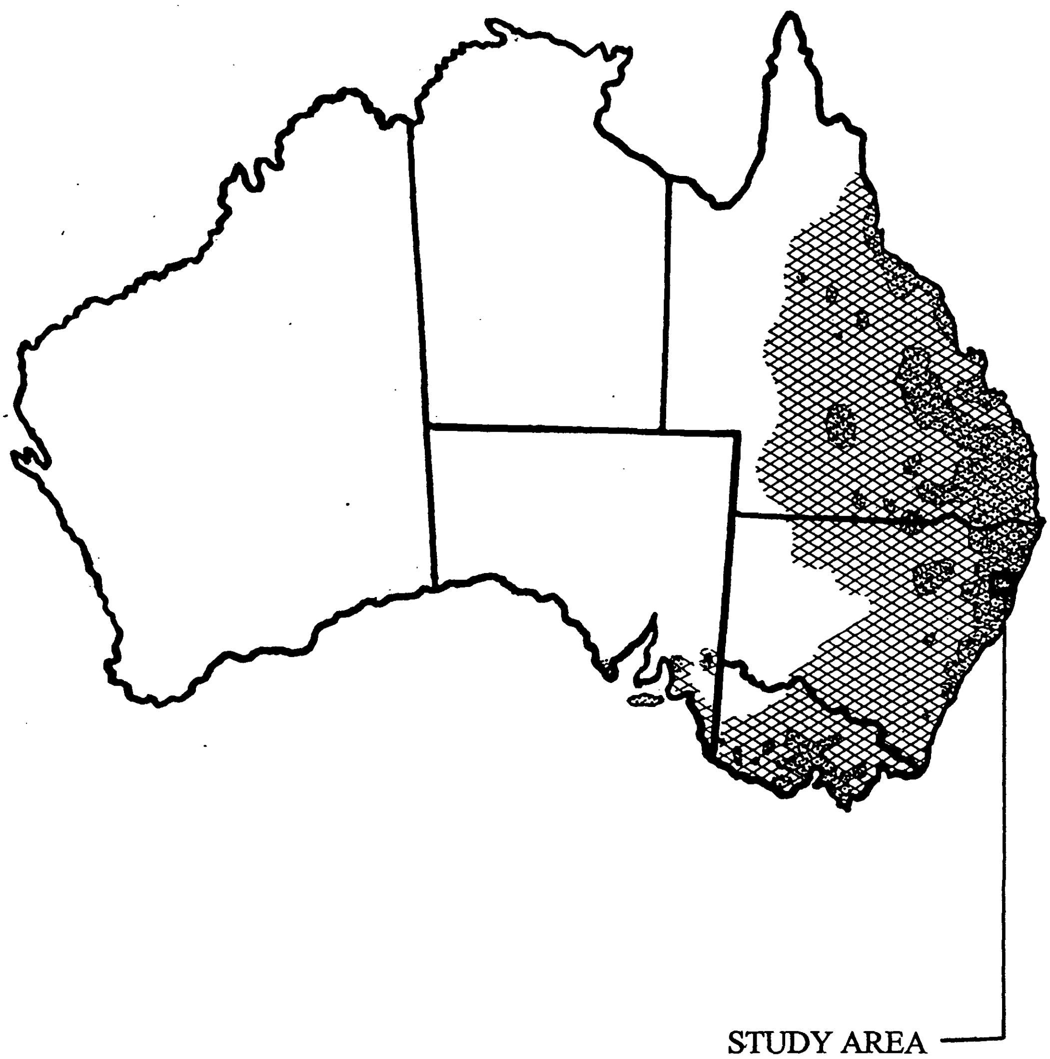
Chapter 1: INTRODUCTION

1.1 Koala Distribution and Abundance:

The koala (*Phascolarctos cinereus* Goldfuss, 1817) (Plate 1) is an arboreal Australian marsupial that is widely distributed across the eastern states of Australia (Figure 1). In New South Wales, dense populations of koalas occur on the north coast as well as in fragmented and restricted areas west of the Great Divide (Reed and Lunney, 1990; Reed et al., 1990; Kavanagh et al., 1995). Low density populations occur in the south (Jurskis and Potter, 1997). Although koalas are mainly found on rural lands in NSW (Reed et al., 1990; Standing, 1990), significant numbers may also occur within State Forests and National Parks (Reed et al., 1990; Jurskis and Potter, 1997).

Once numerous (Gordon and McGreevy, 1978; Warneke, 1978; Lunney and Leary, 1988; Reed and Lunney, 1990), the koala now appears to be in low numbers over most of its range (Reed and Lunney, 1990; Reed et al., 1990). However, high-density localised populations occur in many areas of South Australia, Victoria, Queensland and in NSW, including coastal areas around Port Stephens, Port Macquarie, Coffs Harbour, and Lismore. Most frequently recorded sightings of koalas in State forests occur in the Coffs Harbour area (Reed et al., 1990). Numbers of koalas in the 5 890 ha Pine Creek State Forest near Coffs Harbour have been estimated at between 350 and 450 animals (State Forests NSW, 1997). At Dorrigo in northern NSW, where this study was initiated, the koala occurs throughout the forests in moderate to low numbers (Forestry Commission of NSW, 1985).

Figure 1: Past[1] and present[2] natural distribution of the koala in the eastern states of Australia (from Carrick, 1990).



[1] Hatched areas indicate approximate koala distribution 200 years ago.
[2] Dotted areas indicate approximate current fragmented distribution.

Current estimates of total numbers of koalas in the wild in Australia vary upwards from a conservative 40,000 to 80,000 animals (Australian Koala Foundation, 1994). However, despite efforts to gauge the abundance of the koala in the wild, each year koalas are being killed in alarming numbers due to disease and stress-related ailments, traffic, dogs and loss of habitat. As high as 4000 koala deaths may be occurring annually (Payne, 1995) and the koala is still at risk throughout its range. There are important phylogenetic and national interest reasons why the koala should be conserved, and government fauna legislation is the means by which this is achieved.

1.2 Conservation Status:

Nationally, the koala is not protected under the current *Endangered Species Protection Act 1992*. In New South Wales however, the koala does benefit from protection under the *Threatened Species Conservation Act 1995* that classifies the koala as "vulnerable". This legislative protection has developed dramatically in recent years having important implications for the way that koala habitat has been and is managed.

Prior to 1991, the *National Parks and Wildlife Act 1974* protected most native vertebrate animals (except fishes) in New South Wales, including the koala. On State forest, the early 1990s saw legal battles over the applicability of the *National Parks and Wildlife Act 1974* to forestry activities. These resulted in the extension of the "take or kill" provisions of the Act to include modification of habitat. Out of the disruptions and uncertainty in the industry and forest management that this legal interpretation created, the *Endangered Fauna (Interim Protection) Act 1991* was legislated.

The *Endangered Fauna (Interim Protection) Act* classified the koala as being "Vulnerable and Rare" on Schedule 12 of the Act. A licence under Section 120 of the *National Parks and Wildlife Act* was required for continued timber harvesting operations where there was likely to be an impact upon endangered species, as listed under Schedule 12.

The NSW Department of Urban Affairs and Planning provided more protection for koala habitat on private lands through the provision of the planning guidelines outlined in the State Environmental Planning Policy Number 44, 1995 (SEPP 44) (Lunney et al., 1997). These guidelines required councils to consider all development applications on land larger than 1 ha for potential koala habitat.

Also in 1995, the *Threatened Species Conservation Act* repealed the *Endangered Fauna (Interim Protection) Act*. This Act "*substantially modifies the General (Section 120) licensing provisions to 'take or kill' endangered fauna*" and "*places specific responsibilities on proponents, consent and determining authorities and the NPWS in the fields of environmental planning, development control, recovery planning and threat abatement planning*". Section 120 licences remained a valid authority for State Forests of NSW as an interim approval mechanism (State Forests of NSW, 1997), by becoming licences under Section 6 of the *Threatened Species Conservation Act*.

1.3 Rationale for the Study:

1.3.1 Surveys under the *Endangered Fauna (Interim Protection) Act* 1991:

General fauna surveys were developed in response to the growing number of Environmental Impact Studies that State Forests of NSW were committed to conducting in the early 1990s (York et al., 1991). However, the *Endangered Fauna (Interim Protection) Act* 1991 required the development of specific species prescriptions and, for the koala, the first manifestation of these were outlined in General (Section 120) Licence (Appendix 1) issued following the Wingham EIS determination. The determination identified that "*(iv) The Forestry Commission shall develop a special prescription for the retention of koala habitat in the north-east forests*".

Under Section 120 licensing provisions between 1992 and February 1996, State Forests of NSW were required to adhere to koala protection prescriptions that prescribed "*the extent of habitat use and preferred food trees within the 100 metres radius area.... shall be assessed using a (survey) method approved by the Director-General*", with further prescriptions then applying "*as appropriate to the outcome of that assessment*" (Appendix 1). A critical method of determining the outcome hinged on assessing whether more or less than 20% of trees examined had faecal pellets beneath them. Greater than 20% tree use meant that no logging was permitted in the surveyed area of forest. These surveys therefore became an important aspect of management of State forests because the outcome of a particular survey may have had an impact on both local koala populations and continued timber supply.

This prescription first raised the issue of 'preferred tree species' of the koala and attempted to define these for the 'north-east forests' of NSW. This prescription was then applied to many other northern NSW forest management areas (with EIS's being prepared) because it was the latest determination at that time, and forest managers wanted to conform with latest best practice forest/species management.

1.3.2 The Information Gap:

Because an outcome on logging hung delicately in the hands of surveys, forest managers began to ask many questions, including whether listed tree species (Appendix 1) were the most appropriate for targeting in surveys? Based on some local information and knowledge, managers had "gut feelings" about which tree species koalas were using. However, there has been little scientific information to support local decision-makers, despite a considerable body of research in dense koala populations, eg Victoria and southeast Queensland (Hasegawa, 1995).

While general principles can be applied, it is difficult to draw comparisons about specific koala habitat use from different forest habitat. Hasegawa (1995) commented that tree utilisation needs to be identified for each local population of koalas because habitats and utilisation patterns may change. In the absence of such information, forest managers needed to substantiate current local survey and logging practices in areas where local populations of koalas were known to occur.

Since the publicised court cases of the early 1990s, the general public increasingly became aware of koalas and concerned over logging practices. A lack of local scientific information, this increasing general public pressure and a government requirement to seek the best management practice for koalas in native forests near Coffs Harbour, resulted in withdrawal in October 1995 of approval for harvesting under State Forests' Section 120 Licence TS0041 (State Forests NSW, 1997). In December 1995, the NPWS outlined their requirement for production of a management plan specifically for koalas before approvals for further harvesting could be granted. This prompted local scientific studies on koala habitat, abundance and distribution in the local Pine Creek State Forest attempting to fill the information gap for forest managers in this local area.

1.3.3 Surveys under the *Threatened Species Conservation Act* 1995:

In February 1996, under the *Threatened Species Conservation Act*, a draft set of koala survey guidelines and prescriptions for logging was developed (Appendix 2). This made reference to other tree characteristics such as the spatial arrangement of trees used by koalas and the size of trees. Even though these procedures were becoming more refined in the way they accounted for known koala use of forest habitat, they appeared again to be a "best guess".

These survey guidelines and prescriptions for logging remain today, despite the completion of the local Pine Creek State Forest scientific study and the development for threatened species of "Protocols for Survey of Flora and Fauna" in late 1997. Although the "Protocols" do not cover the koala as yet, new survey guidelines and prescriptions may now be appropriate. The challenge then lies in extrapolating local scientific information from this and the Pine Creek studies to all north coast forests ensuring changes to survey and prescriptions are relevant to local areas.

1.4 Study Significance:

If the koala is to be adequately managed, and ultimately conserved, then survey methods and prescriptions should not only reflect the latest information on koala use of trees, but also endeavour to identify ways of improving what we know of their use. This study will provide scientific evidence on some aspects of the use of trees by koalas that may be helpful to forest managers in their decision-making role in the local area.

There is a wealth of information in the literature on many aspects of the koala's biology and ecology, but many aspects such as tree utilisation are specific to localities (Hasegawa, 1995). This study lends support to theories and findings about tree utilisation by koalas in the same region, such as those from Pine Creek State Forest (SFNSW, 1997).

Part of the significance of this study stems from the fact that the koala is classified as a threatened species in NSW. Any useful addition to the understanding and ultimate conservation of the koala is very worthwhile, particularly as this species is widely and affectionately recognised here and overseas as Australia's ambassador for conservation.

