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Distribution patterns and habitat use of black cockatoos (Calyptorhynchus spp.) in modified landscapes in the south-west of Western Australia

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

Abstract

Conservation planning for animal species inhabiting modified landscapes requires understanding of where animals occur and how they utilise both natural and modified habitats. In this study the distribution and foraging behaviour of the forest red-tailed cockatoo (*Calyptorhynchus banksii naso*), Baudin's cockatoo (*C. baudinii*) and Carnaby's cockatoo (*C. latirostris*) was investigated in three study areas which each contained a different combination of modified habitats. Pickering Brook contained native forest and orchards, Wungong contained a mosaic of native forest and revegetation, while Karnet contained primarily native forest and paddocks.

The relationship between cockatoo distribution and land use types was examined by constructing Generalised Linear Models based on bird counts and land use data along 90.5 km of road transects. The Akaike Information Criterion (AIC) was used to select a set of the most parsimonious candidate models. Models were constructed at two scales: Regional models incorporated the datasets of all three study areas, while study area models used the datasets of single study areas.

Models for the forest red-tailed cockatoo indicated selection against young post-1988 revegetation. This response was apparent at both the regional scale and within the Wungong study area. Baudin's cockatoo selected in favour of orchards at the regional scale, but their distribution was unrelated to any land use variable within the (orchard-rich) Pickering Brook study area. No models were constructed for Carnaby's cockatoo due to a limited number of observations for this species.

Feeding observations demonstrated the importance of the native eucalypts marri (*Corymbia calophylla*) and jarrah (*Eucalyptus marginata*) as a food source for the forest red-tailed cockatoo and Baudin's cockatoo. In contrast Carnaby's cockatoo fed most frequently in plantations of introduced pine (*Pinus* spp.). Contrary to model predictions, Baudin's cockatoo was never observed feeding in apple orchards during the study. This discrepancy may be due to timing of the surveys outside the hours when Baudin's cockatoo fed in orchards, or it could indicate that orchards are of limited importance as a food source.

Forest red-tailed cockatoos consistently fed on particular marri trees while ignoring others, but this selectivity was unrelated to fruit morphology or seed nutrient content. Instead, foraging patterns may have been driven by ingrained habits, or by variation in the concentration of secondary compounds.

In conservation efforts, identification of critical habitats is an important first step. This study highlighted the importance of studying habitat selection and constructing management plans at an appropriate scale, relative to the range of the target species. Wide ranging species like black cockatoos require regional scale protection of important broad vegetation types such as the northern jarrah forest, combined with landscape scale protection and restoration – for instance during post-mining revegetation – of specific feeding habitat and food species, such as pine for Carnaby's cockatoo and possibly Fraser's sheoak (*Allocasuarina fraseriana*) for the forest red-tailed cockatoo.

Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material.

I also grant permission for the Library at Edith Cowan University to make duplicate copies of my thesis as required.

Marieke Weerheim

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Pat Collins from the Forest Management Branch at DEC provided me with information on fire and sawlog harvesting history in all my study sites. She also offered valuable advice when I was selecting my study sites.

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Chapter 1 – General Introduction

1.0 Introduction

Clearance, modification and fragmentation of habitat are the main factors driving species extinctions and decline in biodiversity around the world (Tilman *et al.* 1994, Ehrlich 1995, Huxel & Hastings 1999, Garnett & Crowley 2000). Many animal species currently live in modified landscapes (Western 2001, Hobbs *et al.* 2006). Understanding how modification impacts on species and communities is essential to ensure successful conservation efforts.

The response to loss or modification of native habitat can be very different for animals sharing the same landscape or area; some species are disadvantaged, while others show no response at all or even benefit (McGarigal & McComb 1995, Saunders & Ingram 1995, Lindenmayer *et al.* 2002, Westphal *et al.* 2003). The difference can often be related to specific life-history characteristics (Lindenmayer *et al.* 2002, Coreau & Martin 2007).

The ability to use modified habitat strongly influences the persistence of species in a landscape (Saunders & Ingram 1995, Fahrig 2001, Westphal *et al.* 2003, Tubelis *et al.* 2007). Indeed, although modification of a landscape typically implies a loss of native habitat, it also brings about an increase in new habitat (Andrén 1994, Hobbs *et al.* 2006). Studies on bird communities in modified landscapes show that many species are able to make extensive use of novel habitat types (McGarigal & McComb 1995, Lindenmayer *et al.* 2002, Seddon *et al.* 2003, Westphal *et al.* 2003, Manning *et al.* 2006). These are often mobile species or habitat generalists (Lindenmayer *et al.* 2002, Seddon *et al.* 2003), or species whose preferred habitat is very similar to the novel habitat type. For instance, open-country species tend to benefit from conversion of native forest into pasture or agricultural land (Saunders *et al.* 1985, Cameron 2007). Conversely, habitat specialists, especially those with limited dispersal capabilities, or species requiring large unfragmented areas of native vegetation tend to decline or disappear in modified landscapes (Saunders 1990, Saunders *et al.* 1991, Lindenmayer *et al.* 2002, Graf *et al.* 2006, Coreau & Martin 2007).

Despite the large scale on which humans have altered natural landscapes world wide (Western 2001, Hobbs *et al.* 2006), the full long-term impact on species, populations or communities is largely unknown since empirical evidence of long-

term effects is limited to a few recent studies (Ehrlich 1995, Fahrig 2001). The reason for this is that in many cases modification has occurred only recently or is still ongoing (Fahrig 2001), and the time span over which human-induced landscape alteration takes place is short relative to the response times of most affected organisms (Saunders 1986, Saunders *et al.* 1991, Fahrig 2002, Fuhlendorf *et al*. 2002). Such response times may be several decades (Tilman *et al.* 1994). For this reason, persistence of species in a landscape does not necessarily imply that the habitat is optimal (Johnson 1980, Pulliam 1988, Doak 1995, Lindenmayer *et al.* 2002, Weerheim *et al.* 2003).

To a particular species or individual animal, any landscape, either natural or severely modified, consists of a mosaic of higher and lower quality patches (Pulliam 1988, Pulliam *et al.* 1992), with quality often expressed in terms of preferred or non-preferred habitat (Bowyer & Kie 2006, Graf *et al.* 2006) or as habitat patch and matrix (Lindenmayer *et al.* 2002, Westphal *et al.* 2003, Tubelis *et al*. 2007). Interestingly, degradation of non-preferred patches can impact on species as much as degradation of preferred patches because the benefits gained from visiting the latter will depend on the costs of traversing the former (Fahrig 2001, Bowyer & Kie 2006, Cameron & Cunningham 2006), and because habitat quality in non-preferred patches affects the influx of predators and competitors into preferred patches (Saunders *et al.* 1991). This suggests that conservation needs to consider the quality of the landscape, or perhaps even region as a whole, and not just focus on particular preferred habitat types (Saunders *et al.* 1991, Stoms *et al.* 1993, Huxel & Hastings 1999, Fahrig 2002, Gibson *et al.* 2004a, Recher 2004).

Hence, to understand the impact of landscape changes and make informed management decisions for species or communities in modified landscapes, one needs to know more than simply how much of the original native habitat is left, and how many species or individuals persist. Of equal importance is to know how animals use the modified landscapes and compare this with unmodified ones. This requires information on where animals occur in a landscape, to what extent they use each of the available habitat (land use) types within the landscape and how they use them, and establish whether there are differences in quality within the same preferred habitat type (Pulliam 1988, Pulliam *et al.* 1992).

1.2 Study region and study species

The Southwest Australia Ecoregion, located in the south-western corner of Western Australia, is recognized as a global biodiversity hotspot with high levels of endemism among both plants and animals (Gole 2006). Over the past century, the ecoregion has undergone large scale and rapid changes due to clearing and modification of native vegetation (Saunders *et al.* 1985, Saunders 1986, Gole 2006). Nearly 90% of the original native vegetation has been affected in some way, including but not limited to clearing of native vegetation for agriculture, livestock grazing and urban development and modification of native vegetation through sawlog harvesting and mining (Saunders *et al.* 1985, Bradshaw 1999, McKenzie *et al.* 2003, Johnstone & Cassarchis 2005). Consequently, the ecoregion now has the highest concentration of rare and endangered species on the Australian continent (Gole 2006).

Three taxa of black cockatoo are endemic to the ecoregion: the forest red-tailed cockatoo *Calyptorhynchus banksii naso* (Gould 1837), Baudin's cockatoo *C. baudinii* (Lear 1832) and Carnaby's cockatoo *C. latirostris* (Carnaby 1948).

