning the proposed airport in the Holsworthy Army range.

ACKNOWLEDGEMENTS

This research has been supported financially by the *Macarthur Advertiser* and the Australian Koala Foundation. We also thank the *Macarthur Advertiser* for the publicity provided. We thank the Macarthur branch of the National Parks Association, Corporal R. Thompson, and others who reported koala sightings. We thank Wayne Foster and Anthony Scarman for noting or collecting details of koala sightings. The Campbelltown Council and the Australian Army granted access to property.

REFERENCES

- Close, R. L., 1993. Campbelltown's koalas: what is their future? *Nat. Parks J.* 37: 22-25.
- Cork, S. J., Margules, C. R. and Braithwaite, L. W., 1988. A survey of koalas and their habitat near Wedderburn NSW, suggestions for management and an assessment of the potential effects of a proposed subdivision of four hectare lots. (A report for Campbelltown City Council). CSIRO Division of Wildlife and Ecology, Canberra.
- Curtin, A. and Lunney, D., 1995. A comparison of community-based survey and field-based survey for koalas in a large reserve system on the outskirts of Sydney, New South Wales. Pp. 186-88 in *Proceedings on a conference on the status of the koala in 1995*. Australian Koala Foundation, Brisbane.
- Dobson, S., 1990. Can you help us save the koalas at Wedderburn? P. 178 in *Koala summit. Managing koalas in New South Wales* ed by D. Lunney, C. A. Urquhart and P. Reed. NSW National Parks and Wildlife Service, Sydney.
- Le Page, C., 1993. Koala preservation society of NSW Inc. report. Pp. 73-74 in *Proceedings from the conference on the status of the koala in 1993*. Australian Koala Foundation, Brisbane.
- Leathley, S., O'Connor, S., Lunney, D. and Callaghan, J., 1995. Port Stephens koala management plan. Pp. 120-28 in *Proceedings on a conference on the status of the koala in 1995*. Australian Koala Foundation, Brisbane.
- Leathley, S., Lunney, D. and Callaghan, J., 1993. A koala management plan for Port Stephens. Pp. 29-36 in *Proceedings from the conference on the status of the koala in 1993*. Australian Koala Foundation, Brisbane.
- Lunney, D., Moon, C. and Matthews, A., 1996. A 1990 survey of the koala *Phascolarctos cinereus* population at Huka in northern New South Wales. Pp. 102-22 in *Koalas --- Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1996* ed by G. Gordon. World Koala Research Inc. Brisbane.
- Lunney, D. and Moon, C., 1993. Koala surveys. Pp. 41-42 in *Proceedings from the conference on the status of the koala in 1993*. Australian Koala Foundation, Brisbane.
- Moon, C., 1995. W.I.R.E.S. koalas tell a story. Pp. 49-51 in *Proceedings on a conference on the status of the koala in 1995*. Australian Koala Foundation, Brisbane.
- Natross, A. E. O. and Fielder, K. B., 1996. Koala rescue: the perception and the reality. Pp. 195-35 in *Koalas --- Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1996* ed by G. Gordon. World Koala Research Inc. Brisbane.

- O'Brien, D., 1995. Koalas in the Gosford district. Pp. 230-63 in Proceedings on a conference on the status of the koala in 1995. Australian Koala Foundation, Brisbane.
- Patterson, R., 1996. The distribution of koalas in Queensland — 1986 to 1989. Pp. 75-81 in Koalas — Research for Management. Proceedings of the Brisbane Koala symposium, 22nd-23rd September 1990 ed by G. Gordon. World Koala Research Inc. Brisbane.
- Reed, P. C., Lunney, D. and Walker, P., 1990. A 1986-87 survey of the koala *Phascolarctos cinereus* (Goldfuss) in New South Wales and an ecological interpretation of its distribution. Pp. 55-74 in Biology of the Koala ed by A. K. Lee, K. A. Handasyde and C. D. Sanson. Surrey Beatty & Sons Pty Ltd, Chipping Norton.
- Ridley, D., 1993. Koala management in logging areas — an optional managers perspective with reference to Yurammie west forest, Eden district. Pp. 55-73 in Proceedings from the conference on the status of the koala in 1993. Australian Koala Foundation, Brisbane.
- Robinson, A. C., 1978. The koala in South Australia. Pp. 132-43 in The koala ed by T. J. Bergin. John Sands Pty Ltd, Sydney.
- Sheppard, J., 1990. The Wedderburn koala colony. Pp. 70-73 in Koala summit. Managing koalas in New South Wales ed by D. Lunney, C. A. Urquhart and P. Reed. NSW National Parks and Wildlife Service, Sydney.
- Smith, P. and Smith, J., 1990. Decline of the urban koala (*Phascolarctos cinereus*) population in Warringah Shire, Sydney. *Aust. Zool.* 26: 109-29.

Appendix 3.

Sluiter *et al.* 2002.

KOALA FEEDING AND ROOSTING TREES IN THE CAMPBELLTOWN AREA OF NEW SOUTH WALES

ALAN F. SLUITER, ROBERT L. CLOSE, AND STEVEN J. WARD.

IN assessing habitat quality for koalas (*Phascolarctos cinereus*), the relative importance of trees used for food and for roosting must be established. Robbins and Russell (1978) and Hindell *et al.* (1985) suggested that trees in which *P. cinereus* roosted by day reliably predicted the trees they browsed. Tun (1993) and Hasegawa (1995), however, using leaf cuticle analysis of *P. cinereus* faecal pellets, questioned that suggestion.

Phillips and Callaghan (2000) investigated preferences of *P. cinereus* in the Campbelltown area, 40 km southwest of Sydney, by recording the presence of faecal pellets beneath trees in survey quadrats. They concluded that *Eucalyptus punctata* (grey gum) and *E. agglomerata* (blue-leaved stringy bark) were preferred species on shale-based soils. However, this method still does not distinguish between trees used for roosting and those used for feeding. Cuticle analysis was therefore used at Campbelltown as a test of dietary preference (Table 1). These data on species use were compared with sightings from a radio-tracking study of the same individuals (Table 2), in a separate study (Ward 2002).

Cuticle analysis depends on the assumptions that species are distinguishable by patterns of epidermal and guard cells and oil glands imprinted in fragments of leaf cuticles that survive the digestive processes and that these fragments occur in the faeces in the same proportions as consumed. Ellis *et al.* (1999) showed that these assumptions were valid for the species they used in their studies on *P. cinereus* in Queensland. Sluiter (2000), using a reference collection of cuticles prepared by B. Ellis (Ellis *et al.* 1997), developed a key to distinguish the species used in the current study.