In the local context, Dorrigo is an important area for koalas. There is a long history of koala sightings in the district, particularly around Billy's Creek, Mt Campion and the eucalypt plantations around Cascade. At the same time, timber is an important natural resource to the people and industries in the local area. Dorrigo has seen many dramatic forest protests since the early 1990s, with occasional conflict occurring over the issue of koala conservation versus timber harvesting. Despite a plethora of surveys in the area, this study is significant in that it will be one of the first in the local Dorrigo area to provide scientific information on koala use of forests.

1.5 Aims of the Study:

Forest managers require information on trees and their utilisation by koalas from reliable time and cost efficient surveys. With this information, managers can then have confidence that koalas and their habitat will not be adversely affected from forest management practices. Specific tree information, such as density, size and species, has been sought in past surveys for koala faecal pellets (Appendix 1) and is still a requirement of current surveys (Appendix 2).

Managers are most interested in finding out the general level of usage of forests and trees, rather than being concerned with use of trees by individual koalas. The study of individual tree use would require specific tracking of individuals or close examination of individuals in a specific area, which was not possible in this study. Also, it is not appropriate to examine associations between koala presence and habitat features when one or more koalas may use each study site partially or wholly and scarcely, intermittently or regularly.

Finally, individual koalas may show different tree preferences and preference for individual trees within a species (Hindell et al., 1985), and individuals may differ in their preferences between the sexes (Hindell and Lee, 1987). These factors could confound results if the study examined individual koala use of trees, hence the limitation of this study to examination of forest and tree use by koala populations across the study area.

Therefore, the principal objective of the study is to determine whether koala populations are associated with the structural and floristic composition of forests at Dorrigo, using faecal pellets as the primary measure of koala utilisation. A number of major questions are clearly recognised which reflect this broader objective, and these are:

1. Is koala tree use associated with types of forest?

2. Is koala tree use associated with tree density?

3. Is koala tree use associated with tree size >30cm DBHOB?

4. Is koala tree use associated with tree species?

Chapter 2: BACKGROUND TO THE STUDY

2.1 The Use of Trees for Food:

The koala is folivorous and prefers to feed on young eucalypt leaves (Pahl and Hume, 1990) of one or two locally available tree species (Hindell and Lee, 1990). Although eucalypt foliage is recognised as a poor quality diet, koalas have low nutrient requirements and have a highly specialised digestive system that helps in utilising eucalypt foliage (Cork and Sanson, 1990).

Koalas prefer tree foliage with a high moisture content (greater than 55-65%), a nitrogen content greater than 1.5-1.8% (of dry matter) (Pahl and Hume, 1990; Hume, 1995) and total essential oils greater than 2% (dry matter) (Hume and Esson, 1993). Other composition factors that may also be important are low ash, high lipid and phenolic content (Cork et al., 1983). It is likely that the first set of factors may determine which tree foliage is eaten, but that the amount of acceptable foliage eaten may be determined by a balance between nutrients (eg nitrogen) and antinutrients (eg fibre and tannins) and by the composition of volatile essential oils (Hume, 1995).

Dietary studies have shown that many eucalypt tree species are preferred food by koalas in different parts of Australia (Jurskis and Potter, 1997). A detailed study of faecal pellet material in Pine Creek State Forest (State Forests of NSW, 1997) revealed that Tallowwood (*Eucalyptus microcorys*) occurred in 95% of samples and Grey Gum (*E. propinqua*) and Sydney Blue Gum (*E. saligna*) appeared in 70% of samples. In the same study, up to 15 tree species were being utilised for food, and other studies have shown many other species of eucalypt are eaten (Pahl and Hume, 1990; Osawa, 1993; Melzer and Lamb, 1994; State Forests of NSW, 1997). Other tree genera known to be fed upon by koalas include *Acacia* (Robbins and Russell, 1978), *Angophora, Callistemon, Lophostemon* and *Syncarpia* (State Forests of NSW, 1997), *Casuarina* and *Allocasuarina* (Hasegawa, 1995; State Forests of NSW, 1997), *Leptospermum* and *Melaleuca* (Ough et al., 1988; State Forests of NSW, 1997) and *Pinus* (Lithgow, 1982).

As food choice varies at any given time within a single species (Ullrey et al., 1981), diet may not be the sole reason for tree preference by the koala (Hasegawa, 1995; Jurskis and Potter, 1997). Jurskis (unpublished) suggests that structural factors of trees and forests may outweigh floristic factors in determining habitat use by the koala.

2.2 Shelter and Habitat Structure:

Koalas spend considerable time in trees (Mitchell, 1990), even spending up to 35% of their time in a single tree (Pearse and Eberhard, 1978). Trees are important as shelter for koalas for feeding and for protection from predators and the weather (eg the sun on hot days) (Hindell and Lee, 1990; Jurskis and Potter, 1997). Although koalas spend brief periods on the ground travelling between trees and may make many, sometimes long, movements between trees in 24 hours (Robbins and Russell, 1978; Gordon et al., 1990; Mitchell and Martin, 1990), trees are often used as emergency retreats when danger threatens (personal observation). Distances moved vary with sex, environmental conditions and the season (Melzer and Lamb, 1994).

Many authors have reported associations between koalas and tree size (Hindell and Lee, 1987; Melzer and Lamb, 1994; Hasegawa, 1995; State Forests of NSW, 1997). Larger trees may be preferred because they provide more foliage thereby reducing the frequency with which animals need to move between trees. Larger trees may also be easier to climb (Hindell and Lee, 1990; Jurskis and Potter, 1997). Koalas may climb most efficiently when tree diameter is close to the combined 'reach' of the forelegs (Jurskis and Potter, 1997). Hasegawa (1995) found koala pellets under most large trees (ie >31.8cm DBHOB). Koalas at Pine Creek (State Forests of NSW, 1997) showed a preference for stems in the size class from 50–80cm DBHOB. Jurskis and Potter (1997) found that koalas at Eden generally prefer trees with a diameter between 30 and 90cm DBHOB, rather than saplings or large trees.

However, koala use of different tree sizes may vary with tree species, stand structure or treatment history (Jurskis et al., 1994; State Forests of NSW, 1997). For example, areas at Eden that have been disturbed by wildfire, clearing, logging and windstorm are used by koalas, and are characterised by a variety of age, size and crown condition classes and a high proportion of regrowth trees (Jurskis and Shields, 1995). At Pine Creek, koalas occurred more frequently in native forest than in native species plantation, and scats were least abundant in structurally uniform, single species dominated regrowth native forests and native species plantations with low species diversity (State Forests of NSW, 1997). It was also found that in native forest, scats were most abundant in structurally complex, uneven-aged forests with some mature and old growth elements and mixed species associations dominated by Tallowwood and Forest Oak (*Allocasuarina torulosa)*.

Other structural characteristics of forests, such as height of feed trees (Cork, 1991) and tree density (Hindell and Lee, 1987; Melzer and Lamb, 1994; State Forests of NSW, 1997) may also be significant factors in the utilisation of trees by koalas. Many authors have indicated that koalas prefer open forests and woodlands to taller and denser forests (Martin, 1985b; Lunney and Leary, 1988; Cork et al., 1990; Melzer and Lamb, 1994; State Forests of NSW, 1997). However, other factors such as tree species and abundance may also be influencing koala presence. Melzer and Lamb (1994) found that preferred feed trees were dense and more frequent than other potential feed trees. More specifically, suitable indicators of koala habitat have been defined at Pine Creek as 12 or more preferred food trees per hectare, and 10 or more Tallowwood trees of 10cm DBHOB or more per hectare (State Forests of NSW, 1997).

2.3 Home Ranges and Social Interaction:

Koalas in dense populations have home ranges that often overlap with the ranges of several other koalas of the same age and sex, and also with the ranges of koalas of different ages and sexes (Mitchell, 1990). In areas where population densities are lower, the degree of spatial overlap of home ranges may be negligible, such as the case at Eden on the south coast of NSW (Jurskis and Shields, 1995). Koala densities at Pine Creek (0.07 koalas/ha) and Eden (Jurskis and Shields, 1995) are very low compared to those in other areas such as French Island (0.7-6.2 koalas/ha). At Springsure in

Queensland, koala home ranges had limited overlap and tree sharing which is indicative of a low population density (Melzer and Lamb, 1994).

The size of home ranges for koalas varies considerably from 1.2ha on French Island in Victoria (Mitchell, 1990), 8ha to 14ha at Pine Creek (State Forests of NSW, 1997), to hundreds of hectares at Eden (Jurskis et al., 1994; Jurskis and Shields, 1995; Jurskis and Potter, 1997). Variation in home ranges may be due to carrying capacity of the environment, with many factors such as tree size and density (Mitchell, 1990; Hasegawa, 1995) likely to influence the numbers of koalas an area can support (Jurskis and Potter, 1997; Jurskis, unpublished). Mitchell (1990) found that koala home ranges were small where the density of large trees was high, but that the density of preferred trees also influenced home range size. Male koalas usually have larger home ranges than females (Hindell and Lee, 1988; Mitchell, 1990), although their home ranges are similar in the density of trees, and density and percentage abundance of preferred tree species (Hindell and Lee, 1988).

Koalas are generally solitary animals, but adult males occasionally initiate encounters with other koalas (Mitchell, 1990). Older males scent mark when moving to or entering a tree and this is more prolific during the breeding season (Smith, 1980; Mitchell, 1990). Koalas may also use a few trees repeatedly (Hindell and Lee, 1988; Mitchell, 1990), some of which may be characterised by scratched double trails up the bole of the tree with copious dung at the base of the tree (personal observation).

2.4 Tree Selection by Koalas:

The use of trees by koalas varies in time and space according to variations in their food and shelter. Environmental and demographic fluctuations may require a change in use away from a genuine “preferred” resource. For example, koalas have been shown to change their tree usage from *E. ovata* to *E. obliqua* and *E. radiata* after substantial defoliation of *E. ovata* and coinciding with the new summer growth (Martin, 1985a). However, preference is the disproportionate utilisation of a tree species in relation to its abundance, and often relatively scarce species are preferred.

The preference of trees by koalas has been shown to vary with sex (Hindell and Lee, 1987, 1990), age (Hasegawa, 1995) and season (Martin, 1985a; Hindell and Lee, 1987, 1990). Individuals may show no preference (Hindell and Lee, 1988). Many trees of a preferred species may never be utilised by koalas (Robbins and Russell, 1978), while some individual trees within a species are preferred more than others (Hindell et al., 1985). A commonly held belief is that koalas use mainly one or two locally available tree species (Hindell et al., 1985; Martin, 1985a). However, increasingly studies find that koalas utilise many locally available tree species (Reed et al., 1990; Jurskis et al., 1994; State Forests of NSW, 1997).

Absolute occurrence of ‘preferred species’ may be less important than the relative occurrence of tree species, which may be an indicator of environmental factors determining the carrying capacity of koalas (Jurskis and Potter, 1997; Jurskis unpublished). A floristic association’s occurrence across a narrower environmental domain than a tree species’ occurrence, may provide a better indication of habitat quality (Jurskis, unpublished).

Chapter 3: RESEARCH DESIGN AND METHODOLOGY

3.1 The Study Area:

3.1.1 General Location:

The study area is situated in northern New South Wales in State forests north and west of Dorrigo (Figure 2). The study area is also located about 30km northwest of Pine Creek State Forest where previous intensive koala studies have been carried out (bottom right of Figure 2).

The study area was chosen for three reasons. Firstly, koalas were known to utilise these forests from the many records of koala sightings. Secondly, there had been considerable publicity and concern over management of koala habitat on State forests at Dorrigo. Lastly, the author and others were conducting koala habitat surveys in this area as part of State Forests of NSW management requirements. It is recognised that this study is confined to State forest areas and does not sample private property thought to contain most of the remaining optimal habitat for koalas (Jurskis, 1996). However, the habitat sampled is thought to be representative of most of the recorded locations of koalas in the Dorrigo area.

Twelve State forests occur in the district comprising a total area of 138,309 hectares (Table 1, Figure 2). State forests have traditionally been grouped together into Management Areas, and in this study area these are Dorrigo, Grafton (part thereof) and Coffs Harbour (part thereof) (Figure 2). In 1997, two new National Parks (Nymboi-Binderay and Chaelundi) and one addition to an existing National Park (Guy Fawkes River) were created from State forests, totalling some 13,827.6 hectares in area.