The forest red-tailed cockatoo is one of five subspecies of the red-tailed cockatoo, differing from the nearest neighbouring subspecies, the inland red-tailed cockatoo *C. b. samueli*, by having a larger and heavier bill and brighter striping and spotting of the female's body feathers (Ford 1980, Saunders *et al.* 1985, Johnstone & Storr 1998, Higgins 1999). Baudin's cockatoo and Carnaby's cockatoo are full species but appear very similar, both being mottled black with large white tail panels (Higgins 1999). They were only recognized as separate species in 1974 (Saunders 1974b). The main distinguishing features between the two are length of the upper mandible, calls and diet (Saunders 1974b, Johnstone & Storr 1998, Higgins 1999, Cooper *et al.* 2002).

Each of the three taxa of black cockatoo has a restricted distribution, a specialised diet and a low reproductive rate and requires large natural hollows in 200-300 year old eucalypt trees for nesting (Johnstone & Storr 1998, Higgins 1999, Johnstone & Cassarchis 2003, 2004, 2006). These are all features that make species particularly vulnerable to the effects of habitat clearing and modification (Saunders 1986, Fahrig 2001). Consequently, the drastic alterations to the landscape that have occurred over the past century have brought about dramatic declines in the population size and range of the ecoregion's black cockatoos, and each taxon is currently under threat of extinction (Johnstone & Storr 1998, Higgins 1999, Cale 2003, CALM 2006).

All three taxa of black cockatoo are protected under state legislation in Western Australia, while Baudin's and Carnaby's cockatoo are also listed nationally and internationally. The Western Australian Wildlife Conservation Act (1950) lists all three on Schedule 1: Fauna that is rare or likely to become extinct (Wildlife Conservation (Specially Protected Fauna) Notice 2008). The Commonwealth Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) lists Carnaby's cockatoo as Endangered and Baudin's cockatoo as Vulnerable (Australian Government 1999). The International Union for Conservation of Nature (IUCN 2001) Red List of Threatened Species lists Baudin's and Carnaby's cockatoo as endangered. Because it is a subspecies of the red-tailed cockatoo which as a species is considered least concern (IUCN 2001), the forest red-tailed cockatoo is not mentioned under the EPBC Act or on the IUCN Red List. However, the taxon meets IUCN (2001) Red List criteria to be listed as near threatened (Garnett & Crowley 2000).

1.2.1 Forest red-tailed cockatoo

The forest red-tailed cockatoo is a forest specialist whose range (Figure 1.1) neatly follows the distribution of the marri tree (*Corymbia calophylla*) which is its main food species (Saunders 1980, Saunders *et al*. 1985, Johnstone & Kirkby 1999). The large heavy bill of the taxon is believed to be an adaptation to opening the tough marri fruits (Ford 1980). Within the larger Southwest Australia Ecoregion, the distribution of the forest red-tailed cockatoo encompasses the northern jarrah forest, southern jarrah forest and warren bioregions which are all characterised by dense eucalypt forest and woodlands (McKenzie *et al.* 2003).

The taxon breeds every second year, and there are indications that in any one year only 10% of the population attempts to breed (Johnstone & Kirkby 1999). The small percentage of breeding attempts could indicate that, although food quantity is adequate to sustain adult birds, food quality may limit breeding (Johnstone & Kirkby 1999). The forest red-tailed cockatoo is relatively sedentary, being a year-round resident in its breeding areas, and this may be an additional factor contributing to its vulnerability to loss and modification of its habitat (Johnstone & Kirkby 1999).

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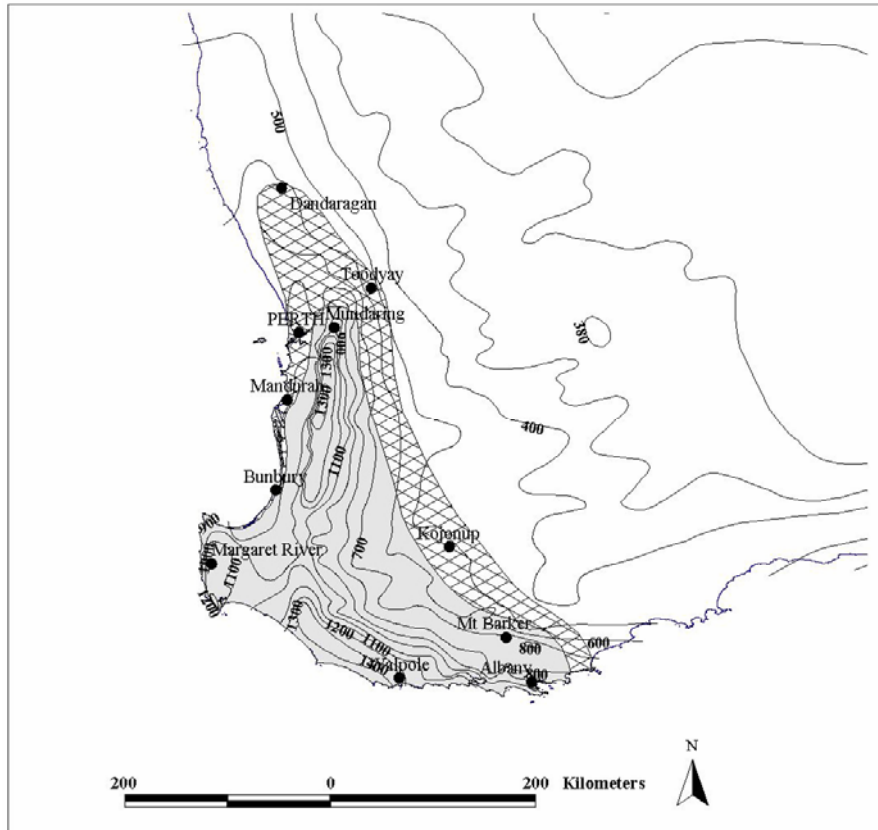
Figure 1.1 – Distribution of the forest red-tailed cockatoo. Grey area shows current distribution and hashed area shows extent of former distribution. Also shown are the isohyets of average annual rainfall (mm). (Map provided by T. Chapman, Department of Environment and Conservation, based on information from Johnstone & Storr 1998).

A decade ago the population size of the forest red-tailed cockatoo was estimated to be between 16 000 and 26 000 birds (Abbott 1998). However, this estimate was based on heavily skewed data and numbers should be regarded as indicative only (Abbott 1998). More recent data suggest a population size of only 15 000 birds (R. Johnstone *pers. comm.* June 2008). Since black cockatoos are long lived (Brouwer *et al*. 2000) and direct threats to the lives of adult birds are considered to be few (Abbott 2001) it is unclear whether the difference in population estimates truly reflects a considerable change in numbers. Given that the forest red-tailed cockatoo has a low density throughout its range and inhabits dense forests where birds may be hard to detect, accurate population estimates are hard to obtain, and different counting methods may result in large differences in estimates (Bibby *et al.* 2000). Nonetheless, it is possible that numbers have indeed gradually declined over the past decade due to adult birds reaching the end of their natural life span while recruitment rates are too low to replace them (Johnstone & Cassarchis 2005).

1.2.2 Baudin's cockatoo

Baudin's cockatoo is also known as the long-billed black-cockatoo (Higgins 1999). Like the forest red-tailed cockatoo, the seeds of marri form the staple diet for Baudin's cockatoo (Higgins 1999) and consequently, there is a strong range overlap between the taxa (Figure 1.2). The bill of Baudin's cockatoo is equally adapted to removing seeds from marri fruits, but rather than a heavy bill suitable for crushing, the bill of Baudin's cockatoo has a long fine tip which allows it to extract the seeds without damaging the fruits (Saunders 1974b, Cooper *et al.* 2002).