The faecal samples came from fresh pellets collected opportunistically during a study in which three female *P. cinereus* were radio-tracked in the

Campbelltown area over a period of three years (Ward 2002). These three *P. cinereus* have been part of a community-based survey (Ward and Close, 1998, 2002) and have featured in a weekly column run in the *Macarthur Advertiser* since 1996. In this column the *P. cinereus* are identified by the names SHIRLEY, LYN and SARAH. These names will be used here rather than their field numbers (C93006, C96002, and C96011 respectively). SHIRLEY and LYN live in KentLYN, a suburb of Campbelltown and were adults (≥ 3 years) for all observations documented here. SARAH resides in Wedderburn (6 km south of KentLYN) and was younger (~ 2 years) when her pellets were first collected for this study.

The breeding population to which these three *P. cinereus* belong occupies areas around the Upper Georges River and its tributaries (Cork *et al.* 1988; Close 1993; Ward and Close 1998). The homerange of SHIRLEY includes a small gully draining into the Georges River (Ward 2002). The vegetation on the upper slopes of the gully is described as Shale/Sandstone Transition Forest (with high sandstone influence and $>10\%$ crown cover) while that on the lower slopes is typical of Hawkesbury sandstone (NPWS 2000). The homerange of LYN, 1 km NE of that of SHIRLEY, includes a shallow gully draining into Peter Meadows Creek, a tributary of the Georges River (S. Ward, unpubl. data). Soils of most of this homerange are derived from Hawkesbury sandstone (NPWS 2000), and the vegetation is typical of those soils. The vegetation on the western edge of the homerange, however, includes Shale-Sandstone Transition Forest ($<10\%$ crown cover) (NPWS 2000). The third animal, SARAH, inhabits a plateau area at Wedderburn, with a steep slope leading into O'Hares Creek in the east and a shallow gully leading into Pheasants Creek in the west (Ward 2002). The vegetation is typical of Hawkesbury sandstone soils (NPWS 2000).

AF Sluiter, RL Close and SJ Ward. 2002. Koala feeding and roosting trees in the Campbelltown area of New South Wales. *Australian Mammalogy* 23: 000-000.

Key words: koala, *Phascolarctus*, diet, leaf cuticle, faecal pellet, scat.

A.F. Sluiter, R.L. Close, and S.J. Ward, School of Science, Food and Horticulture, University of Western Sydney, Campbelltown, Locked Bag 1797, Penrith South DC, New South Wales 1797, Australia. Email: r.close@uws.edu.au. Manuscript received 8 January 2002; accepted 14 February 2002.

Collected pellets from each *P. cinereus* were grouped into three seasons: winter (June to August), summer (December to February) and autumn (March to May). Seasons for analysis for each animal depended on the number of pellets in the opportunistic collection. Three seasons were analysed for SHIRLEY (winter 1997 and 1999, summer 1997-98), and two each for LYN (winter and autumn 1999) and SARAH (winter 1997 and summer 1997-98).

Leaf cuticles were obtained by pooling 2 - 3 mm of the broader ends of each of at least five faecal pellets from each season for each animal. A pinch of acid-washed sand was added to each pooled sample which was then ground for 70 turns of a mortar and pestle. Leaf fragments of various sizes were produced, optimally 200 - 500 μ m in diameter and containing several stomata and their surrounding guard cells. Following a modified protocol of Ellis *et al.* (1997), these fragments were then bleached (White King) to digest leaf mesophyll layers, stained using safranin (Bio-scientific), dehydrated in ascending concentrations of ethanol then mounted on slides using Eukitt (Carl Zeiss). Three replicate slides for each pooled sample were examined.

Individual fragments of cuticle were identified to species by using diagnostic patterns of stomata, guard cells, epidermal cells and oil glands (Ellis *et al.* 1997; Sluiter 2000). The number of cuticle fragments of each species was recorded (Table 1). Contingency tests indicated that counts for each set of replicate slides were consistent (SHIRLEY $\chi^2_{[2]} = 1.85$; LYN $\chi^2_{[2]} = 1.95$; SARAH $\chi^2_{[1]} = 0.21$; all $p > 0.05$).

No significant associations were found between pellet counts and seasons for any animal (SHIRLEY $\chi^2_{[4]} = 7.57$; LYN $\chi^2_{[4]} = 1.96$; SARAH, $\chi^2_{[1]} = 0.22$; all $p > 0.05$). Cuticle fragment results were then pooled for each animal (Table 1).

Animal	Ep	Ea	Cg	Unknown	Total
SHIRLEY	96	19	30	0	145
LYN	61	1	0	4	66
SARAH	73	25	0	0	98

Table 1 Counts of cuticle fragments found in each koala's faecal pellets by species. Ep = *Eucalyptus punctata*; Ea = *E. agglomerata*; Cg = *Corymbia gummifera*.

There were insufficient data to compare observations of tree use (from radio-tracking studies) for the actual seasons in which pellets were collected. However, there were no significant differences between pooled observations (SHIRLEY 37 observations, LYN 22, and SARAH 13) from the periods used for faecal peller analysis and between observations made outside those periods (SHIRLEY $\chi^2_{[2]} = 0.24$; LYN $\chi^2_{[2]} = 2.35$; SARAH $\chi^2_{[1]} = 0.20$; all $p > 0.05$).

Grey gum, *E. punctata*, was the principal component of the pellets, comprising 66 - 92 % of the cuticle fragments for all three animals (Table 1). This species has long been regarded as important to *P. cinereus* (Robbins and Russell 1978; Cork and Warner 1983; Cork *et al.* 1988). However, despite the dominance of *E. punctata* cuticle fragments, there were significant differences among the three animals ($\chi^2_{[6]} = 68.84$, $p < 0.005$). LYN's pellets were almost exclusively *E. punctata*, whilst both SARAH's and SHIRLEY's pellets had significant amounts of blue-leaved stringy bark, *E. agglomerata*, and SHIRLEY's pellets also had many red bloodwood, *Corymbia gummifera*, fragments (Table 1).

There were also significant differences among the three animals in their tree choice as determined by radio-tracking observations ($\chi^2_{[6]} = 36.67$, $p < 0.005$). The percentage of observations in *E. punctata* (17 - 25 %) was consistent for all three *P. cinereus* but 15 % of SARAH's observations were in stringybarks, whilst only 0.5 % of SHIRLEY's observations were in this group (Table 2). Although all three *P. cinereus* were observed most often in trees in the 'Other' category, most of these observations for the two KENTLYN animals were in the densely foliated turpentine, *Syncarpia glomulifera*. This species does not occur at Wedderburn.