3.1.2 History of Land Use and Forest Management:

The entire study area has a long and extensive history of timber harvesting. In 1906 Red Cedar (*Toona ciliata*) and, ten years later, Hoop Pine (*Araucaria cunninghamii*) were extensively sought and selectively harvested across the district (Forestry Commission of NSW, 1985). The 1930s saw a substantial shift towards the very selective harvesting of native eucalypt (or hardwood) species.

Table 1: State forest areas in Dorrigo District as at 16/4/98 (Data courtesy of State Forests of NSW).

State Forest	Area (hectares)
Bielsdown	952
Brooklana	1,137
Chaelundi	41,554
Clouds Creek	18,565
Ellis	11,519
Hyland	5,620
Killungoondie	250
Marengo	18,122
Moonpar	3,715
Muldiva	1,199
Sheas Nob	12,168
Wild Cattle Creek	23,508
Total	**138,309**

Figure 2: Location of State Forests in the Dorrigo Management Area and surrounds of Dorrigo District (GIS map courtesy of State Forests of NSW).

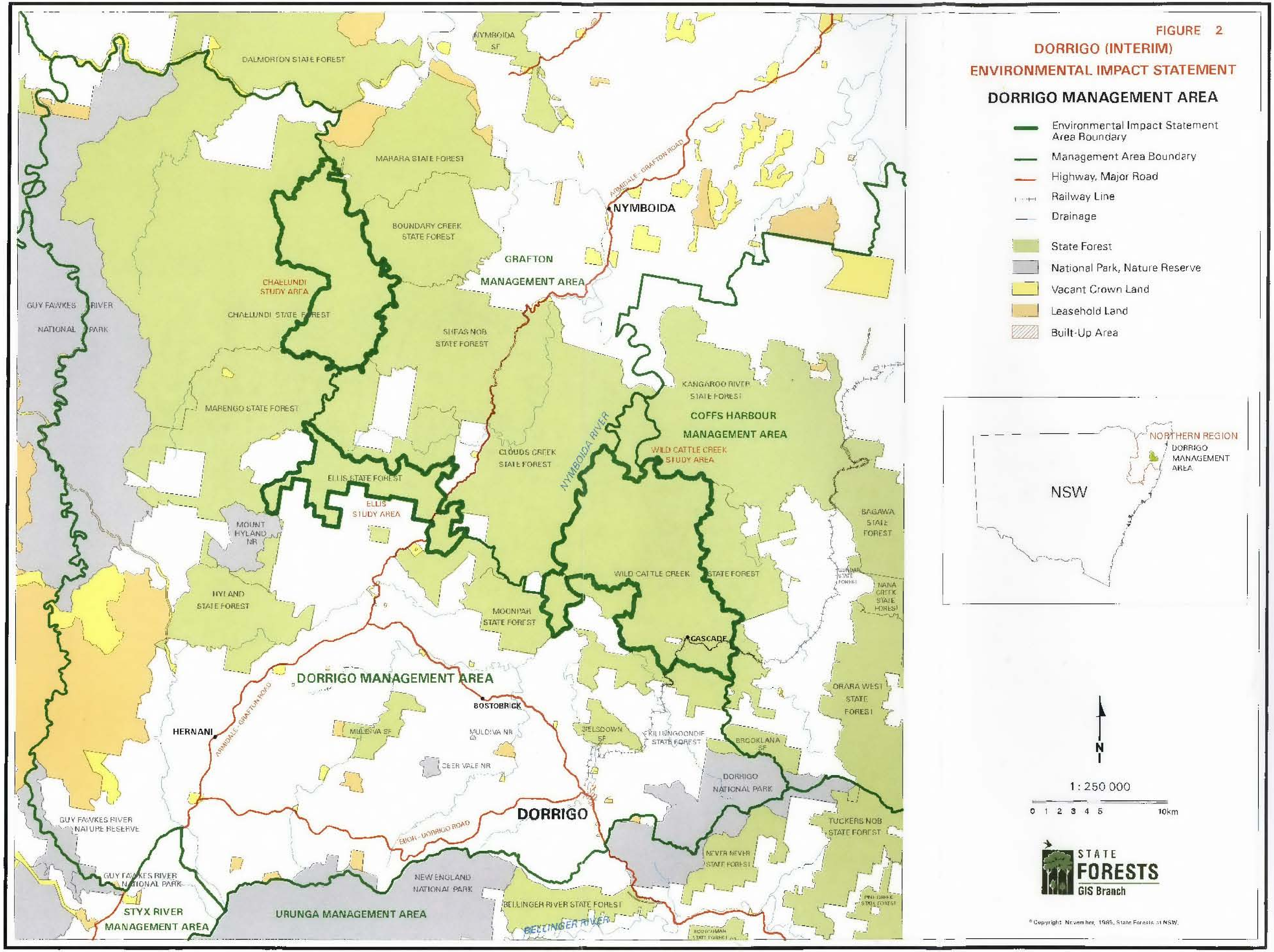


FIGURE 2
DORRIGO (INTERIM)
ENVIRONMENTAL IMPACT STATEMENT
DORRIGO MANAGEMENT AREA
Environmental Impact Statement Area Boundary
Management Area Boundary
Highway, Major Road
Railway Line
Drainage
State Forest
National Park, Nature Reserve
Vacant Crown Land
Leasehold Land
Built-Up Area
NORTHERN REGION
DORRIGO MANAGEMENT AREA
NSW
N
1 : 250 000
0 1 2 3 4 5 10km
STATE FORESTS
GIS Branch
DALMORTON STATE FOREST
NYMBOIDA SF
MARARA STATE FOREST
BOUNDARY CREEK STATE FOREST
NYMBOIDA
ARMIDALE - GRAFTON ROAD
GRAFTON MANAGEMENT AREA
CHAELUNDI STUDY AREA
CHAELUNDI STATE FOREST
GUY FAWKES RIVER NATIONAL PARK
SHEAS NOB STATE FOREST
MARENGO STATE FOREST
KANGAROO RIVER STATE FOREST
COFFS HARBOUR MANAGEMENT AREA
NYMBOIDA RIVER
CLOUDS CREEK STATE FOREST
WILD CATTLE CREEK STUDY AREA
ELLIS STATE FOREST
ELLIS STUDY AREA
MOUNT HYLAND NR
BAGAWA STATE FOREST
WILD CATTLE CREEK STATE FOREST
HYLAND STATE FOREST
MOONPAR STATE FOREST
CASCADE
DORRIGO MANAGEMENT AREA
ORARA WEST STATE FOREST
BOSTOBRICK
HERNANI
MULDIVA NR
DEER VALE NR
BROOKLANA SF
DORRIGO NATIONAL PARK
DORRIGO
EBOR - DORRIGO ROAD
GUY FAWKES RIVER NATURE RESERVE
TUCKERS NOB STATE FOREST
NEVER NEVER STATE FOREST
GUY FAWKES RIVER NATIONAL PARK
NEW ENGLAND NATIONAL PARK
STYX RIVER MANAGEMENT AREA
URUNGA MANAGEMENT AREA
BELLINGER RIVER STATE FOREST
BELLINGER RIVER
© Copyright November, 1995, State Forests of NSW.

In the early 1960s, harvesting became more intensive with the advent of improved access and supervision of operations, as well as a Management Plan for the area (Forestry Commission of NSW, 1985). Areas that contained mature and over-mature trees once left because they were slightly defective or were not required for markets at the time, were re-logged having regard for current markets, future sawlog supply, seed trees and, later, habitat trees.

The result over much of the study area is a predominance of mainly regrowth stands of various age classes, often with scattered mature and over-mature defective stems predominantly located closer to drainage lines and on steeper slopes. Many areas have been harvested more than twice. Few areas remain in mostly an old growth stage.

Over 3,800 hectares of mainly Blackbutt forest type received intensive cultural treatment between 1960 and 1980. Treatment, such as tractor clearing, spot seeding and planting, culling of unmerchantable trees and supplementary enrichment planting of native hardwood species, occurred mainly in Wild Cattle Creek, Clouds Creek, Sheas Nob and Ellis State Forests.

The district is a useful study area because native forest stand conditions are structurally and floristically diverse as a consequence of natural environmental conditions and the extensive and varied treatment history.

3.1.3 Environment:

3.1.3.1 Climate:

The warm temperate climate of the area is characterised by wet summers and dry winters, with wide variations in rainfall (Figures 3) and temperature (Figure 4). In these figures, recent rainfall and temperature data from Dorrigo townsite are compared with historic data from Clouds Creek and Wild Cattle Creek State Forests. Average annual rainfall varies from 2000mm in the east to 700mm in the north, with the bulk of the area between 1000-1500mm (Forestry Commission of NSW, 1985).

Figure 3: Rainfall for State Forests at Dorrigo (from Forestry Commission of NSW Dorrigo Management Plan, 1985).

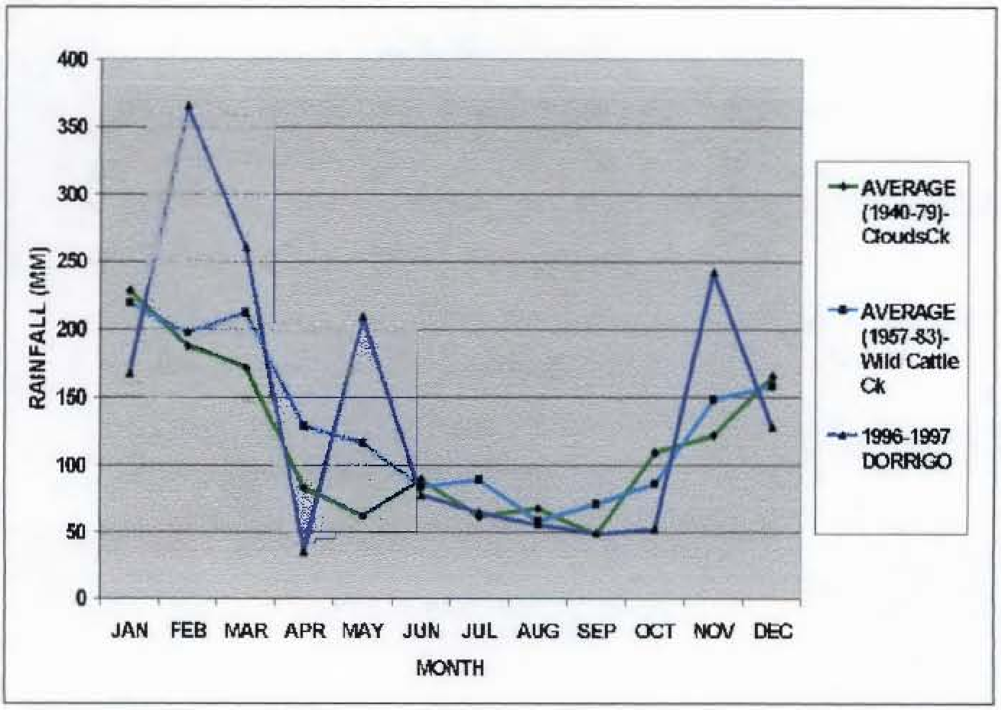
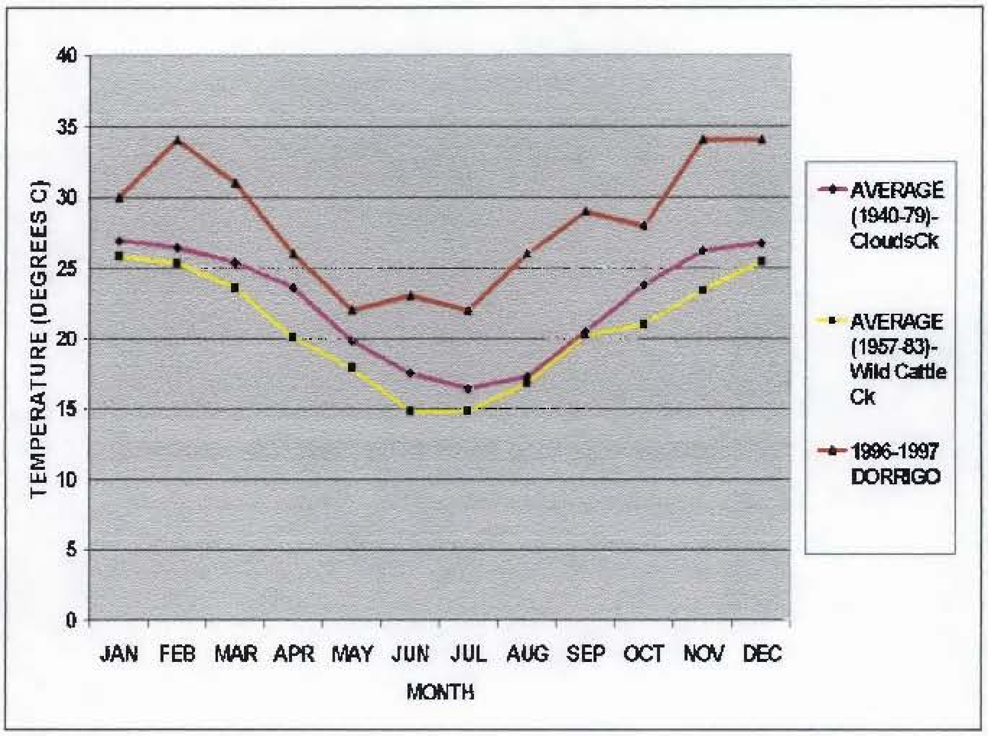


Figure 4: Temperatures from State Forests at Dorrigo (from Forestry Commission of NSW Dorrigo Management Plan, 1985).