Within its current range, the species only breeds in densely forested areas in the southern jarrah forest bioregion (Higgins 1999, McKenzie *et al.* 2003, Saunders 1974b), with the northernmost breeding events recorded near Lowden, 30 km south-east of Bunbury (Johnstone & Storr 1998) and one isolated nest discovered near Serpentine, 40 km north of Perth (Johnstone & Kirkby 2008).
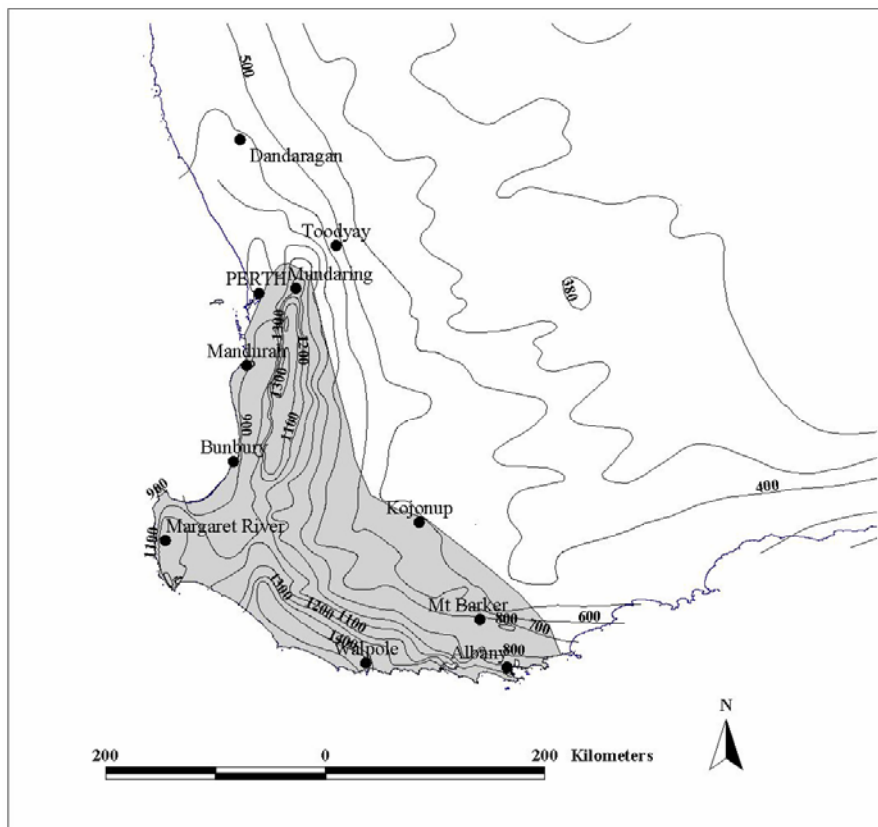
Figure 1.2 – Distribution of Baudin's cockatoo. Also shown are the isohyets of average annual rainfall (mm). (Map provided by T. Chapman, Department of Environment and Conservation, based on information from Johnstone & Storr 1998).

After breeding, from January to July, the birds congregate in large flocks that move north-east searching for food (Saunders 1974b, Johnstone & Storr 1998). During this time, the large foraging flocks may enter commercial orchards where they feed on the seeds and juice of apples and pears (Saunders 1974b, Saunders *et al.* 1985, Chapman & Massam 2005, Chapman 2007a). Because of this habit, Baudin's cockatoo is a declared agricultural pest and, although it is protected by law, illegal shooting by orchardists continues (CALM 2006). Changes in adult survival rates tend to have the strongest effect on population persistence or extinction (Pulliam *et al.* 1992, Fahrig 2001). Hence, illegal shooting is currently considered to be one of the principal threats to the species (CALM 2006, Chapman 2007a, 2007b). Nonetheless, changes in the population size of Baudin's cockatoo are poorly known because early records of white-tailed cockatoos did not distinguish between Baudin's and Carnaby's cockatoo (Saunders 1974b, Higgins 1999).

A decade ago, the population size of Baudin's cockatoo was estimated to be between 10 000 and 15 000 birds (Higgins 1999), but this estimate was considered to be of low reliability (Garnett & Crowley 2000). More recent estimates suggest there are currently between 15 000 and 20 000 birds (R. Johnstone *pers. comm.* June 2008). As mentioned for the forest red-tailed cockatoo, accurate population estimates are hard to obtain and it is possible that since the earlier 1999 estimate was published, numbers of Baudin's cockatoo have in fact declined. Because of their slow reproductive rate, it is unlikely that enough chicks are produced each year to offset the high adult mortality due to shooting (Johnstone & Storr 1998, Chapman 2007b).

1.2.3 Carnaby's cockatoo

Carnaby's cockatoo is also known as the short-billed black-cockatoo (Higgins 1999). It has the largest range of all three taxa (Figure 1.3), reaching far into the Avon wheatbelt bioregion (McKenzie *et al.* 2003), which forms the main breeding area (Saunders 1974b, Johnstone & Storr 1998). In the breeding areas Carnaby's cockatoo is highly dependent on seeds of native vegetation, primarily proteaceous scrubs and heath and marri (Saunders 1974a, 1974b, 1980, 1986, Saunders *et al.* 1985, Johnstone & Storr 1998).

Like Baudin's cockatoo, Carnaby's cockatoo undergoes post-breeding movements. Between December and July birds congregate in large feeding flock

with many moving south-west to the Swan coastal plain. Here they traditionally fed in native heath communities, but after many were cleared, pine (*Pinus* spp.) plantations have become the species' main food source (Saunders 1974a, 1980, Johnstone & Storr 1998).

Because of its seasonal movements, the population size of Carnaby's cockatoo is hard to quantify, since the formation of large flocks may lead to over estimation of numbers (Saunders *et al.* 1985). Consequently, population estimates vary widely, from 11 000 to 60 000 birds (Saunders *et al.* 1985, Higgins 1999), with the most recent estimate suggesting that there are currently 40 000 birds (R. Johnstone *pers. comm.* June 2008). Over the past 50-60 years Carnaby's cockatoo has shifted its distribution considerably westwards and southwards (Johnstone & Storr 1998) with recent nests found in the northern jarrah forest and on the Swan coastal plain (Johnstone & Cassarchis 2003, 2004, 2005).
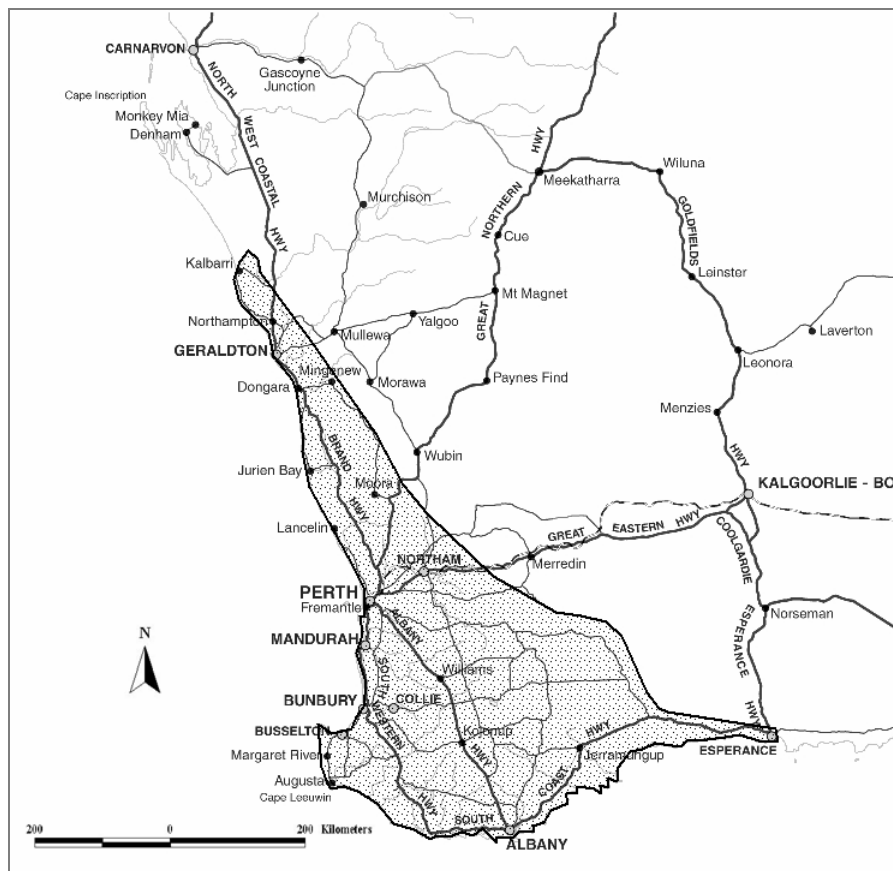
Figure 1.3 – Distribution of Carnaby's cockatoo. (Map provided by T. Chapman, Department of Environment and Conservation, based on information from Johnstone & Storr 1998).

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1.3 Impacts of landscape changes on black cockatoos

The large scale landscape changes that have taken place in south-west Western Australia over the past century have impacted on the region's black cockatoos in direct and indirect ways. Not all changes appear to be negative to the birds, and there is evidence that each taxon has adapted to the modified landscapes to an extent.

This section describes the main processes of landscape alteration that are currently relevant to the conservation status of black cockatoos in south-west Western Australia. Since this study was limited to a single year, only a subset of these processes could be examined. In order to present a more complete picture, all of the most significant current processes will be outlined below, but it must be kept in mind that sawlog harvesting and nest competition fall outside the scope of this study (see Section 1.4). Furthermore, other processes which may be relevant but whose impact on black cockatoos is currently unknown, such as the spread of *Phytophthora cinnamomi* dieback, are not discussed due to paucity of empirical data on their effects. Some of the processes outlined below apply specifically to particular bioregions or vegetation types; for instance sawlog harvesting primarily affects the northern and southern jarrah forest bioregions.