Animal	Ep	Str	Cg	Other	Total
SHIRLEY	33	1	5	158 (81)	197
LYN	23	7	8	53 (32)	91
SARAH	15	11	5	41 (0)	72

Table 2 The number of diurnal radio-tracking observations for each koala in different tree species. Ep = *Eucalyptus punctata*; Str = Stringybarks* = *E. agglomerata*, *E. capitellata*, *E. eugenioides*, *E. globoidea*, and *E. oblonga*; Cg = *Corymbia gummifera*; Other = *Syncarpia glomulifera*, *Acacia* spp., *Angophora costata*, *A. bakeri*, *Banksia serrata*, *Casuarina* spp., *Ceratopetalum apetalum*, *C. gummiferum*, *E. crebra*, *E. haemastoma*, *E. pilularis*, *E. piperita*, *E. sieberi*, *E. tereticornis*, *Glochidion ferdinandi*, *Ligustrum lucidum*, *Melaleuca* spp., *Pitiosporum undulatum*. (From Ward 2002). * Stringybark species were grouped together due to difficulties in distinguishing these species in the field.

The frequency of sightings in *E. punctata* was clearly lower than the 66 - 92 % of *E. punctata* cuticle fragments detected in each animal's pellets. This difference, and the number of *P. cinereus* sightings in trees such as *S. glomulifera*, a species which was not detected in the faecal pellets, indicates that all three animals selected trees for non-dietary reasons, presumably because of the shelter they provide. *S. glomulifera* has dense, leafy foliage, and may be chosen because the dense foliage protects *P. cinereus* from sun and predators.

Our results are consistent with the hypothesis that *E. punctata* and stringybarks (principally *E. agglomerata*) are the preferred dietary species of Campbelltown *P. cinereus*, and with the findings of Phillips and Callaghan (2000) that *E. punctata* and *E. agglomerata* were significantly preferred. In New South Wales the State Environmental Planning Policy 44 (SEPP 44) provides legislative controls over development of potential *P. cinereus* habitat. Whilst *E. punctata* is listed in the SEPP 44 as a recognised food tree, *E. agglomerata* is not. We believe that there is now strong evidence, from two separate studies, that *E. agglomerata* is a significant browse species, and therefore should be listed under Schedule 2 of SEPP 44 legislation. Other stringybark species may also prove to be important food sources in the Sydney region.

ACKNOWLEDGEMENTS

We are grateful to LYNN Coxall for her assistance with radio-tracking, data recording and scat collection. The Australian Koala Foundation provided funding to set up the cuticle reference collection and supported the work of S. Ward. *The Macarthur Advertiser* and the University of Western Sydney provided the PhD scholarship for S. Ward. Professor Ian Hume provided constructive comments on the manuscript.

REFERENCES

- CLOSE RL, 1993. Campbelltown's koalas: what is their future? *National Parks Journal* 37: 22-25.
- CORK SJ, MARGULES CR AND BRAITHWAITE LW, 1988. A survey of koalas and their habitat near Wedderburn NSW, suggestions for management and an assessment of the potential effects of a proposed subdivision of four hectare lots. (A report for Campbelltown City Council). CSIRO Division of Wildlife and Ecology: Canberra.
- CORK SJ, AND WARNER ACI, 1983. The passage of digesta markers through the gut of a folivorous marsupial, the koala *Phascolarctos cinereus*. *Journal of Comparative Physiology* 152: 43-51.
- ELLIS B, CLOSE RL AND WARD S, 1997. Identification of leaf fragments in koala faecal pellets. Pp. 68-72 in *A conference on the status of the koala in 1997: incorporating the sixth national carer's conference*. Australian Koala Foundation: Brisbane.
- ELLIS W, CARRICK KP, 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.
- HASEGAWA M., 1995. Habitat utilization by Koalas (*Phascolarctos cinereus*) at Point Halloran, Qld. M.Sc. thesis, University of Queensland, Brisbane.
- HINDELL MA, HANDASYDE (NÉE LITIGOW) KA AND LEE AK, 1985. Tree species selection by free-ranging koala populations in Victoria. *Australian Wildlife Research* 12: 137-144.
- NPWS (NATIONAL PARKS AND WILDLIFE SERVICE), 2000. Native vegetation of the Cumberland Plain, Western Sydney Map series, Campbelltown 1:25,000. NSW NPWS: Hurstville.
- 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.
- ROBBINS M AND RUSSELL E, 1978. Observations on movement and feeding activity of the koala in a semi-natural situation. Pp. 29-41 in *The koala* ed by T.J. Bergin. Zoological Parks Board of New South Wales: Sydney.
- SLUITER AF, 2000. Determination of preferential consumption of tree species by the koala, *Phascolarctos cinereus*, using faecal pellet analysis. Honours thesis, University of Western Sydney, Campbelltown.
- TUN N, 1993. Re-establishment of rehabilitated koalas in the wild and their use of habitat in Sheldon, Redland Shire, South-east Queensland with particular reference to dietary selection. M.Sc. thesis, University of Queensland, Brisbane.
- WARD SJ AND CLOSE RL. 1998. Community assistance with koala *Phascolarctos cinereus* sightings from a low density population in the south-west Sydney region. Pp. 97-102 in *Ecology for everyone: Communicating ecology to the scientists, the public and the politicians* ed by R.T. Wills and R.J. Hobbs. Surrey Beatty and Sons: Sydney.
- WARD SJ, 2002. *Koalas and the community: a study of low density populations in southern Sydney utilising community reports, opportunistic captures and radio-tracking techniques*. Ph.D. thesis, University of Western Sydney, Campbelltown.
- WARD SJ AND CLOSE RL, in press. Sydney's urban koalas: community research, education, politics at Campbelltown. Pp. ?? in *Urban ecology* ed by D. Lunney. Royal Zoological Society of New South Wales: Sydney.

Appendix 4.

Koala Hotline and Educational Handouts.

Information on Southern Sydney Koalas.

Koalas are found in eucalypt (gum tree) forests in the states of Queensland, New South Wales, Victoria and South Australia. The size and other characteristics of the koala varies. For example, Victorian and South Australian koalas weigh up to 15kg and have long fluffy brown fur, New South Wales koalas weigh up to 11kg and have shorter grey fur, whilst Queensland koalas are similar to those in NSW but are rarely over 10kg in weight.

The area each koala uses (ie. its home-range) varies too. In areas with fertile soils, koalas may use only 2-3 hectares each (a hectare is an area of land measuring 100m by 100m). In the southern Sydney area, the soils are usually less fertile and koalas use a much larger area: males 80-150 hectares and females 10-60 hectares.