3.1.3.2 Topography and Geology:

The forests within the study area are spread over the eastern slopes of the Great Dividing Range, from elevations of 1300m in Chaelundi State Forest to 400m in Wild Cattle Creek State Forest.

The geology of Dorrigo District is largely sedimentary, with soils throughout the study area mostly reflecting the underlying geology. Local variations in rainfall and geology have contributed to the natural development of a landscape that is characterised by mostly slight slopes (<20 degrees) with steep falls into deeply incised river valleys, and a variety of vegetation types.

3.1.3.3 Vegetation:

Vegetation communities at Dorrigo generally grade from a mix of closed, sub-tropical rainforest and moist sclerophyll forest in the eastern part of the study area to open, dry sclerophyll Spotted Gum and New England forest in the northern and western parts of the study area. Forest Types and grouped "Leagues" describe vegetation communities on State Forests, as per Research Note 17 (Forestry Commission of NSW, 1989).

Each forest type is distinguished by one or two main species, as well as a number of associate species. For example, Forest Type 47 (Tallowwood-Sydney Blue Gum) has Tallowwood and Sydney Blue Gum as the main species. Brush Box (*Lophostemon confertus*), Turpentine (*Syncarpia glomulifera*), Narrow-leaved White Mahogany (*E. acmenoides*), Flooded Gum, Silvertop Stringybark (*E. laevopinea*) and New England Blackbutt (*E. andrewsii ssp. campanulata*) are all associate species (Forestry Commission of NSW, 1989). Examples of some of the more common and important timber-producing tree species throughout the study area, such as Tallowwood, Blackbutt, Sydney Blue Gum, Turpentine, Brush Box, Narrow-leaved White Mahogany and Forest Oak, are shown in Plates 2 to 7.

Tallowwood is a species common to many forest types in the Dorrigo area, being associated with 24 forest types. Other tree species are also associated with multiple forest types. These include Grey Gum (*E. propinqua*) (28 forest types), Sydney Blue Gum (28), Blackbutt (20), Turpentine (20), Red Mahogany (*E. resinifera*) (14), Brush Box (12), Silvertop Stringybark (11), Flooded Gum (6), Narrow-leaved White Mahogany (6), Forest Oak (6), and

Diehard Stringybark (*E. cameronii*) (5). However, Nicholls (1991) describes Forest Oak as being associated with Blackbutt, Sydney Blue Gum, Tallowwood, Narrow-leaved White Mahogany, Grey Ironbark, Grey Gum, Turpentine and Brush Box.

Some of these species are associated with many others because of their general latitudinal distribution throughout NSW (eg Blackbutt) or their longitudinal distribution from the coast (eg Tallowwood), while others are more restricted to specific habitats (eg Forest Oak in moister forests). Tallowwood, for example, also occurs atypically in the drier, more open forests in the northeast as an occasional tree within a favourable microclimate. Figure 5 shows the distribution of Forest Type 47 (Tallowwood-Sydney Blue Gum) across State forests in the district.

The occurrence of "broad" forest types in the District is shown in Table 2 and of fine forest types in Appendix 3. Forest Type 47 is of most interest in this study because not only were most experimental sites located in this type, but also koala sightings were observed the most in this type (refer to Section 4.3.1). Forest Type 47 constitutes part of the Sydney Blue Gum/Bangalay League and comprises about 10.5% of the district State Forest area.

Plate 2: Example of a mature Tallowwood (*Eucalyptus microcorys*) and regrowth Sydney Blue Gum (*Eucalyptus saligna*) within Compartment 539 in Wild Cattle Creek State Forest, Dorrigo District.

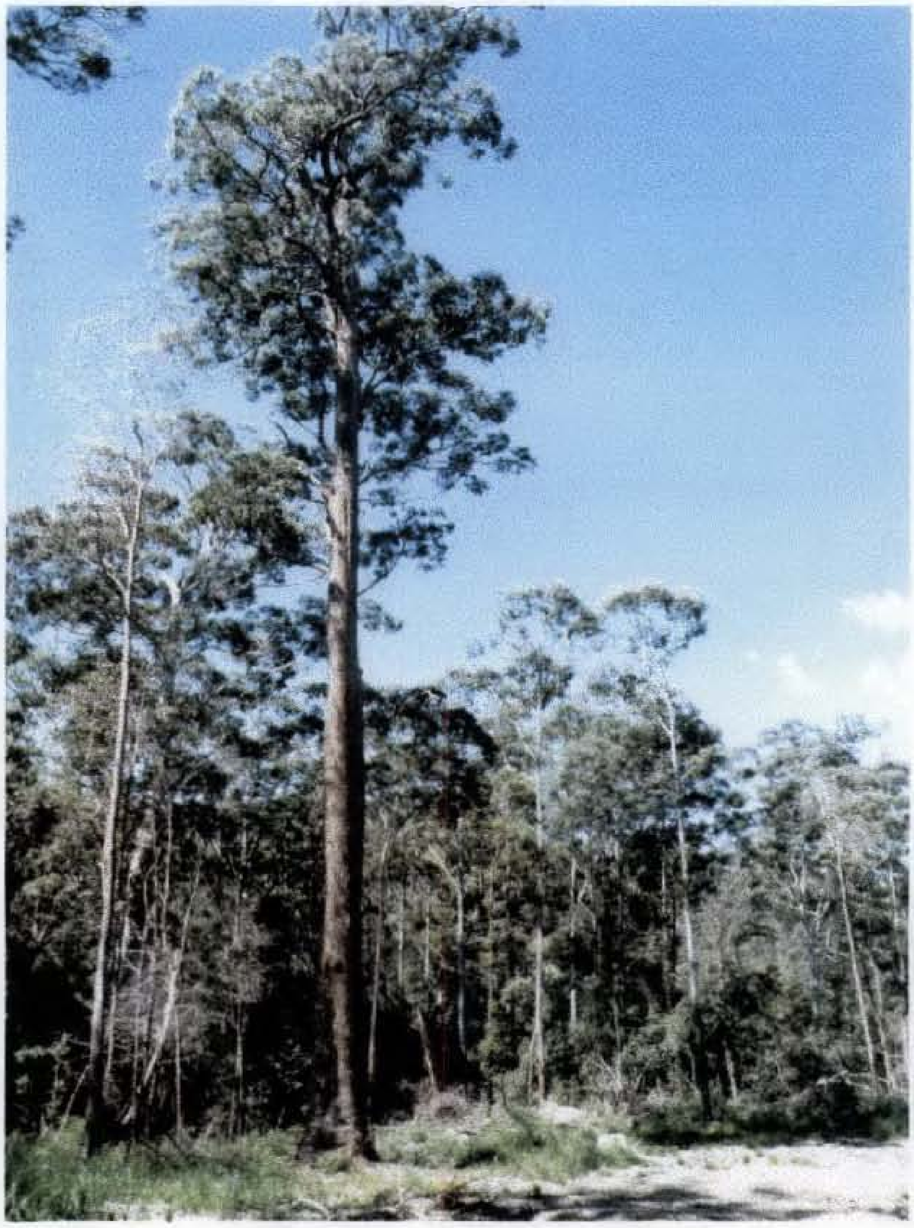


Plate 3: Example of a mature Forest Oak (*Allocasuarina torulosa*) tree along the Forest Drive in Moonpar State Forest, Dorrigo District.

Plate 4: Example of a Narrow-leaved White Mahogany (*Eucalyptus acmenoides*) tree along the Forest Drive in Wild Cattle Creek State Forest, Dorrigo District.

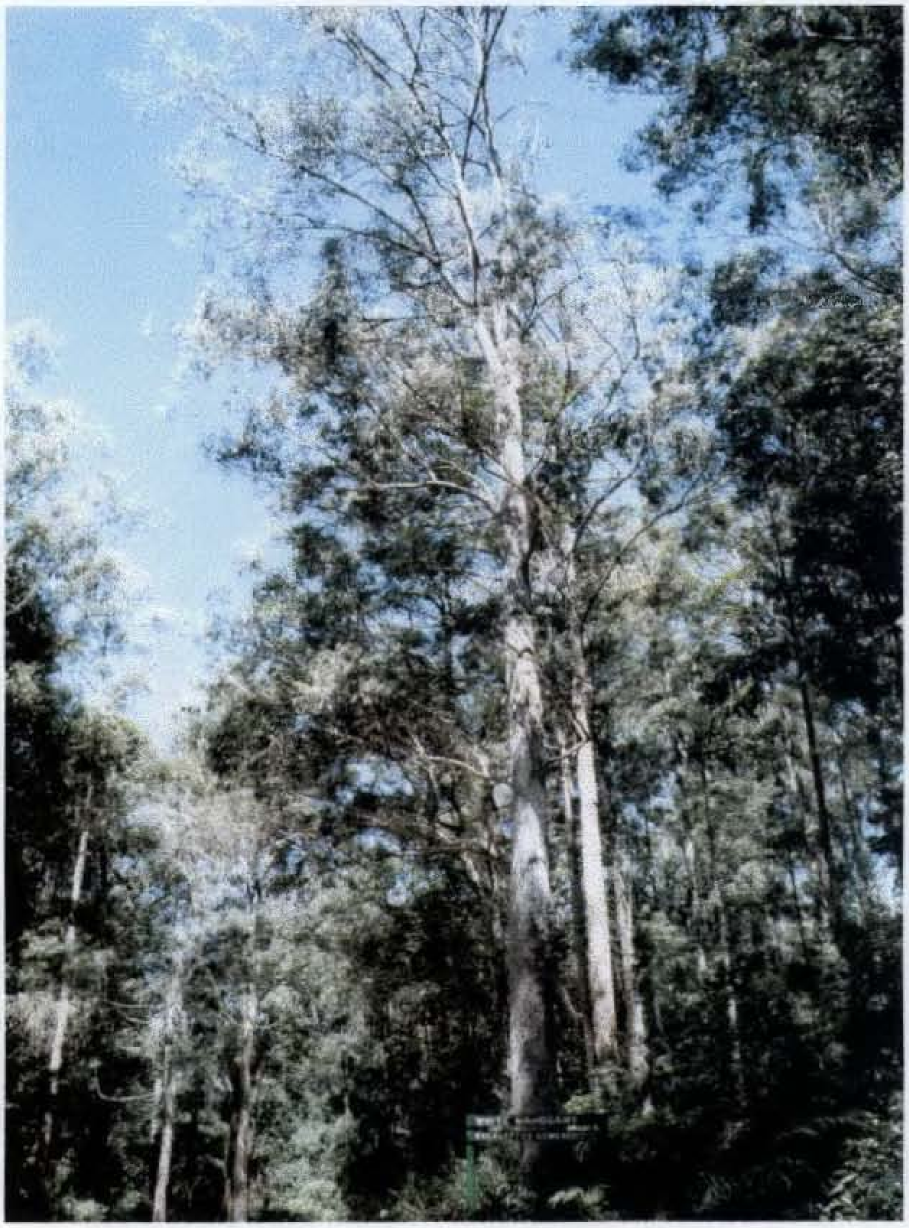


Plate 5: Example of a Turpentine (*Syncarpia glomulifera*) tree along the Forest Drive in Wild Cattle Creek State Forest, Dorrigo District.