1.3.1 Clearing of native vegetation

Of all landscape scale processes, outright clearing of native vegetation obviously has the strongest impact on black cockatoos, bringing about an abrupt range reduction as species simply cannot persist where suitable habitat has disappeared (Ehrlich 1995). The bioregions where habitat loss has been especially severe are the Avon wheatbelt and the Swan coastal plain (Saunders 1991, McKenzie *et al.* 2003). Clearing for agriculture, stock grazing and, especially on the Swan coastal plain, urban development, has reduced the native vegetation to a few remnants (Saunders *et al.* 1985, Saunders 1990, Gole 2006), most of which are in poor condition (McKenzie *et al.* 2003).

Carnaby's cockatoo, for which the wheatbelt and Swan coastal plain are important breeding and feeding areas, respectively, has been heavily impacted by the large scale clearing (Saunders 1990). The species traditionally nested in extensive areas of salmon gum (*Eucalyptus salmonophloia*) and wandoo (*E.*

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wandoo) woodland, while feeding in nearby heathlands (Saunders 1974b). At present only a scattered mosaic of small woodland remnants remains, and these are virtually the only source of nest trees available to the species (Saunders 1977b, Saunders *et al.* 1985). Many of the remnants are degrading due to senescence of trees, damage by grazing cattle and invasion of weeds (Gole 2006). At the same time, remnant patches of native heath vegetation are widely scattered, making it hard for the birds to locate and utilise them effectively (Saunders 1990). Although pine plantations offer the birds an alternative food source (see Section 1.3.2), the overall loss and fragmentation of breeding and feeding habitat has been severe. Carnaby's cockatoo has disappeared from over a third of its original range (Saunders *et al.* 1985, Saunders 1990, Higgins 1999) and there is strong evidence that its population size has halved over the past 45 years (Garnett & Crowley 2000).

In comparison to the wheatbelt and Swan coastal plain, the jarrah forest bioregion stands out as one of the few areas where a large proportion of the native vegetation cover still remains (McKenzie *et al.* 2003). However, the jarrah forest too has been heavily impacted by human activity. Since European settlement, clearing for agriculture, orchards, cattle grazing and urban development has reduced the original extent of 2.8 million hectares to a current 1.8 million hectares (Gardner & Stoneman 2003). Consequently, the forest red-tailed cockatoo has disappeared from 36% of its former range and is believed to have declined in density over another 14% (Garnett & Crowley 2000). Baudin's cockatoo has disappeared from 25% of its former range following clearing in the southern jarrah forest, while partial clearing in another 25% has led to a decline in density (Garnett & Crowley 2000).

1.3.2 Exotic plant species

Where the original native vegetation has disappeared, many exotic plant species have taken its place. Black cockatoos are able to take advantage of some of these exotic species as a source of food and there is evidence that the birds may be shifting their distribution to incorporate areas where these novel food species occur (Stranger 1997, Johnstone & Storr 1998, Abbott 2001). However, the extent to which novel foods can compensate for the loss of native food species remains to be studied.

In recent years, forest red-tailed cockatoos have been reported feeding on the introduced cape lilac (*Melia azedarach*). This behaviour was observed on the Swan

coastal plain (Stranger 1997), in locations near Perth (Abbott 2001) as well as in modified areas in the northern jarrah forest (T. Kirkby *pers. comm.* June 2006). The first two locations are areas which previously fell outside the range of this taxon. As yet they appear to be visited exclusively for foraging as there are no reports of nesting or roosting in these areas (Abbott 2001). Since forest red-tailed cockatoos are faithful to their roost sites, birds feeding on cape lilac on the Swan coastal plain undertake very long foraging trips and this may be exhausting the birds (R. Johnstone *pers. comm.* March 2008).

Other introduced food species known to consumed by forest red-tailed cockatoos are the seeds of the eastern Australian eucalypts spotted gum (*Corymbia maculata*) (Johnstone & Kirkby 1999) and lemon-scented gum (*C. maculata citriodora*) (T. Kirkby *pers. comm.* June 2006). However, these trees occur only in small scattered groups and their overall abundance in Western Australia is low.

Baudin's cockatoo has been known to feed on apples and pears in commercial orchards since the early 1900s (Halse 1986 cited in Chapman 2007a). It is suggested that the birds feed in orchards to compensate for their loss of feeding habitat, since damage appears to be most severe in years with a poor marri crop (Saunders 1974b), but this claim has never been tested. Whatever benefit Baudin's cockatoo may have gained from tapping a new and temporarily abundant food source, it is unlikely to compensate for the losses the species has suffered from shooting in the past. Based on current estimates of reproduction and mortality, even low levels of shooting may lead to complete extinction of the species in the next 100 years (Chapman 2007b).

Carnaby's cockatoo, unlike the other cockatoo species living in the wheatbelt, does not take advantage of the abundant cereal crops but instead still feeds exclusively on native vegetation (Saunders *et al.* 1985). However, in its post-breeding areas on the Swan coastal plain, the large pine (*Pinus* spp.) plantations have become an increasingly important food source since roughly the 1930's (Saunders 1974a, 1980). A growing dependency on pine, combined with the ongoing decrease in nest trees in the Wheatbelt, is believed to be the driving factor behind the south- and westward shift in distribution of Carnaby's cockatoo (Johnstone & Storr 1998). However, as yet there is no quantitative information available on the value of pine trees for the population of Carnaby's cockatoo. Incidentally, since 2005 Baudin's cockatoo is also known to use pine plantations as a food source, albeit still to a minor extent (Johnstone & Cassarchis 2005).

1.3.3 Mining and revegetation

Nearly all of the northern jarrah forest falls under a mineral lease granted to Alcoa World Alumina in 1961 (Gardner & Stoneman 2003). Alcoa commenced mining for bauxite in 1963 (Alcoa 2003). By 1999 about 10 000 ha of jarrah forest had been cleared for bauxite mining (Bradshaw 1999) and current rates of clearing are estimated at 550 ha per year (Gardner & Stoneman 2003). Based on the occurrence of the richest deposits, it is estimated that bauxite mining operations will eventually disturb about 6% of the entire northern jarrah forest, while the southern jarrah forest bioregion has very little bauxite deposits (Gardner & Stoneman 2003).

Bauxite mining necessarily involves clear felling of all vegetation and removal of topsoil. In adherence to its code of practice, Alcoa revegetates all of its sites once mining is completed (Alcoa 2003, Grant & Koch 2007, Koch 2007a). Studies on soil characteristics (Jasper 2007), flora richness (Koch 2007b, Koch & Samsa 2007) and fauna recolonisation (Majer *et al*. 2007, Nichols & Grant 2007) show that most revegetated sites are on a desirable trajectory towards a pre-mining state. However, the revegetated sites are still very different from unmined forest and it will take centuries before the similarities outweigh the differences (Ward *et al.* 1990, Bradshaw 1999, Nichols & Nichols 2003, Grant *et al*. 2007, Koch & Hobbs 2007).

The value of revegetated mine pits for south-western Australia's black cockatoos is yet unknown. Based on the demographics of trees suitable for nesting by black cockatoos, the eucalypts in Alcoa's revegetation are too young to provide the birds with nest hollows for at least the next one or two centuries (*cf.* Saunders 1979b, Saunders *et al.* 1985, Whitford 2001, 2002). However, observations of Carnaby's cockatoo feeding on seeds and flowers of young proteaceous shrubs in revegetated areas of the Boddington Gold Mine (H. Finn *pers. comm.* May 2008), suggests that some revegetation can provide black cockatoos with a food source. Whether the revegetated bauxite pits in the northern jarrah forest are also utilised as a food source by black cockatoos has not been studied (Nichols *et al.* 1985, 1991, Nichols & Muir 1989, Alcoa 2003, Nichols & Grant 2007).

1.3.4 Sawlog harvesting

Sawlog harvesting is a process that has caused important disturbance in the jarrah forest bioregion (McKenzie *et al.* 2003). Of the two-thirds of the jarrah forest left uncleared, almost every part has been harvested for sawlogs some time in the past and remnants of unlogged forest remain only on hillcrests and along rivers and streams (Wykes 1985, Bradshaw 1999, Craig 2004, Nichols & Nichols 2003). Even these remnant areas may have experienced some minor harvesting before 1950, involving taking of a few large trees, but records of the DEC Forest Management Branch indicate no harvesting in the past 30-50 years. Sawlog harvesting in the jarrah forest continues today.