The density of koalas (ie. the number of koalas in a set area, for example cities have a high density of people compared to country areas) is low in the southern Sydney area because the soil is not fertile enough to support lots of koalas. Much of the soils in the southern Sydney area are sandstone, which has a very low fertility. The more fertile soil type is the area is derived from shale, although lenses, or patches, of shale may occur amongst the less fertile sandstone soils. However, much of the vegetation on shale soils has been cleared, so it is important to conserve as much shale soil vegetation which remains as possible.

Koalas are normally solitary (ie. they live alone), except a mother and young, or male and female may sometimes be found sharing the same tree. Wild koalas may live for up to 10 to 15 years. Males are mature at about age 4, when they may start competing with the large dominant males so they can mate with females. A mature male has a "sternal gland". This gland oozes a smelly substance down the middle of the male's chest and stains the white chest fur a dark brown colour. The smelly substance from this gland is left on trees to tell other koalas where that male's territory is.

Females can have young from when they are two years old, although the youngest female observed to have young in southern Sydney was three years old. Females normally have only one young, which is called a joey, or cub. The females living in bush on shale soils can rear almost one joey every year, but those on sandstone soils only tend to only raise a joey once every two years.

When a joey is born it is very small, about 3-4 cms long, only has small arms, no fur, and its eyes will not yet have opened. Immediately after the birth the joey crawls up into its mother's pouch and then starts feeding on milk. It will stay in the pouch while it grows for the next 6 months. After this time the joey starts to emerge and usually leaves its mother when 12-18 months old. The joey, particular males, may then move long distances away from the mother, sometimes 20 kilometres or more.

The koala breeding season is from September to February. During this time males will often bellow to tell other koalas where they are. This is a strange grunting sound, sounding a little bit like a pig, and people are often surprised when they find out that this is the kind of noise a koala would make. You can hear a recording of a male bellowing by calling (02) 4620 3200.

Threats to koalas include clearing of bush, cars and dogs. Clearing bushland destroys both the koalas food and their home, and so is the most serious threat. The most significant way residents with bushland can help is to keep the bush (ie. not clear their land). Residents may also want to consider allowing previously cleared areas to regenerate, and possibly by planting koala food trees. The best saplings will be those obtained from local seed stocks. Tree species used for food by koalas in the southern Sydney area include Grey Gums (*Eucalyptus punctata*), Stringybarks (*Eucalyptus agglomerata*), Forest Red Gum (*Eucalyptus tereticornis*) and Bloodwoods (*Corymbia gummifera*). Other tree species are also used with the thick bushy Turpentine (*Syncarpia glomulifera*) being particularly favoured for shelter, while the Blackbutt (*Eucalyptus pilularis*), Sydney Peppermint (*E. piperita*), and Smooth Barked Apple (*Angophora costata*) are used for shelter and possibly eaten. Those considering planting trees should note, however, that given the right conditions some of the species listed here can grow to become very large trees.

Clearing is not the only threat to koalas, however, as vehicles like cars and trucks can hit koalas while they are crossing a road; koalas have little or no road sense. If koalas occur in the area where you live, you should be on the lookout whilst driving, particularly at night.

Dogs can also attack koalas and kill them. An adult koala is strong, and has sharp teeth and claws, so may have a chance against one dog, but little against a pack of dogs. Dog owners can assist koalas by making sure that their dogs cannot escape from their property, and that dogs are inside or chained up at night, which is the time when koalas will mainly come down to the ground to move between trees.

If a sick or injured koala is found it should be left alone and the University of Western Sydney contacted on the koala hotline as soon as possible on (02) 9962 9996. A pager message will then be sent to the koala researchers. Please make sure to have the page include that the koala is injured, as well as giving your name and a contact number so that the researchers know that your message is urgent. We also recommend that you contact an animal care group too, as it is not always possible for the researchers to respond immediately to a message. Some animal care groups in the Sydney region are WIRES, Sydney Metropolitan Wildlife Service, AWARE and NANA. Please also note that, even if hurt, wild koalas will see humans as a threat and will resist capture by biting and clawing and can inflict nasty wounds.

Reporting all koala sightings will help koalas as it allows researchers to get a better idea of where they occur. Sightings can be reported on (02) 9962 9996, whether recent or historical, or if the koala was alive or dead. Please leave your name and a contact number so you can be contacted to get the full details of the sighting. Messages also occasionally go astray so please call again if you have not been contacted in a day or so.

Koalas are captured by University of Western Sydney (UWS) researchers where possible, to gather information on the koala's age, sex, condition, and other data (under licences from the National Parks and Wildlife Service). Captured koalas have a coloured tag placed in each ear and are then released in the capture location. If a koala has ear-tags, and you note down the colour of the tag in each ear, we can identify the koala, because each koala has a unique colour combination. The tags can be very difficult to see though because a koala's ears have long, thick fur.

If you wish to find out more about koalas a 20 minute video "Koala Tales: Koalas in Southern Sydney" is available for purchase from Associate Professor Robert Close at UWS; call the koala hotline for more details. You could also join Mac's Koala Club, run by the *Macarthur Advertiser* [ph: (02) 4640 5151], or try the recommended references below.

Koala Hotline: (02) 9962 9996

Recommended references:

- R. Martin & K. Handasyde (1999). *The koala: natural history, conservation and management*. NSW Uni Press, Sydney.
- B. Phillips (1990). *Koalas: the little Australians we'd all hate to lose*. Aust. Government Publishing Service, Canberra.
- University of Western Sydney Campbelltown (1999). *Koala Tales: koalas in southern Sydney*. 19 min. video.

This research has been supported by:

THE MACARTHUR
Advertiser



AUSTRALIAN KOALA FOUNDATION

Conditions of Use: Approval is given for this two-page handout to be used without charge, provided that the conditions of use section is included with all copies made and that neither the content of this handout or this section are changed or altered in any way.

Author: Steven Ward, 30th October 2001.

Wanted - Koala Sightings (02) 9962 9996

University of Western Sydney Macarthur

Current or historical koala sightings,
alive or dead, 24 hours a day.

If a koala is spotted please note the colour of ear-tags (if present)

Wanted - Koala Sightings
(02) 9962 9996

University of Western Sydney Macarthur

Current or historical koala sightings,
alive or dead, 24 hours a day.

If a koala is spotted please note the colour of ear-tags (if present)

Wanted - Koala Sightings
(02) 9962 9996

University of Western Sydney Macarthur

Current or historical koala sightings,
alive or dead, 24 hours a day.

If a koala is spotted please note the colour of ear-tags (if present)

Wanted - Koala Sightings
(02) 9962 9996

University of Western Sydney Macarthur

Current or historical koala sightings,
alive or dead, 24 hours a day.