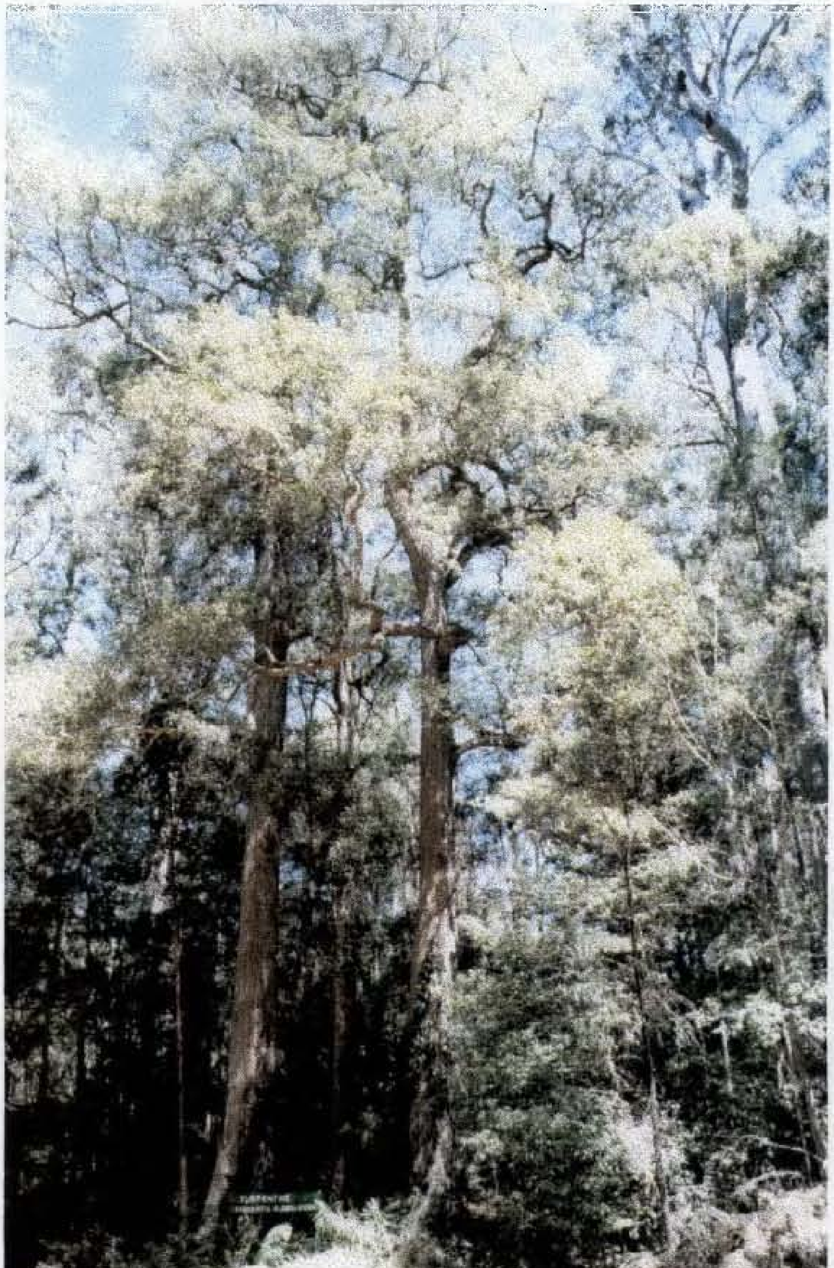


Plate 6: Example of a regrowth Brush Box (*Lophostemon confertus*) tree along the Forest Drive in Wild Cattle Creek State Forest, Dorrigo District.

Plate 7: Example of a regrowth Blackbutt (*Eucalyptus pilularis*) tree along the Forest Drive in Moonpar State Forest, Dorrigo District.

Figure 5

Distribution of Tallowwood/Sydney Blue Gum in Dorrigo District.

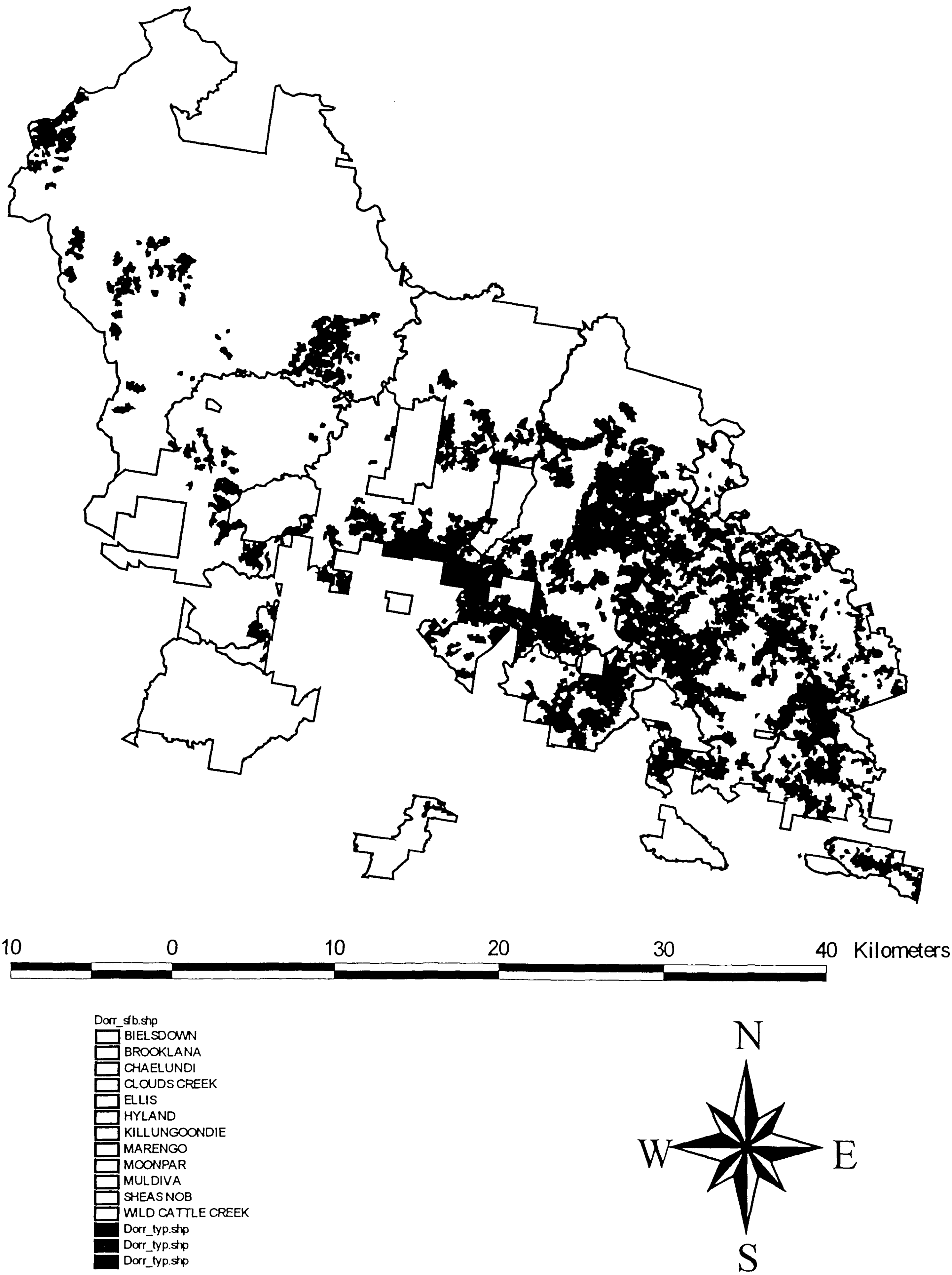


Table 2: Percentage of broad forest types or leagues within Dorrigo District (data courtesy of State Forests of NSW).

Forest Type Group or League	% Gross Area
Untyped	3.8
Rainforest Group	7.6
Blackbutt League	8.0
Sydney Blue Gum/Bangalay League	16.4
Grey Gum-Grey Ironbark League	4.0
Spotted Gum League	26.6
Red Gum League	0.7
Scribbly Gum-Stringybark League	2.3
Snow Gum League	2.8
Messmate-Brown Barrel League	22.2
Plantations	3.4
Cleared, Rock, Water & Other	1.2

3.2 Survey Location and Procedure:

3.2.1 Koala Records:

The distribution of koala location records in relation to forest type (from the State Forests of NSW Dorrigo office dating back as far as 1977) was examined. This information was used in a preliminary assessment of general habitat of the koala in the Dorrigo area.

The historical distribution of koala sightings was not used to determine the location and numbers of experimental sites. However, the relationship between forest types of study sites and koala sightings is further examined in Chapter 4.

3.2.2 Surveys for Koala Faecal Pellets:

Koalas are difficult animals to survey because they are nocturnal, arboreal and can be relatively mobile. Many studies of different animals such as deer (Bennett et al., 1940), rabbits (Cochran and Stains, 1961) and small mammals (Emlen et al., 1957) have sampled faecal pellets because they are a readily available and easily collected source of information. They can provide a wealth of ecological information about animals, including diet and habitat use (Putman, 1984). A search for faecal pellets is a very suitable method for surveying koalas (Jurskis et al., 1994) and has been extensively used to examine habitat utilisation (Moon, 1990; Jurskis et al., 1994; Callaghan and Phillips, 1995; Hasegawa, 1995; State Forests of NSW, 1997).

The search for faecal pellets is a useful indicator of the use of trees by koalas. This is because koalas do not defecate during locomotion (Smith, 1979), and considerable time is spent in trees feeding (up to 4.7 hours) (Hindell, Handasyde and Lee, 1985; Nagy and Martin, 1985) and resting (up to 20 hours per day) (Mitchell, 1990). Pellets that are defecated from a koala in a particular tree are likely to fall vertically to the ground beneath the tree and can, through pellet searches, indicate tree utilisation by koalas.

Faecal pellet surveys compare favourably against many other forms of survey for koalas (Appendix 4), although the use of any technique may depend on the information sought. Faecal pellet surveys may be a poor indicator of feeding habits of koalas as the technique does not distinguish tree species used for food from those used for other purposes (Hasegawa, 1995). However, this study is limited to the survey of faecal pellets because of the reasons previously outlined and because it is not the intention to determine species only used for food. The validity of this method of survey depends on pellet detectability, which may be influenced by factors such as (i) the identification of pellets, (ii) the independence of environmental conditions, (iii) environmental variation, (iv) defecation rate and search ability, and (v) pellet durability and decomposition.

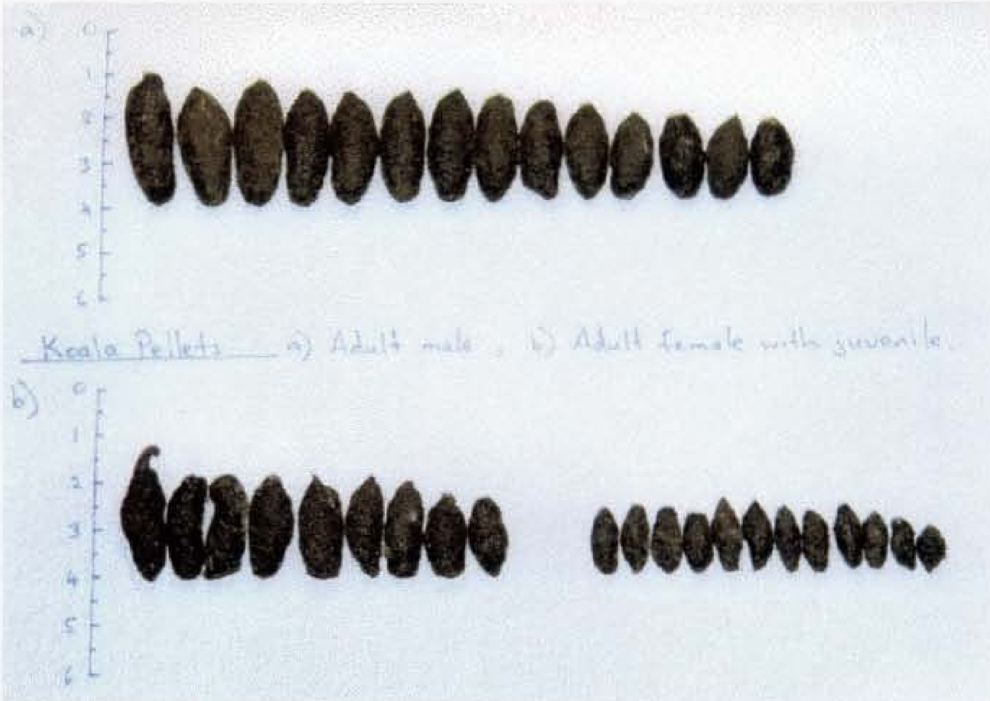
3.2.2.1 Pellet Identification:

Koala pellets are distinctive because of their colour, shape, size and other distinguishing features. The external pellet colour is generally brown or red-brown, but varies from yellow-brown to blue or grey-green (Triggs, 1996). The colour may change with a change in durability from fresh to hard and with subsequent weathering. Recent pellets often have a shiny appearance.