Sawlog harvesting alters the forest structure by reducing the proportion of older, larger trees (Recher 1985, Recher 2004). It is these large old trees that are of special significance to black cockatoos. First, mature trees produce flower and seed crops many times greater than those of young trees (Robinson 1960, P. Mawson *pers. comm.* October 2006). Second, and perhaps more importantly, only mature 200-300 year old eucalypts produce hollows large enough for nesting by black cockatoos (Johnstone & Cassarchis 2003). Calculations made by Abbott (1998) suggest that ten years ago the number of nest trees was not limiting to the forest red-tailed cockatoo (but see Recher 2004). However, this does not remove the need for protecting existing nest hollows wherever possible, especially in the light of increased competition for breeding hollows from other bird species and feral honey bees (see Section 1.3.5). For Baudin's cockatoo only limited nesting data is available because the species breeds in densely forested areas and its nest hollows are hard to find (CALM 2006).

In recent decades, management of the jarrah forest has changed substantially, with a growing emphasis on conservation of biodiversity (Whitford & Stoneman 2004). The current Forest Management Plan 2004-2013 dictates the retention of five habitat trees per hectare, and an additional retention of six to eight secondary habitat trees (Conservation Commission 2004). However, these guidelines can be seen as a "risk spreading strategy" at most, given that knowledge of hollow density requirements of most forest fauna is currently insufficient to quantify a target density of habitat trees (Whitford & Stoneman 2004).

1.3.5 Nest competitors

Transformation of native vegetation into agricultural land has promoted open-country cockatoos like the galah (*Eolophus roseaicapilla*) and little corella (*Cacatua sanguinea*) and tree nesting ducks like the Australian wood duck (*Chenonetta jubata*) and Australian shelduck (*Tadorna tadornoides*) (Saunders *et al.* 1985, Cale 2003, Cameron 2007). With ongoing clearing and provision of permanent water, numbers of these species have greatly increased (Higgins 1999) and they are now competing with black cockatoos for nest hollows (Cale 2003, Johnstone & Kirkby 2008).

In the case of Carnaby's cockatoo, whose breeding habitat in the wheatbelt is particularly limited, nest competition is believed to have been a significant contributing factor to its decline in numbers and disappearance from much of its former breeding range (Hobbs *et al.* 1993).

For the forest red-tailed cockatoo and Baudin's cockatoo, which breed in forested areas, there is growing evidence that the feral populations of the introduced European honey bee (*Apis mellifera*) are significant nest competitors (Garnett & Crowley 2000, CALM 2006, Johnstone & Kirkby 2008). Feral bees have been recorded killing nestlings and adult females and generally render hollows unsuitable for cockatoos by filling them up with wax (Saunders 1979b, 1982, Saunders *et al.* 1995, CALM 2006).

1.4 Scope and objectives of the study

On of the key elements of species conservation is identifying and protecting essential habitat. Especially for large and mobile animals like black cockatoos this requires a landscape scale approach (Fahrig 2002, Cushman & McGarigal 2004, Coreau & Martin 2007). In order to develop management plans for south-west Western Australia's black cockatoos, it is important to know how each taxon makes use of the landscape as a whole, and compare this between natural and modified landscapes. This involves studying where the birds occur in the landscape, whether and how they utilise each of the available land use types within, and whether there may be differences in quality within the same land use type.

In this study the distribution patterns and foraging behaviour of black cockatoos was recorded in three different study. The study areas were located in the

northern jarrah forest ecoregion in Western Australia. This region contains large amounts of native jarrah forest as well as a wide range of human-modified land use types, and forms the overlap zone for the three taxa of black cockatoo for at least part of the year (Johnstone & Storr 1998). The study took place over whole year of 2007, with surveys for black cockatoos conducted every second month, hence in six survey periods.

Since black cockatoos are large and mobile birds, with a daily foraging range of several km (Johnstone & Kirkby 1999, T. Kirkby *pers. comm*. June 2006), obtaining information on a scale relevant to the birds required surveying very large areas. This placed limits on the scope and detail of information that could be collected over the course of a one year study. Therefore, the study focused on distribution patterns related to food availability and did not attempt to identify nest sites and roost sites, asses the impact of sawlog harvesting or determine the presence and impact of nest competitors.

There were several reasons for this. First, the availability of food resources is known to be an important factor influencing the status and distribution of cockatoo species between landscapes (Saunders 1980, Cameron & Cunningham 2006). Furthermore, forest red-tailed cockatoos spend up to 10-12 hours a day feeding (Johnstone & Kirkby 1999), which suggests that during most of the daylight hours the distribution of birds within a landscape will be strongly related to the distribution of food resources.

Conversely, the spatial distribution of nest trees is only expected to influence the cockatoos' daily distribution patterns between egg laying and fledging of the chick, which takes on average three months (Higgins 1999). The great majority of Carnaby's and Baudin's cockatoos breed respectively far north or far south of the study areas (Johnstone & Storr 1998, Higgins 1999), while only 10% of the population of forest red-tailed cockatoos was expected to breed (Johnstone & Kirkby 1999). More importantly, nest trees are difficult to find, labour intensive to monitor (cf. Johnstone & Cassarchis 2003, 2004, 2005) and attempts to assess the status of nest trees would risk disturbance to the already endangered taxa. Hence, sufficiently detailed and reliable data on the availability and location of nest trees would be virtually impossible to obtain over the course of a single year study and even then would be of limited value for explaining landscape use by black cockatoos.

Data on sawlog harvesting may serve as an indirect means of establishing availability of nest trees, since intensity of harvesting affects the number of large

hollow-bearing trees remaining (Recher 1985, Recher 2004). However, the history of sawlog harvesting in all study landscapes is very complex: Some forest patches were harvested once and others several times with the most recent harvest often preceding bauxite mining. The intensity of early harvests was not recorded (P. Collins *pers. comm.* May 2008).

Regarding nest competition, although the presence and abundance of avian species known to be nest competitors can be recorded with little additional effort at the same time that black cockatoos are surveyed, their nests are equally labour intensive to find. Without knowledge on the availability of nest hollows in a landscape, it is hard to establish whether competition is occurring at all. The impact of feral honeybees, although possibly substantial (cf. Johnstone & Cassarchis 2003. 2004), is even harder to assess. Bee colonies in tree hollows can only be heard when up close; hence reliable data on density of bee colonies would be impossible to obtain given the size of the study areas and the limited time available. Although foraging honeybees can be easily recorded, it is virtually impossible to determine whether these bees are feral, given the presence of commercial beehives in all of the study areas.

Roost trees may play a role in determining distribution of black cockatoos between landscapes, as they are known to forage within 4-5 km from their roost trees (Johnstone & Kirkby 1999, T. Kirkby *pers. comm.* June 2006). However, there is no evidence suggesting that the availability of roost trees may be limiting, and a single tree is sufficient to provide a roost for hundreds of birds (Higgins 1999). Unpublished work by Johnstone and Kirkby shows that there is no easy relationship between the location of roost sites and foraging areas (R. Johnstone *pers. comm.* March 2008). Hence, the location of roost trees was unlikely to yield information regarding daytime utilisation patterns of a landscape and the various land use type within.

Since all cockatoos need to drink at least once a day (Cameron 2007), the location of sources of drinking water can be presumed to be an important factor influencing bird distribution. However, it was impossible to obtain sufficient quality data on the location of drinking water over an area of the size required for this study. Most of the sources of drinking water used by black cockatoos, such as tree hollows, streams, pools and cattle troughs (Abbott 2001) are hard to map over larger areas and many are ephemeral: Except for larger streams, most water sources are too small to appear on aerial photographs, especially when they are under the forest

The aims of this study were to: (1) Map the distribution and abundance of black cockatoos within the three study areas; (2) Investigate whether observed distribution patterns can be related to specific land use types in order to establish preference for or avoidance of particular land use types; (3) Record feeding behaviour throughout the year to discover how black cockatoos utilise the different land use types as a food source and to; (4) Investigate whether preferential feeding by forest red-tailed cockatoos on particular marri trees can be explained by morphological or nutritional characteristics of their fruit crop.

Chapter 2 provides a detailed description of the study areas. The three study areas were selected on the basis of each having a different combination of the most common land use types in the northern jarrah forest region. These land use types include native jarrah forest, orchards, paddocks, roads and houses and revegetated mine pits.

Chapter 3 addresses how cockatoo distribution between and within the three study areas was related to the various land use types present within them. The presence and abundance of black cockatoos was recorded by means of extensive transect surveys, while land use data was obtained from existing GIS maps. Presence and abundance of black cockatoos was linked to distribution of land use types using generalised linear-nonlinear modelling (GLM).

Chapter 4 addresses foraging behaviour of black cockatoos in the three study areas. The range of food items consumed by each taxon, as well as their relative importance (frequency of occurrence) in the diet is described. Since different food resources became available over the course of the study year, the range of food items taken was compared between each of the six study periods. Since black cockatoos leave distinct feeding signs or "chewings" which allow identification of the taxon that produced them, these chewings were a useful source of indirect information on presence, abundance and feeding behaviour. The degree to which cockatoo abundance could be estimated based on chewings data alone was also addressed.