If a koala is spotted please note the colour of ear-tags (if present)

Wanted - Koala Sightings
(02) 9962 9996

University of Western Sydney Macarthur

Current or historical koala sightings,
alive or dead, 24 hours a day.

If a koala is spotted please note the colour of ear-tags (if present)

KOALAS AND THE COMMUNITY:
A STUDY OF LOW DENSITY POPULATIONS
IN SOUTHERN SYDNEY.

By

Steven John Ward

A thesis
presented to the University of Western Sydney
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

July, 2002

© SJ Ward 2002



PLEASE NOTE

The greatest amount of care has been taken while scanning this thesis,
and the best possible result has been obtained.

Acknowledgments

This research has been supported financially by *The Macarthur Advertiser*, the Australian Koala Foundation, the Hacking River and Georges River Catchment Management Committees, and Sydney philanthropists who donated funds for video production. I also thank the Macarthur Advertiser for the publicity provided. I thank the Macarthur branch of the National Parks Association, Corporal Thompson, NSW National Parks and Wildlife Service, and others who reported koala sightings, and Campbelltown Council and the Australian Army for access to their land.

I thank my supervisor, Associate Professor Robert Close, for his assistance and extraordinary dedication to the research project, and my cosupervisor, Robert Whelan.

I thank Lynn Coxall for taking over koala radiotracking, and for assistance in deciphering, organising and entering data. Wayne Foster provided assistance with eucalypt identification. I also thank Wayne Foster and Anthony Scarman for the use of their koala sighting data. Brett Tyler, climber extraordinaire and technology buff assisted with many koala captures.

I would also like to thank: Gaylene Parker for care of sick and injured animals; Phil Ronaldson for assistance with MapInfo; Gary Schoer for advice with the postal survey; Simone Kleyn and Robyn Wosinki for postal survey data entry; and the many other volunteers who assisted with fieldwork.

Map Acknowledgments

Maps on pages 20, 21, 59, 62, 63, 69, 73, 82, 83, 88, 118, 186 are copyright © Commonwealth of Australia, AUSLIG, Australia's national mapping agency. All rights reserved. Reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Industry, Science and Resources, Canberra, ACT.

Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from AUSLIG. Requests and Inquires concerning reproduction and rights should be addressed to the Manager, Australian Surveying and Land Information Group, Department of Industry, Science and Resources, PO Box 2, Belconnen, ACT, 2616, or by e-mail to copyright@auslig.gov.au.

Maps on pages 17, 18 and 85 are copyright © and use Sydney (1983), Wollongong – Port Hacking (1985), and Penrith (1991) 1:100,000 geology maps, with the permission of the Department of Mines and Mineral Resources. All rights reserved.

NPWS Data Acknowledgments

Data from the Atlas of New South Wales Wildlife database was provided on the 1st September 2000 is used with the permission of the NPWS. Data came from: zone 56, 200000E to 350000E, and 6150000N to 62255000N.

Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in whole or in part, for a degree at any other institution.

Steven Ward

.....
(Signature)

TABLE OF CONTENTS

List of Tables	v
List of Figures	vii
Abbreviations	ix
Abstract	x
1 General Introduction	1
1.1 Conservation and Distribution of the Koala.....	1
1.2 Sub-species Differences.....	1
1.3 Energy.....	2
1.4 Nutrition.....	3
1.5 Water Balance.....	4
1.6 Plant Defences, Soil Fertility and Herbivory.....	5
1.6.1 Resource-Availability.....	5
1.7 Social Behaviour.....	7
1.8 History.....	7
1.9 Threats to Koalas.....	8
1.10 Are Human Impacts on Sydney Koalas Increasing?.....	10
1.11 SEPP44.....	11
1.12 Low Density Koala Populations: Reasons for a Paucity of Information.....	12
1.13 The Value of the Study Populations.....	13
1.14 Objectives.....	13
2 Site Characteristics	15
2.1 Two Study Regions.....	15
2.2 Soils.....	16
2.3 Rivers and Topography.....	19
2.4 Remnant Vegetation.....	22
2.5 Local History.....	23
2.6 Known Koala Populations.....	25
2.7 Problems Arising from the Characteristics of the Study Area.....	26
2.8 Advantages of this Study.....	26
3 Search Techniques	28
3.1 Introduction.....	28
3.1.1 Locating Koalas.....	28
3.1.2 Techniques for Density Estimation.....	28
3.1.3 Survey Techniques to Investigate Koala Distribution.....	33
3.1.3.1 Faecal Pellet Surveys.....	33
3.1.3.2 Asterix Method.....	35
3.1.3.3 Pre-logging Surveys.....	35
3.1.3.4 Community Surveys.....	36
3.1.4 Previous Studies of Southern and Greater Sydney Region Koalas.....	39
3.1.4.1 Southern Sydney Region.....	39
3.1.4.2 Greater Sydney Region.....	40
3.1.5 Techniques Used in this Study.....	41
3.1.6 Objectives.....	43
3.2 Methods.....	43

3.2.1	Data Sources for Koala Sightings.....	44
3.2.2	Estimating Koala Population Numbers	51
3.2.3	Data Management.....	52
3.2.3.1	Postal Survey Data.....	52
3.2.3.2	Koala Sighting Data.....	52
3.3	Results	55
3.3.1	Number of Reports	55
3.3.2	Sighting Quality and Reliability.....	56
3.3.3	Distribution of Southern Sydney Sightings.....	60
3.3.4	Distribution of Greater Sydney Sightings	64
3.3.5	Koala Ages	66
3.3.6	Females with Young.....	67
3.3.7	Dead or Injured Koalas.....	70
3.3.8	Temporal Changes.....	74
3.3.9	Seasonal Variation in Koala Reports.....	81
3.3.10	Koala Movements	81
3.3.11	Soil Fertility	84
3.3.12	Density Estimates.....	86
3.3.12.1	Volunteer Searches	86
3.3.12.2	Home Range Estimate	87
3.3.13	Estimates of Koala Numbers.....	87
3.3.14	Sutherland Postal Survey	89
3.4	Discussion.....	90
3.4.1	Sutherland Postal Survey.....	91
3.4.2	Comparison of Data Sources	94
3.4.3	Southern Sydney Distribution	96
3.4.4	Greater Sydney Distribution.....	97
3.4.5	Estimates of Koala Numbers	98
3.4.6	Population age structure	98
3.4.7	Koala Movements.....	99
3.4.8	Dead / Injured Koalas.....	99
3.4.9	Temporal Changes.....	100
3.4.10	Soil Fertility	102
3.4.11	Volunteer Searches.....	102
3.4.12	Conclusions about Search Techniques.....	103
4	Population Parameters.....	104
4.1	Introduction	104
4.1.1	Aging Koalas.....	105
4.1.2	Sex ratio.....	105
4.1.3	Death, Disease, and Parasites	106
4.1.3.1	Natural Predators	106
4.1.3.2	Car and Dog Mortalities	106
4.1.3.3	Disease.....	107
4.1.3.4	Parasites	109
4.1.4	Fertility	109
4.1.5	Condition.....	112
4.1.6	Capture Methods	112
4.1.7	Objectives.....	113
4.2	Methods	114
4.2.1	Measurements.....	115
4.2.2	Data Handling.....	117
4.3	Results	118