Pellets, usually long, oval or cylindrical in shape (Triggs, 1996), can vary quite dramatically depending on animal sex, age and digestion. However, koala faecal pellets ranged in size from about 10 to 30 mm in length and 5 to 10 mm in width (Plate 8), often with distinctive ridges along their length.

Koala pellets often smell of eucalyptus oil, particularly when fresh. However, they have little odour when they dry (Triggs, 1996).

Plate 8: Fresh koala faecal pellets from an adult male and an adult female with her juvenile young, showing variability in the size and shape of pellets (Scale is in cm).



Koala pellets may be confused with the Mountain Brushtail Possum (*Trichosurus caninus*), which has an overlapping range and similar looking pellets. Triggs (1996) described the diagnostic features of Mountain Brushtail Possum pellets as "cylinders, both ends usually rounded, coarser texture and larger than Common Brushtail Possum". Possum scats are usually found in small groups (personal observation), are sometimes stuck together (Hasegawa, 1995), have a different strong odour (personal observation) and contain coarser plant fragments within pellets than those of the koala, with occasional insect material (Triggs, 1996).

In these respects koala pellets are readily identified, except perhaps to the untrained observer.

2.2.2.2 Independence of Environmental Conditions:

Arboreal marsupials have reduced levels of activity and may be less detectable during adverse environmental conditions, such as dreariness, wind, rain, fog and dripping vegetation (Davey, 1990). Pellet surveys have the advantage in that pellets can be detected independently of climatic factors.

2.2.2.3 Defecation Rate:

Koalas appear to have moderate rates of defecation producing averages of between 78 and 100 faecal pellets per day (Smith, 1979). However, this compares with about 400 per day for Eastern Grey Kangaroos *Macropus giganteus* (Hill, 1981), and an average of 820 per day for European Rabbits *Oryctolagus cuniculus* (Taylor and Williams, 1956).

Cochran and Stains (1961) and Smith (1964) found that the rate of defecation was affected by factors such as levels of food intake, the type of forage consumed and the age of individual animals. Juvenile Mule Deer (*Odocoileus hemionus*) appeared to have higher rates of defecation than mature deer, and consumption of coarse woody material produced higher defecation rates than consumption of equivalent nutritious food.

It was assumed that the rate of defecation of the koala is high enough to ensure that surveys based on finding faecal pellets have a reasonable chance of success. Experienced observers are likely to increase the chances of finding at least one pellet beneath a tree, especially in areas where there have been previous koala records or in areas where they are likely to occur. However, koalas may not defecate at all under a particular tree and, because little is known about the impact of these factors on defecation rates of koalas, some caution should be used when investigating habitat utilisation based upon pellet counts.

2.2.2.4 Environmental Variation and Search Ability:

The detection of faecal pellets is dependent on a number of factors such as survey plot area or size, the density of surface vegetation and the decomposition rate of the pellets (Cochran and Stains, 1961; Smith, 1964; Putman, 1984).

Koala pellets may be difficult to detect amongst heavy undergrowth or ground cover and procedures should involve thorough searches at pre-determined locations, such as at a set distance along a transect or at a point in relationship to the tree crown (Jurskis et al., 1994). The koala has more of a non-random defecation pattern which can affect the search procedure adopted and the suitability and applicability of results. In this study, searches were made in a fixed area under tree crowns, surrounding the tree base, where koala pellets are more likely to be found and therefore habitat use patterns can be studied.

The area immediately adjacent to a tree may be freer of understorey vegetation than further out from the trunk of the tree because of competition by the tree for light, water and nutrients (Stoneman, 1994). However, Suresh and Vinaya Rai (1988) found that particular species of *Eucalyptus* and *Casuarina* suppress ground vegetation through production of chemical inhibitors rather than through competition for light, water or nutrients (Plate 9). Therefore, a pellet survey based on searching this area may have more chance of success.

However, tree species and individual trees vary in the amount of bark, branches and leaf litter deposited at the base of trees, and this also varies with tree age and climatic events. For example, Sydney Blue Gum (*Eucalyptus saligna*) is a smooth-barked tree and sheds bark more prolifically and regularly than rough-barked species (Plate 10). This can affect the detection of pellets at the base of trees because shed bark may hide pellets from view. However, in this study considerable effort was taken during pellet searches under trees with undergrowth or litter to ensure adequate levels of detection under each tree.

Plate 9: The base of a Forest Oak (*Allocasuarina torulosa*) showing lack of undergrowth around the base of the tree.

Plate 10: The base of a Sydney Blue Gum (*Eucalyptus saligna*) tree showing the amount and arrangement of bark and litter fall around the tree.

It is unlikely that many koala scats are directly deposited on the ground, as the koala does not defecate during locomotion (Smith, 1979) and spends a great deal of time in trees, only moving on the ground between trees when necessary. However, Moon (1990) indicates that koalas may have a peculiar habit of base marking of trees with pellets, which may be a form of territorial behaviour.

2.2.2.5 Pellet Durability and Decomposition:

Koala faecal pellets are soft and moist when defecated, but harden to become reasonably durable (Triggs, 1996). However, depending on the weather, the hardening phase may not be reached for many pellets.

The rate of disappearance of faecal pellets can have serious consequences for the study of populations and their habitat use. Cochran and Stains (1961) examined faecal pellets of Cottontail rabbits (*Sylvilagus floridanus*) and found that decomposition rates of pellets vary with location, temperature, composition of pellets and disturbance by invertebrates, with more than 50% of pellets remaining from two weeks to five months. At Eden NSW, Jurskis and Potter (1997) showed that fresh koala pellets in a natural situation persisted from nearly one to more than two years in dry forest and from six to 12 months in wet forest.

Taylor and Williams (1956) suggested that high rainfall and thick vegetation cover increase the decay rate of European Rabbit (*Oryctolagus cuniculus*) droppings. Similarly, Wallmo et al. (1962) suggested that rainfall is a major cause of the disappearance of deer pellet groups, with 38% of pellet groups removed by rains in less than 2 months and 91% in 4 months. In studies with

Eastern Grey Kangaroos (*Macropus giganteus*), Johnson and Jarman (1987) found that warm and wet conditions contributed to a rapid disappearance of pellets in contrast to the cold, dry months of winter. However, rain had no apparent effect on dry pellets.

At Dorrigo, the warm and wet summer climate may cause a problem with the persistence of many koala pellets, and pellets on wetter sites may be more difficult to find (Jurskis et al., 1994). However, it was assumed in this study that koalas continually use their home ranges throughout the year and that regular periodic deposition would ensure that all sites would stand an equal chance of finding pellets at any one point in space and time across the forested landscape.

Heavy rainfall and over-bark flow from the canopy of larger trees may wash away pellets at the tree base (Plate 11), or may significantly soak or change the constitution of pellets so that they are unrecognisable or are prone to disintegration. Sampling may be compromised with the placing of one quadrat at one point at the base of a tree, as done by Hasegawa (1995). Sampling of pellets in this study around the entire circumference of the tree base avoids this problem of rain washing pellets away, because there is a very high probability of finding at least one pellet from a detailed search, if any were there.

Plate 11: Over-bark flow of water from the canopy of a large Blackbutt (*Eucalyptus pilularis*) tree in Chaelundi State Forest, Dorrigo.

Invertebrate activity might also be an important factor in the survival of pellets (Johnson and Jarman, 1987). Cochran and Stains (1961) found that the scarab beetle was responsible for removing faecal pellets. Three moth larvae (Lepidoptera: Oecophoridae), *Telanepsia scatophila*, *T. stockeri* and *T. tidbinbilla*, have been found in koala faecal pellets in southeastern NSW (Common and Horak, 1994) feeding on, and within, the scat. Although seventeen species of *Telanepsia* have been identified in Australia, with many still undescribed (Common and Horak, 1994), only these three species appear to have an identified relationship with koala faecal pellets. Some of these larvae have an annual life cycle and feed and pupate entirely within pellets. Therefore, a year round supply of pellets may be essential to their survival (Jurskis and Potter, 1997). Common and Horak (1994) also found that koala scats with actively feeding insect larvae within the scat became mouldy quickly, whereas scats with larvae in diapause were resistant to mould for months under the same conditions.

3.2.3 Main Survey Sites:

Twenty-eight survey sites were selected from four forest types within Dorrigo District (Figure 6). The 52,069ha area of these forest types, Forest Types 37 (Dry Blackbutt), 47 (Tallowwood/Sydney Blue Gum), 60 (Narrowleaved White Mahogany-Red Mahogany-Grey Ironbark-Grey Gum) and 163 (New England Blackbutt), comprised the “study area”.

Sample sites were chosen on two sets of criteria. One set of fourteen surveys (Appendix 5) initially occurred at sites where forest officers, demarcating areas to be logged, found evidence of (i) koala scratch or "track" trees, (ii) trees with evidence of greater than 10 pellets beneath them, (iii) numbers of trees grouped together with pellets beneath, or (iv) a koala. The second set of fourteen surveys (Appendix 5) occurred on randomly selected sites. The design of this study was affected by a change in the original design, looking at determining what level of forest use constituted "high use" by koalas, to examining general associations between forests/trees and koala use.

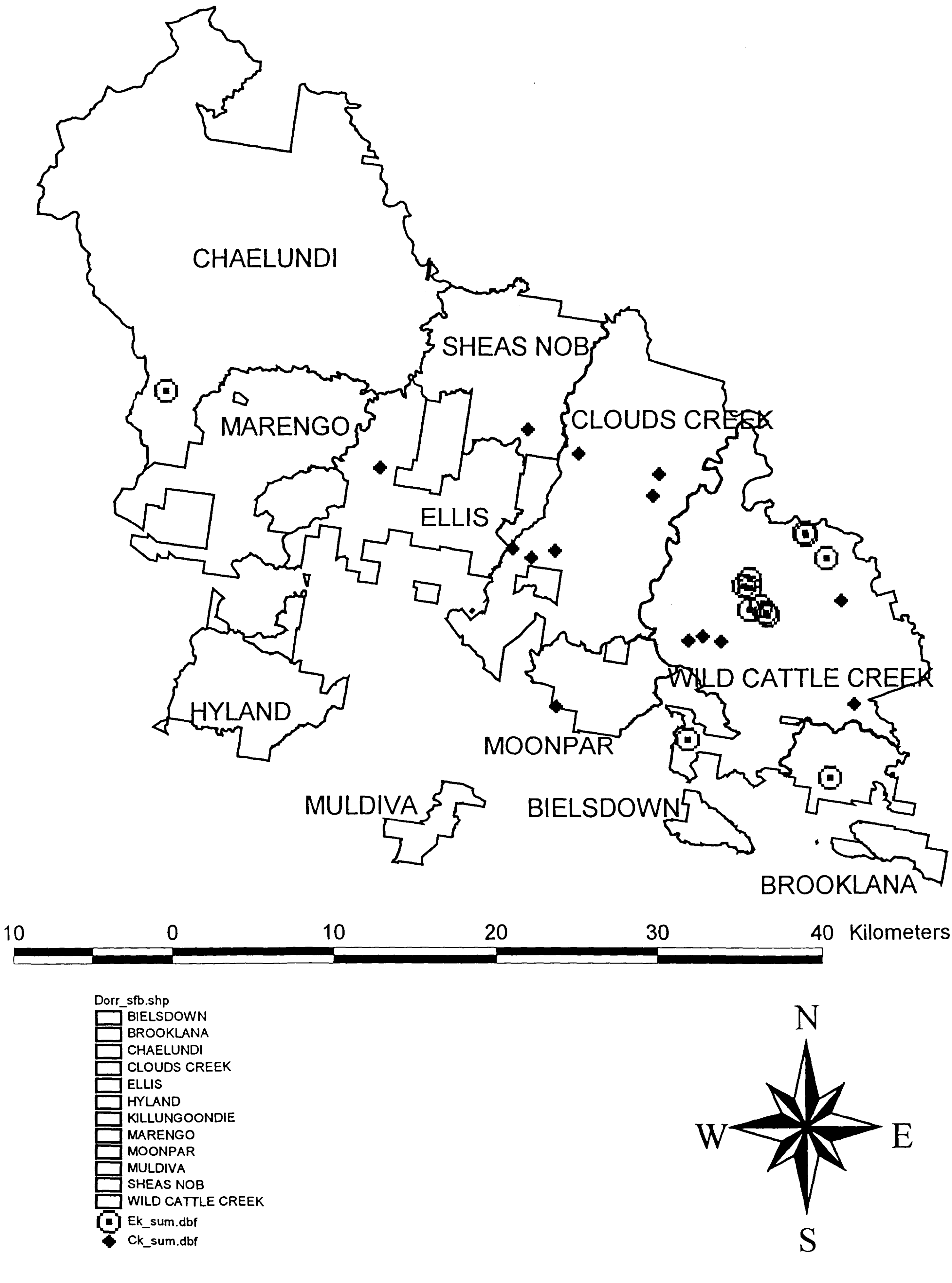
The latter sites were located by the following procedure:

1. Sites were selected on the basis of stratified random sampling within the forest types in which the previous fourteen sites were located. Forest types were mapped across the District using GIS.
2. Random numbers were used to measure and identify coordinates on each forest type map using a millimetre scale grid, with sites being suitable for selection if they landed on a targeted forest type.
3. Sites were then referred to a 1:25,000 scale topographic/forest type map, where they were selected for field location if located "predominantly" or "entirely" within the mapped forest type.
4. Bearings and distances were calculated from identifiable field locations on a 1:25,000 map and were measured in the field by vehicle odometer, hip-chain and Suunto compass.