Chapter 5 investigates whether there are differences in fruit or seed characteristics between trees fed in or ignored by forest red-tailed black cockatoos. Forest red-tailed cockatoos consistently feed in some trees, while ignoring others and this suggests there may be fine-scale differences in habitat quality within the

jarrah forest. Fruits were collected from 20 marri trees that had been recently fed in and 20 trees that showed no signs of feeding. The fruits and the seeds within were subsequently compared on several morphological and chemical characteristics.

Chapter 6 integrates the findings from Chapters 3, 4 and 5 and discusses management implications.

In this document the names of cockatoos follow Cameron (2007). All other bird names follow Higgins (1999). Plant names follow FloraBase (Western Australian Herbarium 2007), except for *Malus domestica*, *Pyrus communis* and *Quercus* spp. which do not occur in this database.

Chapter 2 – Study areas

2.1 Site selection and data source

The distribution, abundance and feeding behaviour of black cockatoos was studied over a 12 month period in 2007. Fieldwork was conducted in three study areas located in the northern jarrah forest (McKenzie *et al*. 2003), east and south-east of the Perth metropolitan area (Figure 2.1). The study areas were within the range of the three study taxa, the forest red-tailed cockatoo (*Calyptorhynchus banksii naso*), Baudin's cockatoo (*C. baudinii*) and Carnaby's cockatoo (*C. latirostris*) (Chapter 1, Figures 1.1, 1.2, 1.3), although only the forest red-tailed cockatoo was expected to be present year-round.

The study areas were selected on the basis of each containing a different combination of the most common land use types in the northern jarrah forest and differed in both the type of modification and levels of human activity. Each study area was defined as a 400 km^2 (20x20 km) quadrat. Based on the daily foraging range of black cockatoos (Johnstone & Kirkby 1999), an area of this size was deemed to constitute the landscape scale relevant to the life history of black cockatoos, while the study areas were sufficiently far apart to be considered independent of one another. In each study area, 30 km of road transects were positioned along which black cockatoos were recorded.

2.2 History of land use in the study areas

Detailed data on sawlog harvesting and fire history was provided by the Forest Management Branch of the Department of Environment and Conservation. Harvesting history was current on 31 December 2006, and fire history was current on 30 June 2007. The history of sawlog harvesting in all study areas was very complex with some forest patches harvested once and others several times with the most recent harvest often preceding bauxite mining (P. Collins *pers. comm*. May 2008). Before the Forest act of 1918 was passed, sawlog harvesting happened largely uncontrolled; there was great variation in the intensity of harvesting, but this was not recorded (Bradshaw 1999). Consequently, although the available records indicate that some "old growth remnants" of jarrah forest were never harvested, it is very unlikely that these are truly "untouched" native forest.
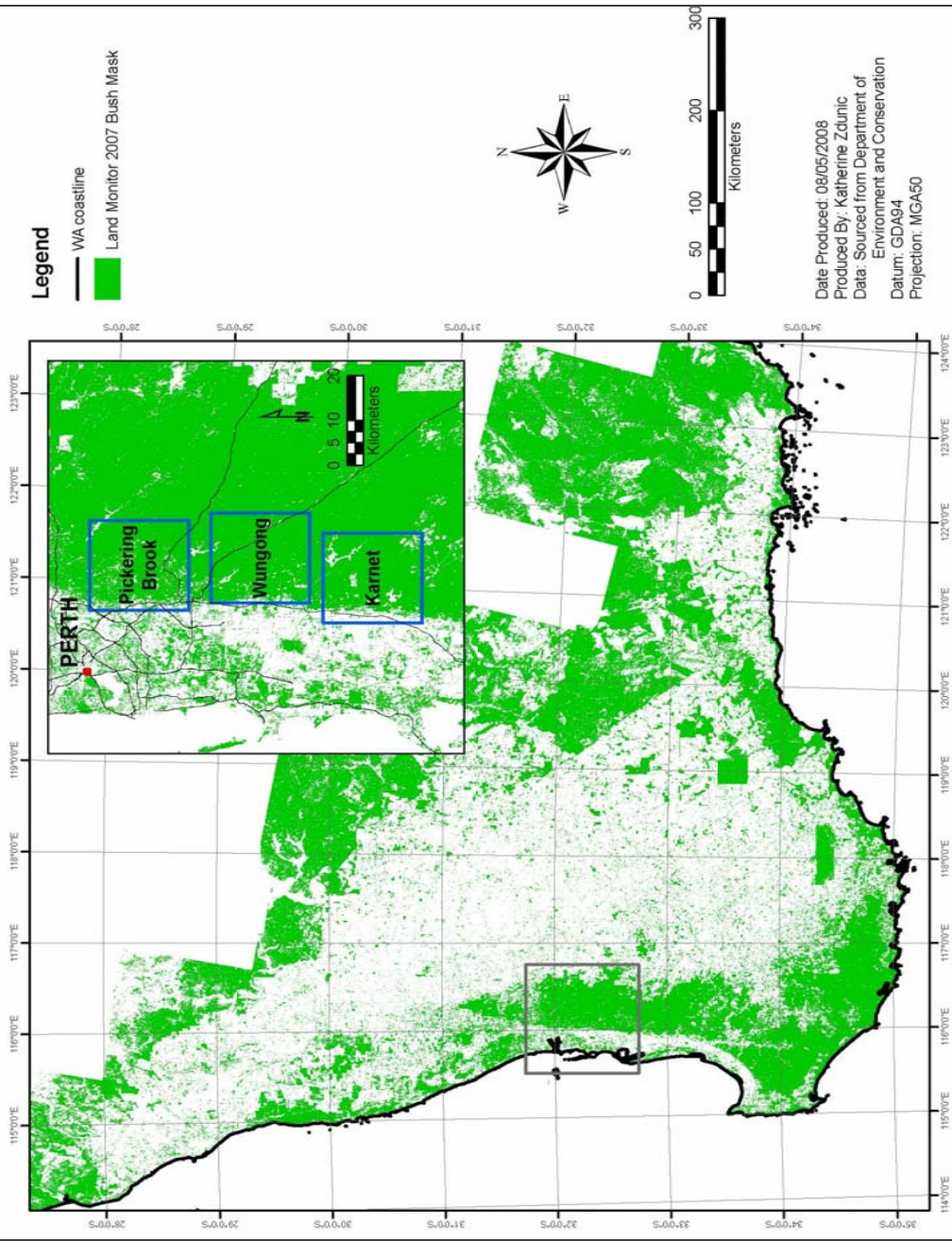
Figure 2.1 – Location of the 2007 study areas Pickering Brook, Wungong and Karnet. Coloured area represents extent of forested areas in Western Australia at the time of the study. Data source: Furby *et al.* 2007).

2.1.1 Pickering Brook

The Pickering Brook study area (Figure 2.2) encompassed the municipalities of Carmel, Bickley, Pickering Brook, Canning Mills, Karragullen and Illawarra. The mid point of the 400 km^2 landscape quadrat was located roughly 35 km east of the Perth metropolitan area (32º03'S – 116º07'E, Datum: WGS 84). The 400 km^2 study area quadrat included the eastern suburbs of Perth in the south-western corner and the city of Armadale in the south-western corner. For the purpose of this study the name Pickering Brook will be used to denote the entire area.

The Pickering Brook area is characterised by moderately steep hills, covered in native jarrah forest. In the vicinity of the study transects, the forest in the valleys and on the gentler hillsides has been cleared for extensive orchards and vineyards, a process that began in the mid-1800's (Shire of Kalamunda 2007). On the hillcrests and steeper slopes the jarrah forest cover remains while large mature marri trees line most of the road sides. Apart from orchards, other modified land use types occurring along or near the transect roads are pasture, housing, sheds, small dams and patches of native vegetation within the boundaries of town sites (classified as green urban, Chapter 3). The study area quadrat includes 20 pine plantations, varying in size from 1-100 ha. Two of the smaller pine blocks, about 4 ha in size, occur in the vicinity of the transects, as well as several scattered clumps of one or more pine trees. The study area includes two large water bodies, the Mundaring Weir and the Victoria Reservoir, while the Canning River crosses the south-western corner.

Three quarters of the study area is covered in native jarrah forest, which occupies roughly the eastern half of the landscape quadrat. Nearly all of the old growth forest was harvested before 1930. After the first harvests, a quarter of the forest was not harvested again, while the remainder of the forest was harvested one or more times afterwards, in a relatively fine grained mosaic of 100-200 ha patches.