4.3.1	Sex Ratio	118
4.3.2	Deaths	119
4.3.3	Chlamydia	120
4.3.4	Parasites.....	121
4.3.5	Growth Curves	121
4.3.6	Size and weight	122
4.3.7	Condition	123
4.3.8	Fertility Rates	124
4.3.9	Ages of Male Koalas	126
4.4	Discussion.....	126
4.4.1	Size, age, weight and condition	127
4.4.2	Fertility Rates	128
4.4.3	Capture Success and Sex Ratio	130
4.4.4	Mortalities and Parasites.....	131
5	Sightability and Home Range.....	132
5.1	Introduction	132
5.1.1	Definition of Home Range	133
5.1.2	The Effect of Sex and Age on Home Range	133
5.1.3	Home range Analysis Techniques	134
5.1.4	Issues in Home Range Analysis	135
5.1.4.1	Fix Resolution.....	135
5.1.4.2	Location Autocorrelation.....	136
5.1.4.3	Isopleth Value Selection.....	137
5.1.4.4	Number of Fixes Required.....	137
5.1.5	Koala Home Range Studies.....	138
5.1.6	Objectives.....	139
5.2	Methods	140
5.2.1	Fix Resolution	140
5.2.2	Time between Fixes.....	142
5.2.3	Isopleth Values.....	142
5.2.4	Number of Fixes.....	143
5.3	Results	146
5.3.1	Home Range Size	146
5.3.2	Male versus Female Home Range Size	148
5.3.3	Female Home Range Shapes	149
5.3.4	Male Home Range Shapes.....	151
5.3.5	Sightability	153
5.4	Discussion.....	155
5.4.1	Comparison with Published Koala Studies	155
5.4.2	Size and Shape.....	157
5.4.3	Analysis Techniques.....	158
5.4.4	Sightability	158
6	Tree Use and Preferences.....	160
6.1	Introduction	160
6.1.1	SEPP44.....	160
6.1.2	Definition and Assessment of Tree Preferences.....	160
6.1.2.1	Relative Utilisation.....	162
6.1.3	Roost Trees and Feed Trees	162
6.1.4	Tree Size Preferences	163
6.1.5	Reuse of Trees	163

6.1.6	Objectives.....	164
6.2	Methods.....	164
6.2.1	Formulae for Relative Utilisation.....	165
6.3	Results.....	165
6.3.1	Tree Use.....	165
6.3.2	Tree Use by Sex and Location.....	166
6.3.3	Relative Utilisation.....	168
6.3.4	Schedule 2 SEPP44 Vegetation.....	170
6.3.5	Tree Size Preferences.....	171
6.4	Discussion.....	171
6.4.1	SEPP44.....	171
6.4.2	Tree Species Preferences.....	173
6.4.3	Tree Size Preferences.....	173
6.4.4	Roost versus Feed trees.....	174
6.4.5	Tree Reuse.....	174
7	Koala Management in the Southern and Greater Sydney Regions.....	176
7.1	Introduction.....	176
7.1.1	Review of Relevant Findings from this Study.....	176
7.1.2	The Declining-Population and Small-Population Paradigms.....	179
7.1.3	Minimum Viable Population Size.....	180
7.1.3.1	Effective Population size.....	180
7.1.4	Koala Plans of Management (KPoM).....	181
7.2	Discussion.....	182
7.2.1	Koala Numbers.....	182
7.2.2	Revising SEPP44 Legislation.....	183
7.2.3	Habitat Clearing.....	183
7.2.4	Mortalities.....	184
7.2.4.1	Road and Rail.....	184
7.2.4.2	Dogs and Feral Animals.....	189
7.2.4.3	Fire.....	191
7.2.5	Habitat Restoration.....	192
7.2.6	Education.....	192
7.2.7	Addressing Information Gaps on Koala Ecology in Sydney.....	193
7.2.8	Tourism.....	194
7.2.9	Translocations.....	195
7.3	Recommendations.....	196
8	References.....	200
	Appendix 1. Report on the Sutherland Postal Survey.....	216
	Appendix 2. Ward and Close 1998.....	235
	Appendix 3. Sluiter <i>et al.</i> 2002.....	242
	Appendix 4. Koala Hotline and Educational Handouts.....	246

LIST OF TABLES

Table	Page
1.1 Increase in human populations from 1986 to 1996 for Local Government Areas in the study area where koalas were found.	11
3.1 Published koala densities, the location of the population studied and the method used to estimate density..	31
3.2 Details of published koala postal surveys..	37
3.3 Credible, historical and total number of reports of koala sightings for the southern and greater Sydney study regions.	55
3.4 Number of public reports of credible and historical koala sightings by the year they were reported, for the southern Sydney and greater Sydney regions.	56
3.5 Sighting date quality by data source for the southern and greater Sydney regions combined.	57
3.6 Sighting location quality by data source for the southern and greater Sydney regions combined.	58
3.7 Number of non-koala and koala reports by source, for both the southern and greater Sydney study regions..	58
3.8 Number of credible reports in one of three age categories based on the reporter's description of the size of the koala.	67
3.9 Number of credible and historical reports of koalas with young for both the southern and greater Sydney regions..	67
3.10 Details for historical sightings of note for the southern Sydney region, together with the number assigned to the records.	80
3.11 Details for historical sightings of note for the greater Sydney region, together with the number assigned to the records.	81
3.12 Details for all volunteer searches conducted.	86
3.13 Strengths and weaknesses of the data sources used.	94
4.1 Published information on koala fertility rates, and the incidence of chlamydial infection (if available)..	111
4.2 Sex ratios within three categories for all koalas captured from 1990 to 2000 ...	119
4.3 Causes of known koala deaths.	119
4.4 Details for koalas that returned positive, or 'suspect' positive results, for the IMAGEN slide immunofluorescence test.	120
4.5 Weight and headlength cut off points used to determine the age of female koalas to 4 years old.	122
4.6 Average weights and head lengths for female koalas ≥ 2 years old (≥ 4.62 kg and ≥ 116 mm headlength), with standard deviation.	122
4.7 Average adult male (≥ 2 years old: ≥ 6.2 kg and ≥ 129 mm headlength) weights and head lengths with standard deviations.	123
4.8 Adult male (≥ 2 years old: ≥ 6.2 kg and ≥ 129 mm headlength) condition estimates from all captures.	123
4.9 Adult male and female (adults defined as ≥ 2 years old, females ≥ 4.62 kg and ≥ 116 mm headlength, males ≥ 6.2 kg and ≥ 129 mm headlength) condition estimates.	124
4.10 Data by region, for whether female koalas 36 months or older gave birth to a young in a breeding season.	125
4.11 Ages of male koalas in breeding habitat and areas where sightings of female koalas with young were few.	126
5.1 Comparison of published home range areas.	139