Between these two sets of sites, a balanced coverage of forest types, structure and floristic composition was obtained, with most statistical tests showing little difference between them. The total percentage plot coverage over the study area is about 0.08% (ie 28 sites at 1.44ha each, as a percentage of 52,069ha).

Figure 6

Distribution of Koala Study Sites in Dorrigo District.



On an initial analysis of the first 7 sample sites, the number of sites required in the main survey so that we can be sure 95% of the time the mean number of tree species will be within 10% of the true value is 32 sites (Equation 1).

Equation 1: $$\mathbf{n = [(C \times t)/e]^2}$$

Where 'n' is the number of sites required, 'C' is the coefficient of variation (%), 't' is the student's 't' at the normal probability level, and 'e' is the required level of accuracy (%). If we accept a confidence level of 90%, then the required number of sites from a sample of the first seven sites is 20 sites. Therefore, 28 sites represents a reasonable level of sampling, given that the number of sites was constrained by the number of these type of surveys done for logging operations at the time. Figures 9 and 11 (Sections 4.1.2 and 4.1.3, respectively) also illustrate the relationships between cumulative tree species and size diversity and sampling effort.

At each main survey site, for every tree with a diameter at breast height over bark (DBHOB) of 30cm and over, records were taken of (i) tree species, (ii) diameter (cm), and (iii) the number of koala scats beneath the tree within 1 metre of the tree base.

This size limitation was adopted because initially, when decisions were made on how to meet survey requirements for Section 120 licensing, it was thought that only trees above this size would be affected by logging and possibly taken for timber products. Although a more accurate picture of tree preferences by the koala may have been possible by examining trees down to as low as 10cm DBHOB, the measurement of smaller trees would have substantially increased survey time and cost. Jurskis and Potter (1997) found in forests at Eden that trees less than 30cm DBHOB were not often "preferred", and Hasegawa (1995) found that koalas used trees greater than 24cm DBHOB more frequently than smaller trees in forests of southeastern Queensland.

All rainforest and wattle trees species were pooled into these two groups for analysis because of the difficulty in identifying the range of non-eucalypt, broadleaf trees in rainforest habitat. Considerable time would have been required in sampling and identification, and there is little evidence that rainforest tree species are preferentially utilised by koalas.

The sample unit area was confined to a 1-metre radius from the base of each tree to focus observer attention, ensure a thorough search and to reduce survey time. If it is assumed that koalas rest and defecate close to the main stem, there is a high probability that at least some pellets will fall and be found within the 1 metre search area around the tree base. This is more likely in the case of younger, actively growing trees than mature trees with spreading crowns. On steeper slopes the tree crown may be not aligned directly over the tree base, however pellets should still be found close to the base if the tree is used. If pellets were opportunistically observed in the space between trees and beneath tree crowns, nearby trees were then thoroughly searched.

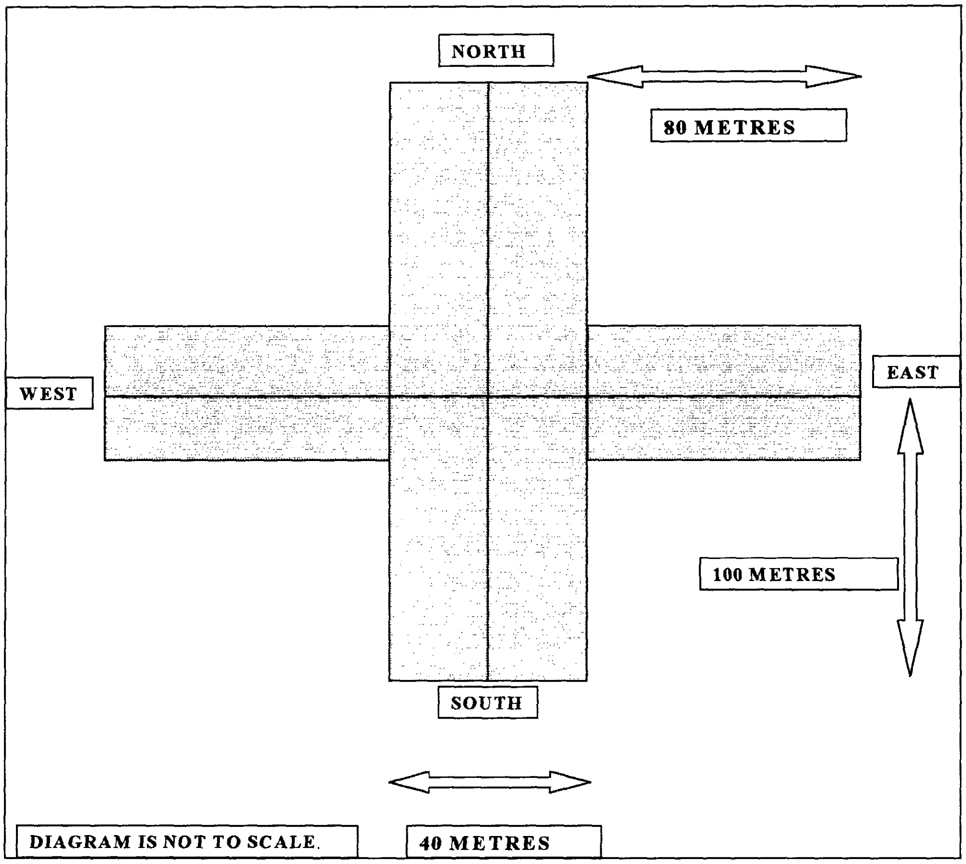
In forests, the crowns of trees often interlock or superimpose over one another. On occasion, trees grew quite close together making it difficult to determine which tree pellets came from. In this study, the distance between close trees was halved giving each tree an equal chance to yield a positive result. Because pellets were often found dispersed around trees that were utilised, an objective decision on the tree most likely to be utilised could be made from examination of pellet location in relation to the type and spread of the canopy of each tree.

Survey sites were sampled according to a modified version of the "asterisk" method (Jurskis and Potter, 1997). This study did not try to determine the most optimal survey method because various methods sample trees in different ways making comparisons difficult. Although this survey technique may not be the most efficient technique, this study adopted the modified "asterisk" survey recommended by State Forests of NSW for the sake of consistency. Each modified "asterisk" survey samples two 100 metre transects in the north and south cardinal compass bearings and two 80 metre transects in the east and west cardinal compass bearings (Figure 7). Each transect is 20m wide either side of a centre line (ie 40m total width). Each survey directly samples 1.44 hectares of forest, but is spread over about a 3-hectare survey site. It is assumed in this study that this area is large enough to adequately detect the presence of koalas.

Advantages of this survey technique for detecting koala faecal pellets are that:

- The survey is not reliant on locating a koala, compared with radio tracking and direct observation studies,
- Results can be expressed in area-based terms (eg numbers of trees per hectare),
- Surveys can focus on a confined area thereby reducing effort,
- A spatial representation of habitat use by the koala can be obtained, and
- The survey is repeatable and results can be confidently expressed.

Figure 7: Diagrammatic representation of the plot layout for the modified "Asterisk" koala survey procedure used in this study at Dorrigo.



The "star and transect" method, developed jointly by New South Wales' State Forests and National Parks and Wildlife Service in 1996 (Appendix 2), only selectively samples the species, size and scat presence of "primary browse" tree species (ie Tallowwood, Grey Gum, Forest Red Gum *Eucalyptus tereticornis* or Swamp Mahogany *E. robusta*) >15cm DBHOB along a series of transects. This method determines a relative index of 'forest use', rather than an area-based result, and is open to greater observer bias. Also, numbers of koala faecal pellets are not counted (except when there are close to 20 scats), which may generalise the degree of use of individual trees where scats are found.

Surveys by Callaghan and Phillips (1995) for the Koala Habitat Atlas assess 'forest use' in a similar way to this study, where all trees are examined for scats within a confined search area of 40m by 40m. However, the number of scats beneath trees and tree size are two factors that do not appear to be taken into account. Also, as with the "star and transect" methodology, there has been an interpretation of what constitutes a "high use area" or "core (critical) koala habitat", defined in both cases as being about 30% of sampled trees showing koala use. This appears to be an arbitrary benchmark figure, and further research needs to be done to define koala habitat use in areas of different koala densities.

All tree species were surveyed, regardless of known koala usage or preference. All koala pellets were removed from each tree where they were found. Details of other factors were gathered either at the site (eg. slope) or upon examination of office map and database records (eg. logging history).

Any potential for observer bias in the search and identification of koala faecal pellets was minimised by the use of trained and experienced personnel. Six people assisted in the survey of sites where koala sign was detected during normal forestry operations. The author surveyed all randomly chosen sites. An indicative length of time taken for one observer to survey an average site is up to 3 hours, depending on the density and size of trees and koala use.

3.2.4 Deterioration of Koala Pellets:

A small experiment was also conducted to investigate the rate of deterioration of koala pellets in forests typical of the study area. This information is relevant to findings discussed later in this thesis.

Fresh koala pellets were deposited in eight groups of twelve pellets at each of two sites and three groups of twelve at one further site. Pellet groups were generally three to five metres apart from each other, and ranged in location at a site from adjacent to trees (both small and large) to open ground with no canopy overhead. Sites were located within Wild Cattle Creek State Forest in:

1. the drier Blackbutt forest type of Compartment 530 (AMG: 475600, 6663425) along Flaggy Falls Road,
2. Tallowwood-Sydney Blue Gum forest type within Compartment 540 (AMG: 473650, 6660300) along Retrievers Road, and
3. Tallowwood-Sydney Blue Gum forest type within Compartment 554 (AMG: 479400, 6655850) along Measuring Hut Road.

Pellets were placed at field sites during winter (18^{th} August 1996) and summer (8^{th} February 1997). Fresh pellets for this experiment were supplied courtesy of the Coffs Harbour Zoo. At the time of placement at field sites, the pellets were reliably estimated to be around 36 hours old. Therefore, consistency and freshness of the sample pellets was ensured.

The pellets in all groups at both sites were inspected once every four weeks until they had noticeably broken down into unrecognisable pellet remains. At each inspection, each pellet group was thoroughly searched for about five minutes. This length of search time was more than the usual one-minute search time applied to the main survey sites because an accurate indication of deterioration was required.

3.2.5 Koala Pellet Content Analysis:

Small quantities of koala pellets were analysed to determine whether Forest Oak and Tallowwood form part of the diet of the koala, particularly as Forest Oak often exists as a large understorey tree below a canopy of eucalypts. Other studies elsewhere have confirmed the use of Forest Oak in the diet of koalas (State Forests of NSW, 1997), but samples were taken and studied only to examine the relevance of tree preference data to dietary preference. Detailed dietary analysis was not undertaken in this study mainly because of time, cost, equipment and expertise factors.