The fire history of the Pickering Brook area is characterised by wildfires, the most noticeable being the January 2005 wildfire which burned 27 000 ha of native forest between Pickering Book and Mundaring. Unplanned and occurring in the heat of summer, this wildfire was particularly fierce. It affected nearly half of the forested area within the boundaries of the study area quadrat and destroyed or damaged several known roost and nest trees of the forest red-tailed cockatoo (Johnstone & Cassarchis 2005).
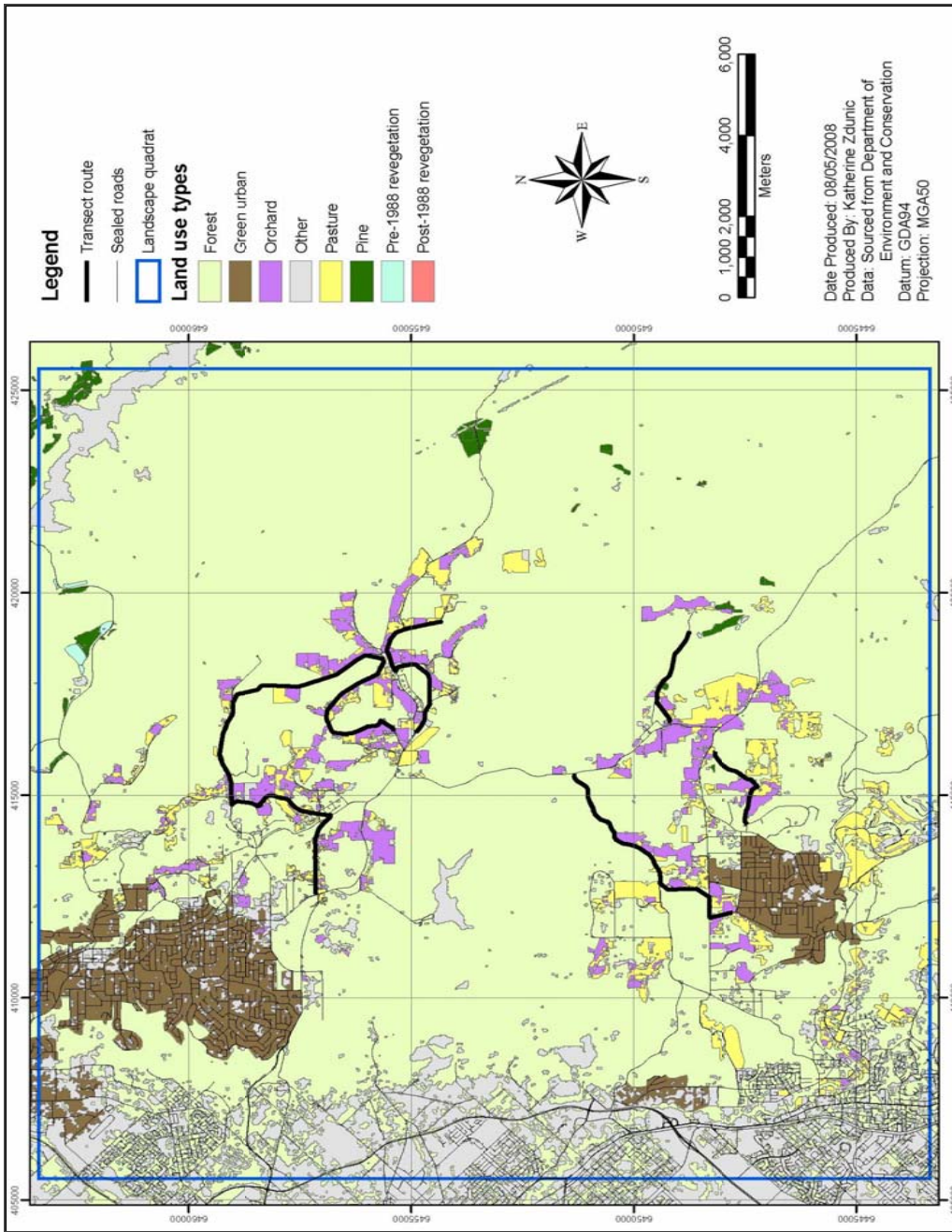
Figure 2.2 – Pickering Brook study area. Blue square encompasses the 400 km² landscape quadrat. Also shown are the various land use types. The location of the road transects is depicted by bold black lines.

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Of the forest areas that were unaffected by the 2005 wildfire, about one third was prescribed burned one year later. At the time of the study, about 2% of the forest inside the landscape quadrat had a fuel load of 15 years or more, with most of these long unburned areas lining the northern parts of the Pickering Brook transect.

2.1.2 Wungong

The Wungong study area (Figure 2.3) is located approximately 60 km south-east of the Perth metropolitan area, with Jarrahdale as the nearest town. The 400 km^2 study area quadrat, centred on the mid point between the transect roads (32°16'S – 116°07'E, Datum: WGS 84) includes the south-western corner of the Wungong Catchment. For the purpose of this study the name Wungong will be used to denote the entire area.

The dominant land use type in the Wungong area is native forest, primarily regrowth but also some old growth remnants. In the vicinity of the transect roads roughly 35% of the area is revegetated forest, ranging in age from 6 to 40 years. At the scale of the entire study area, revegetation occupies nearly 10% of the total area. Other modified land use types in the Wungong study area are pasture, some orchards, a few town sites and 40 pine (*Pinus* spp.) plantations ranging in size from 1-100 ha. Four of the pine blocks occur next to the study transects. The Wungong study area contains two large water bodies, the Wungong Reservoir and part of the Canning Reservoir.

Alcoa World Alumina Australia started mining bauxite in the Wungong catchment approximately 40 years ago (Alcoa 2003, 2005). As a code of practice, all mine pits and haul roads were revegetated once mining was completed. All mining operations in the Wungong area had ended at the time of the study, with the last pits and haul roads revegetated in 2001. Since bauxite ore bodies are deposited in patches of high and lower quality, the process of mining and revegetation has created a mosaic of unmined and revegetated forest patches of varying shape and size. Until about 1988 most depleted mine pits were revegetated with fast growing exotic species such as pine and eastern-state eucalypt species (Wykes 1985, Nichols *et al.* 1985; 1991).

In the early days, revegetation with native species was deemed to be unfeasible due to their susceptibility to *Phytophthora cinnamomi* dieback (see Lewis & Colquhoun 2000, Garkaklis *et al.* 2004).
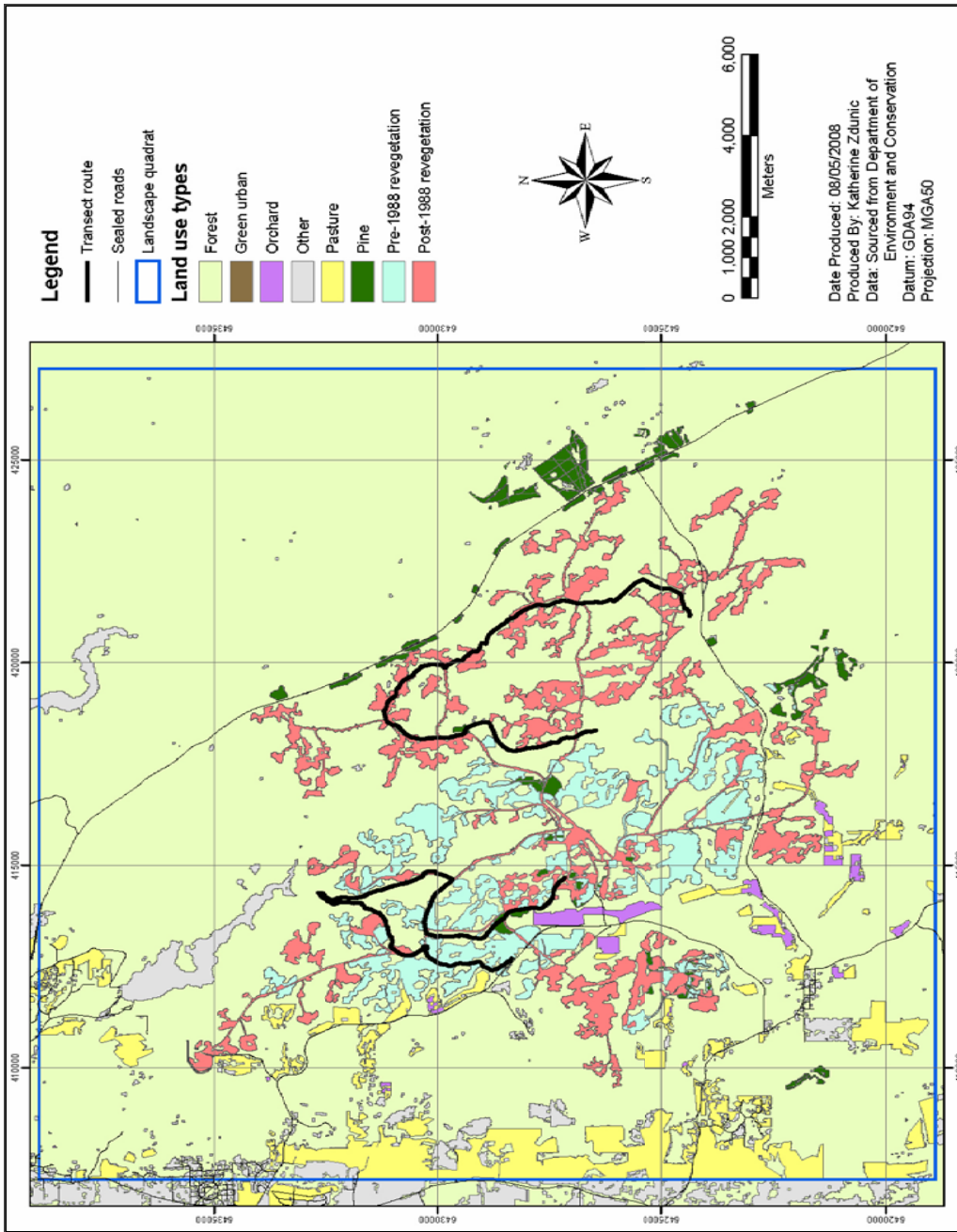
Figure 2.3 – Wungong study area. Blue square encompasses the 400 km² landscape quadrat. Also shown are the various land use types. The location of the road transects is depicted by bold black lines.