5.2	Details for koalas that had ≥ 10 radiotracking observations.....	146
5.3	Home ranges size for female koalas with 10 or more locations 5 days apart	147
5.4	Home ranges size for male koalas with 10 or more locations 5 days apart.	147
5.5	Comparison of male and female home range size.	149
5.6	Subjective comparison of home range size estimates from this study to estimates from other studies.....	156
6.1	Reuse of individual trees by adult koalas (females ≥ 3 years, males ≥ 4 years) located ≥ 15 times on different days.	166
6.2	Average number of sightings per tree for adult male and female koalas.....	166
6.3	Number of observations in different tree species for adult koalas (females ≥ 3 years, males ≥ 4 years) located ≥ 15 times.....	167
6.4	Relative utilisation (RE) for three adult female koalas, of stems with a diameter at breast-height (dbh) of ≥ 3.8 cm and a height of ≥ 3 m.....	169
7.1	Priority list for relevant authorities of management recommendations made in this study	199

LIST OF FIGURES

Figure	Page
2.1 Location of the study regions, coastline, towns and main roads.....	15
2.2 Geology of the southern Sydney region.....	17
2.3 The topography of the southern Sydney	20
2.4 Map of the greater Sydney region.....	22
3.1 From Caughley (1977): the sequence of decisions by which a census method (other than a mark-recapture technique) is chosen.....	29
3.2 Photographs of toy koalas.....	49
3.3 Map of the areas to which 25 925 University of Western Sydney postal surveys were distributed.....	50
3.4 The location accuracy for credible reports of koala sightings in the southern Sydney region.....	59
3.5 Locations of credible koala sightings by the source of the sighting in the southern Sydney region.....	62
3.6 Locations of historical sightings in the southern Sydney region	63
3.7 Locations of credible koala sightings by the source of the sighting in the greater Sydney region.....	65
3.8 Locations of historical koala sightings in the greater Sydney region.....	66
3.9 Locations of sightings of koalas with young, both credible and historical, in the southern Sydney region.....	69
3.10 Locations of sightings of koalas with young, both credible and historical, in the greater Sydney region	70
3.11 Graph of the percentage of reports, by data source, of dead or injured koalas for both the southern and greater Sydney regions	71
3.12 Locations of sightings of dead or injured koalas in the southern Sydney region	73
3.13 Locations of sightings of dead or injured koalas in the greater Sydney region ...	74
3.14 Graph of the percentage of the total number of koala sightings (both credible and historical) within given time periods, for both in the southern and greater Sydney regions.....	75
3.15 Locations of koala sightings, both credible and historical, that occurred from 1991 to 2000.....	76
3.16 Locations of koala sightings, both credible and historical, that occurred from 1981 to 1990.....	77
3.17 Locations of koala sightings, both credible and historical, that occurred prior to 1981.....	78
3.18 Graph of the total number of credible and historical koala sightings per month for all data sources.....	81
3.19 Map 1 of selected koala movements greater than 2km.....	82
3.20 Map 2 of selected koala movements greater than 2km.....	83
3.21 Locations of credible koala sightings separated by the source of the sighting, plotted over the geology of the southern Sydney region.....	85
3.22 The estimated area used by breeding female koalas in the southern Sydney region	88
3.23 The estimated area used by breeding female koalas in the greater Sydney region	89
4.1 Map of the area subgroupings used for comparisons of koala weight, headlength and female fertility	118

4.2	Graph of weight and head length growth curves derived from measurements for three female koalas of known age.....	121
4.3	Graph of the percentage of females with young within three age categories for the Kentlyn region (shale and sandstone soils) and the Wedderburn region (sandstone soils).....	125
5.1	Diagram of a theoretical minimum convex polygon (MCP) home range.....	134
5.2	Theoretical plot of isopleth values, in 5% increments, against the percentage of the maximum home range size (99% isopleth) for that isopleth value.....	137
5.3	Graph of Schoener's t^2 / r^2 ratio against the time between paired daily locations for Shirley, an adult female koala.....	142
5.4	Plots used to select core home range isopleth values.....	143
5.5	Graph of the percentage of the maximum home range size (harmonic mean) versus the number of fixes for seven male and seven female koalas with 10 or more locations.....	145
5.6	Plots of 60% and 90% harmonic mean isopleths for seven females with ≥ 10 locations.....	150
5.7	Overlay of adult and juvenile 60% and 90% harmonic mean isopleths for three female koalas.....	151
5.8	Plots of 60% and 90% harmonic mean isopleths for male koalas with ≥ 10 locations.....	152
5.9	Plot of 60% and 90% harmonic mean isopleths for the male koala, Ray, with the outlier on 18/12/98 removed.....	152
5.10	Graph of the mean percentage of locations for 3 radiotracked adult female koalas from Kentlyn and Wedderburn in a subjective sightability index score.....	153
5.11	Graph of the percentage of 73 pooled sightability index scores for three radiotracked adult male koalas from Kentlyn.....	154
5.12	Graph of the percentage of pooled locations for a sightability index score for females with back young, pouch young, or no young.....	155
6.2	Graph of relative exploitation (RE) of trees $\geq 3\text{m}$ in height against breast height diameter.....	171
7.1	Map of koala sightings and Local Government Boundaries for the southern and greater Sydney regions.....	177
7.2	Map of roads of concern, koala blackspots and potential crossing points for koalas in the southern Sydney region.....	186
7.3	Map of road and rail koala mortalities and possible crossing points in the greater Sydney region.....	187

Abbreviations

Abbreviations used in the text are:

AKF = Australian Koala Foundation

cm = centimetre

dbh = diameter at breast-height (120cm above ground level)

GIS = Geographic Information System

GPS = global positioning system

ha = hectare

ha year⁻¹ = hectares per year

kg = kilograms

koalas ha⁻¹ = koalas per hectare (density)

KPoM = Koala Plan of Management

LEP = Local Environment Plan

LGA = Local Government Area

m = metre

MCP = minimum convex polygon (home range analysis method)

mm = millimetre

NPA = National Parks Association

NPWS = National Parks and Wildlife

NSW = New South Wales

RE = relative exploitation

sd = standard deviation

SEPP44 = State Environment Planning Policy number 44

t ha⁻¹ = tonnes of fire fuel per hectare

UTM = Universal transverse mercator

UWS = University of Western Sydney (source of koala sightings)

WIRES = Wildlife Information and Rescue Service

Abstract

Prior to this study, low density koala populations were known to exist south of Sydney. The aim of this study was to investigate the distribution, density, health, condition, fertility, causes of mortality, home range size and tree preferences, of koalas in these low density populations. This information was then used to make management recommendations; good management is needed because there is rapid human population growth and pressure for development of koala habitat in the Sydney region.