Three samples were supplied to the Department of Ecosystem Management at the University of New England, Armidale, and Kate MacGregor undertook an analysis. The three samples came from one section of about 2 to 3 hectares of Compartment 539, Wild Cattle Creek State Forest, from beneath:

1. a small Tallowwood "Koala" high-use tree (A),
2. a large Forest Oak located nearby a large Tallowwood "Koala" high-use tree (B), and
3. a small Forest Oak "Koala" high-use tree (C).

One pellet from each sample was examined. The pellet was removed from the sample and left soaking overnight in water. The pellet was placed in a beaker with a small amount of alcohol and was broken up using a glass rod. A sub-sample of the pellet was collected using a Pasteur pipette and this was placed on a microscope slide, covered with a coverslip and examined under the microscope.

Leaf samples of Tallowwood and Forest Oak were supplied with the pellets and, from these, reference slides were prepared of epidermal cells. Epidermal cell patterns of eucalypts and allocasuarinas are distinctly different and readily identifiable under a microscope (Kate MacGregor, personal communication). Forest Oak epidermal cells are generally regularly oriented and square-shaped with regularly spaced stomata. In contrast, Tallowwood epidermal cells have an irregular pattern with stomata spread out across the leaf. Also, the characteristic leaf tips of allocasuarinas are not present in eucalypts.

In September 1997, small quantities of faecal pellets containing larvae were sent to State Forests Research Division in Pennant Hills, Sydney for the identification of larvae. In April 1998, these larvae pupated into moths and were then sent to CSIRO Division of Entomology in Canberra for further identification.

3.2.6 Changes in Site Characteristics following Logging:

Control Site 2 in Compartment 539, Wild Cattle Creek State Forest, was initially surveyed on 17th March 1996 (Appendix 5) as part of the random selection of sites within this study. The compartment had also been scheduled for logging in 1996 and was logged shortly after initial measurement. This provided an opportunity to examine changes in tree species, density and size class composition that might be expected from a selective (thinning) harvesting operation.

The specific results cannot readily be used to extrapolate to other forest, but they may provide an insight into how similar circumstances may affect the koala, based on findings from this study. This will be further discussed under implications later in this thesis.

3.3 Ethical and Legal Issues:

A special Animal Care and Ethics Committee licence was not required for main surveys, because field measurement procedures did not directly sample or affect the behaviour of individual koalas.

Spotlighting may have disturbed some koalas at night. However, this sampling procedure was covered under Animal Care and Ethics Committee Licence approval for State Forests' staff involved in fauna surveying for harvest plan licensing and other requirements.

3.4 Data Analyses:

3.4.1 Independent Variables:

A number of independent variables were used for comparison with dependent variables and with each other at different stages of analysis. These include:

1. Stand Characteristics of;

- tree species
- tree size (diameter measured in centimetres at breast height over bark)
- density of trees
- numbers of tree species (ie species richness)
- density of recognised food trees (according to Table 3 in State Forests of NSW, 1997)
- numbers of individuals of eucalypts and non-eucalypts.

2. Topographic Characteristics of;

- slope (degrees)
- altitude (metres above sea level)
- aspect (north, east, south, west)

3. Management Characteristics of;

- The total number of logging events
- Time since last logging (years)

Several further limitations on the use of data occurred in this study. Tree size was measured to the nearest 1cm DBHOB from 30cm up to 230cm DBHOB. In theory, 200 one-centimetre diameter classes could have been analysed for association with dependent variables. However, for the most part during this study, size class intervals of 30cm (ie 30-60cm, 60-90cm, 90-120cm etc) were chosen for analysis because this seemed to provide a compact sample of size classes with which to analyse.

'Koala food trees' were classed as any of those tree species found in this study that were identified in koala faecal pellets from Pine Creek State Forest (Table 3).

Table 3: Tree species identified in scats from Pine Creek State Forest (from State Forests of NSW, 1997).

Allocasuarina torulosa	*Eucalyptus resinifera*
Angophora costata[2]	*Eucalyptus robusta*[2]
Callistemon salignus[1]	*Eucalyptus saligna*
Casuarina glauca[2]	*Eucalyptus siderophloia*[1]
Eucalyptus acmenoides	*Eucalyptus tereticornis*[1]
Eucalyptus grandis	*Lophostemon confertus*
Eucalyptus microcorys	*Lophostemon suaveolens*[2]
Eucalyptus pilularis	*Melaleuca stypheloides*[2]
Eucalyptus propinqua	*Melaleuca quinquinervia*[2]
	Syncarpia glomulifera

[1]Known from the Dorrigo study area, but not sampled.
[2]Not known from the Dorrigo study area.

Soil type data was not completely available for analysis, so this factor was omitted from the study. Geology data was available, but the data were not sufficiently variable to enable statistical analysis. Records on logging history date back only to the mid-1950s, when a devastating fire destroyed the Dorrigo office around 1953/4 (Barbara Carter, personal communication). Logging history information often becomes more inadequate the further back records go. The Dorrigo District covers three management areas with each having different historical management standards, varying distances to markets, and different states of records. For example, in 1985 compartment numbers within the Grafton Management Area were changed by amalgamation of compartment areas and numbering based on uniqueness within the management area.

3.4.2 Dependent Variables:

The main dependent variable in analysing associations between habitat features and koala utilisation throughout this study has been the presence of trees with scats beneath them. Frequencies were often compared between trees with scats and trees without scats.

Numbers of scats beneath trees is also used as a dependent variable because faecal accumulation, in addition to location, is also strongly related to the amount of time spent by animals in parts of their habitats (Leopold et al., 1984). Patterns of high use (numbers of scats) may occur that are different from total use (numbers of trees with scats).

3.4.3 Preference and Importance Indices:

In this study, the use of trees by koalas was compared with the proportion of the same tree class on the sites. If koalas are not selective in their utilisation of trees, then the frequency of use will be in proportion to the relative frequency of occurrence of that tree class, ie the relative exploitation (RE) index equals '1' (White and Kunst, 1990). If the expected use of a tree class is significantly different from the observed use, the preference or avoidance can be expressed as either "over" (RE>1) or "under" (RE<1) exploitation.

The relative exploitation index is a simple method of assigning preference ranks to trees, based on relative proportions of use to availability (White and Kunst, 1990; Jurskis et al., 1994; Jurskis and Potter, 1997). The Preference Index (Martin, 1985a; Hindell et al., 1985) is a different way of expressing the same disproportionate use of trees (Equation 2), and has also been used by Jurskis et al. (1994) and Hasegawa (1995).

Equation 2: **Preference Index (P_i) = (u_i / a_i) / T**

Where 'a_i' is the number of trees of species 'i', 'u_i' is the relative utilisation of species 'i', and 'T' is $\Sigma(u_i / a_i)$.

The Preference Index of tree species may vary considerably with the survey technique. Hasegawa (1995) examined tree preference values using faecal pellets, radio-tracking and pellet cuticle analysis and found that the preference of *E. tereticornis* (converted to a percentage) increased from 33% to 63% and 95%, respectively, whilst similar sized proportionate decreases in preference of other species were seen.

However, the Preference Index does not necessarily convey importance, and some tree classes that may be highly preferred may not contribute significantly to the overall population survival. This index is said to provide a "more realistic appraisal of how koalas are using the trees available" (White and Kunst, 1990). The Importance Index (White and Kunst, 1990) was derived by adjusting the Preference Index to reflect the preference for a class of tree, as well as the abundance of trees in that class (Equation 3). For example, a particular tree species that is considerably over-exploited or highly preferred by koalas, but has a low relative abundance may be less important than a tree species that is also reasonably abundant.

Equation 3: **Importance Index (I_i) = (p_i * n_i) / T**

Where n_i is the number of individuals in species 'i', 'p_i' is the preference index of species (i), and 'T' is $\sum(pi * ni)$.

Use of the Importance Index overcomes problems associated with floristic heterogeneity because the index gives weight to common species that are relatively more uniformly distributed than uncommon species (Jurskis, unpublished).

The importance of particular tree species as feeding resources to the koala usually dominates analyses of tree use, and it is often overlooked that trees are used for more than just food. While the various indices (relative exploitation, Preference Index and Importance Index) may not indicate significant food species, they can still be used to broadly indicate a tree species' ranking according to its relative utilisation by koalas.

The relative utilisation of trees in this study is taken to mean the relative occurrence and/or abundance of faecal pellets beneath trees for all koalas across the Dorrigo study area. The terms utilisation, preference and importance do not imply specific behaviour by koalas.

Although preference and importance indices have been mainly used to examine the utilisation of tree species by koalas, Jurskis and Potter (1997) show that these indexes can also be used to examine the utilisation of other factors, such as tree size. This study describes the use of both tree species and sizes by koalas.

3.4.4 Statistical Procedures:

Data collected for analysis consists broadly of two types:

- a set of tree counts per site with characteristics of each tree recorded (ie tree species and size, with numbers of koala pellets), and

- a number of variables with one value per site recorded for each of the 28 sites (eg slope).

The sample data on tree characteristics and occurrence of scats are assumed to be representative of those from the forest type in which they were selected. This is because (i) survey sites were selected randomly, and (ii) large quantities of data were collected from an adequate number of sites across the study area (Sections 3.2.3, 4.1.2 and 4.1.3). Any bias in detecting koala scats is thought to be very minimal because only a few trained personnel were surveying, only a relatively small area (radius of 1m) was searched around each tree and, if a scat was detected, further time was spent ensuring a thorough search around that tree. The length of time spent in searching around the base of each tree was considered to provide a reasonably accurate result for each tree.

Data were assumed to be independent because of the random location of sample sites. However, data were not assumed to be normally distributed in all cases. Normality of data was tested by examining the appearance of frequency histograms of relevant data, ensuring that roughly 68% of observations were drawn from within ± 1 standard deviation from the mean.

Most analysis in this study examines trends and associations in the count data of trees and scats across all sites, as well as with/between other site variables. Green (1979) comments that the use of several analysis methods, each based on differing assumptions, increases the robustness of decisions reached by statistical analysis. Although multivariate analyses (not used in this study) can provide stronger conclusions than sets of single comparisons, there are limitations, which highlight the benefit of univariate methods (James and McCulloch, 1990). In this study, methods of data analysis have been mainly confined to descriptive, non-parametric (distribution-free) and simple parametric techniques. There may be more to be learned using multivariate statistics.

For some of the minor experiments, statistical procedures differed from those used for the rest of the study data. Numbers of trees with scats were examined for ten repeated cumulative random samples of 100 metre transects. This was done to determine the likely survey effort required to adequately detect a number of scats that does not vary by more than 20% from the average. Thirty-two samples were taken in each case and the standard deviations were graphically compared.

Analysis of frequencies in one-way and two-way classifications (ie Chi-square analysis) were mainly used to compare frequency distributions for association, because Chi-square calculated from a two-by-two contingency table is a valid measure of the association between two variables (Green, 1980). Tests of homogeneity and independence were also performed. The 'G' statistic, although having the flexibility to handle lower cell frequencies in contingency tables, was not used because expected frequencies were generally not very low. "Yates' Correction for Continuity" was applied where there was only one degree of freedom. The 0.05 level of probability was accepted as indicating statistical significance, with the 0.01 and 0.001 levels of probability also indicating higher degrees of significance, where appropriate.

One-way analysis of variance (ANOVA) is a rigorous test (Fowler and Cohen, 1990) that has been used in this study to compare the means of a number of samples. Analysis of Variance assumes random and normally distributed data as well as similar variances of samples (Fowler and Cohen, 1990). This is not the case in most data sets analysed using ANOVA in this study, and so transformation was used to normalise the data and stabilise the variances. Data representing "numbers of trees", where there were often "zero" counts, were also transformed for use in one-way ANOVA using the natural log transformation, $y = \log (x + 1)$ (Alder and Roessler, 1972). The 0.05 level of probability was accepted as indicating statistical significance, with the 0.01 and 0.001 levels of probability indicating higher degrees of significance. The Tukey Test was used following some ANOVA where sample sizes were equal, so that it could more sensitively distinguish mean differences that are significant (Fowler and Cohen, 1990).

Correlations among sets of variables were sought using the parametric Product Moment Correlation Coefficient (r), because of mainly interval data. Log transformation was used to overcome problems of non-normality of data where appropriate. As often indicated, high correlations do not necessarily indicate causation and it may be that other variables, measured or not, may be influencing the variability in samples.

Simple linear regression was used to define linear relationships between two variables that appeared to be meaningful, and had a high correlation, a general linear association between points in a scattergram, and an even scatter of points over the length of the line. The F-statistic, by means of ANOVA, was used to test for the significance of calculated regression lines