State Environment Planning Policy 44 (SEPP44) is New South Wales legislation that relates to developments affecting koala habitat. Problems in the application of SEPP44 in the Sydney region were found to exist, such as Sutherland Local Government Area (LGA) not being covered, and changes to this legislation are also recommended.

Details for 904 koala-related reports, primarily from the community, but also from other sources, were collated and entered into a database with filters to improve the data quality. Breeding groups of koalas were found to occur in suburbs to the east of Campbelltown, in the Cordeaux, Avon and Nepean Dam catchments, and at Joadja, Canyonleigh and Yerrinbool. Breeding groups may also exist between Springwood and Lapstone, at Darkes Forest, and in areas not comprehensively surveyed. Breeding animals may also be scattered through the Sutherland and Blue Mountains regions.

Reports of koalas were used to estimate the area of breeding habitat, and together with density estimates of 0.035, and 0.049 koalas ha⁻¹, from modified bounded transect and home range methods, respectively, the koala populations, excluding dependent young, were estimated to be 90-200 between Sydney and Appin, with a further 170-700+ individuals from Sydney west to Katoomba, and south to Marulan. These estimates should, however, be used with caution, as they are essentially educated guesses.

A review of the resource-availability hypothesis, whereby plants on low fertility soils have a higher investment in anti-herbivore defences than those on more fertile soils, suggested that soil fertility could affect koalas. Soil type appeared to affect adult females (≥ 2 years), as those with access to the more fertile shale soil vegetation were significantly heavier (7.28 ± 0.78 kg), and in significantly better condition, than those with access to sandstone soil vegetation only (6.36 ± 0.98 kg). No females were observed

to breed before 3 years of age, and females ≥ 3 years with access to shale soil vegetation were significantly more fertile than those without access (68% and 37.5% respectively). Chlamydial infection was detected, but no effect upon fertility rates was observed. No associations between soil type and male koalas' condition or weight were detected. Vegetation on shale soils which are more fertile than sandstone soils, thus appears to constitute more favourable habitat for female koalas.

Captured koalas were radiotracked to investigate home range size. To minimise autocorrelation, only fixes 5 days apart were used in home range analyses. To reach the asymptote in harmonic mean home range size 60 fixes were needed. Only three adult females had a sufficient number of fixes estimates, and the harmonic mean home range size estimates for these animals ranged from 11.6 - 36.0ha (90% isopleth), and 4.8 - 9.4ha (60% isopleth). A number of males, and one female, had larger home range size estimates despite having insufficient fixes to reach the home range size asymptote. These home range estimates are larger than estimates from many other published studies.

Tree preferences, defined as utilising a species more often than its occurrence, were determined for the three adult female koalas who had ≥ 60 fixes. All preferred *Eucalyptus punctata*, *E. pilularis* and stringybarks (*E. agglomerata*, *E. capitellata*, *E. eugenioides*, or *E. globoidea*). Those females with access to *Syncarpia glomulifera* and *E. piperita* also preferred these species. There is no evidence that *S. glomulifera* was browsed, and I conclude that this species was preferentially selected for the shelter it provided. All three females avoided *Acacia* (various species), *Corymbia gummifera*, *Persoonia* (various species), and stags or stumps.

Large trees, between 30 and 39.9cm diameter at breast height (dbh), were most preferred. There were numerous stems < 10 cm dbh in the home ranges of all three females, and all the koalas used these stems less often than their availability; but these stems still constituted 7% of observations for two females. Many studies only examine trees > 10 cm dbh because this is considered to be the "minimum" size for koala use; I suggest that a 5cm "minimum" dbh value would be more appropriate.

SEPP44 legislation uses koala tree preferences to define "potential koala habitat" as

“Areas of native vegetation where the trees of the types listed in Schedule 2 constitute at least 15% of the total number of trees in the upper or lower strata of the tree component” (Anon 1995). When stems $\geq 8\text{m}$ height and $\geq 38\text{mm}$ dbh within the 90% harmonic mean isopleth for the three adult females were counted, vegetation used by one animal did not meet the SEPP44 definition of potential koala habitat, despite this female having been observed raising young. This means that, in its current form, approval may be given under SEPP44 to develop habitat used by some breeding females. I therefore recommend that the SEPP44 definition of “potential koala habitat” be modified to 10% of trees listed in Schedule 2 (rather than the current 15%). I also recommend that *E. agglomerata* be included in the Schedule 2 list, and as I have collated 103 reports of koala sightings from the Sutherland LGA (excluding hoaxes, false alarms, unreliable and multiple reports), I recommend that this LGA be included in Schedule 1 of SEPP44.

Shale soil vegetation, which appears to be favourable habitat for female koalas has been extensively cleared, and much that remains is on private land in prime areas for housing development. A high priority for koala management south of Sydney should be the conservation of remnant shale soil vegetation. This will be a challenge for local councils, particularly as the human population and development pressures in the region are increasing. The database of koala sightings constructed during this study will be useful in providing information to assess the impact of proposed developments.

Low population sizes, such as estimated in this study for koala populations to the south of Sydney, are prone to loss of genetic variation. Maintaining habitat links to facilitate koala movements, and subsequent gene flow between populations, should help to reduce losses in genetic variation. Nine locations where culverts under roads or railways would facilitate koala movements, and minimise fatalities, were identified. Councils should also minimise mortalities by encouraging responsible pet ownership, including preventing dogs from roaming. Preparation of Koala Plans of Management and Local Environment Plans in LGAs to restrict development in koala habitat will also be of assistance, particularly in the shires of Campbelltown, Wollondilly and Wingecarribee. Anecdotal evidence suggests that large, intense fires can cause problems for koala populations, and scientific input should be obtained regarding environmental impacts of proposed fire regimes.