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This view changed in the late 1980's and since 1988 Alcoa's revegetation program has become increasingly sophisticated, with a growing emphasis on creating a forest structure and flora composition that matches the original jarrah forest as closely as possible (Nichols & Nichols 2003, Alcoa 2003, 2005).

Current restoration practices involve returning the original topsoil, surface ripping to improve soil structure and seeding native jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) trees and a rich variety of understorey species including hakeas, grevilleas and banksias (Alcoa 2003, 2005, Grant & Koch 2007, Koch 2007a).

Most of the jarrah forest inside the study area quadrat was first harvested before 1920, with harvesting intensity varying from taking one or two large jarrah trees per ha or taking nearly all trees of suitable size, but never reached the level of clear felling (Stoneman *et al.* 1989). Following these early harvests, about 5% of the jarrah forest was never harvested again, while the remainder was harvested again in later years with some areas harvested more than three times. The most recent harvests were all associated with clear felling for bauxite mining. Despite the intensive harvesting in the Wungong landscape, a few old growth remnants still remain on hillcrests and along streams. At the time of the study all former bauxite mines in the 400 km^2 study area quadrat were revegetated. In the second half of 2007 the Water Corporation commenced forest thinning in to promote water runoff to the dams and reservoirs (Water Corporation 2005). Trees were poisoned but not removed and the effects this will have on the forest structure remains to be seen.

Low intensity prescribed burns (control burns) were carried out regularly by the Department of Environment and Conservation (Nature Base 2008). At the time of the study roughly 20% of the forest had a fuel load of 15 years or more. Most control burns happened in patches of roughly 1000 ha in size. The most recent prescribed burn in took place in July 2007 and affected a small proportion of the area traversed by the study transects. Fire scars on the tree trunks indicated that the flames had not reached much much higher than one to three meters, and by December 2007 most of the vegetation along the affected transect sections appeared to have recovered from the fire.

2.1.3 Karnet

The Karnet study area (Figure 2.4) encompasses the municipalities of Karnet and Myara, with its mid point located approximately 75 km south-east of metropolitan Perth (32º29'S – 116º05'E, Datum: WGS 84). For the purpose of this study the name Karnet was used to denote the entire area.

The study area quadrat contains nearly exclusively native jarrah forest, and also a substantial amount of pasture along the western edge. Less prevalent land use types in study area are bauxite mines in the far south, a few small town sites and the Karnet prison farm. A number of large water bodies are (partially) included in the study area quadrat, the most prominent of which are the Serpentine Dam, the North Dandalup Dam and the smaller Pipehead Dam.

Nearly all jarrah forest in the Karnet landscape was harvested several times since the 1920's. The most recent sawlog harvests were associated with bauxite mining in the southern part of the landscape, and involved thinning along the banks of the Serpentine dam to promote water runoff.

A major fire event affected the Karnet study area in January 1961 when the extensive Dwellingup wildfire burned all of the forest inside the landscape quadrat. Control burns were carried out in subsequent years and were conducted in very large continuous areas, with an average size of 2000 ha. At the time of the study roughly 15% of the forest had a fuel load of 15 years or more.

The Karnet study area contains high quality bauxite ore deposits. During the study contractors were regularly conducting test drills throughout the study area and some preliminary clearing and upgrading of the main access roads commenced in the second half of the 2007 study year.
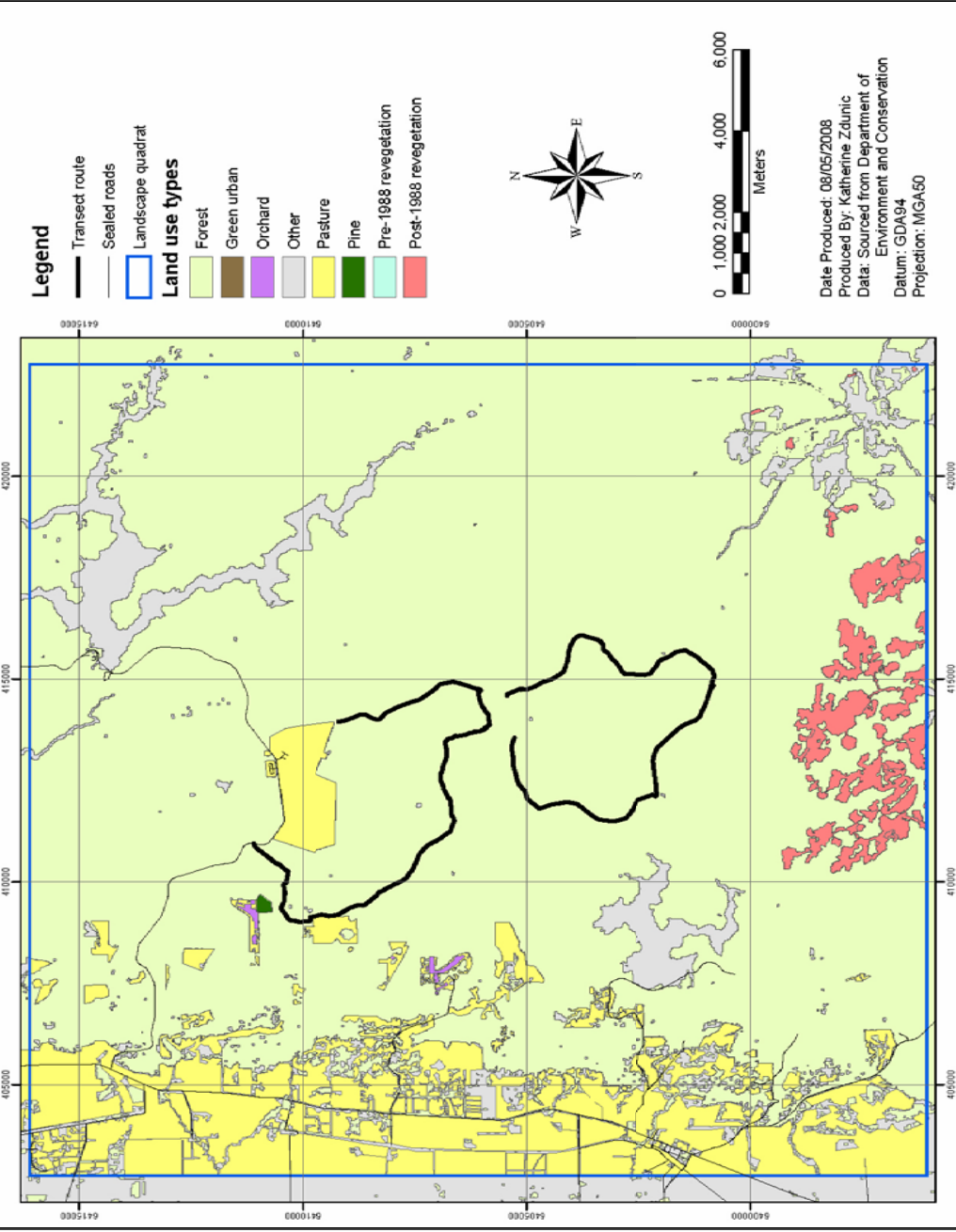
Figure 2.4 – Karnet study area. Blue square encompasses the 400 km² landscape quadrat. Also shown are the various land use types. The location of the road transects is depicted by bold black lines.

Chapter 3 – Landscape use by black cockatoos

3.1 Introduction

3.1.1 Brief outline

Being able to explain and predict where organisms occur in a landscape is critical for conservation and management (Austin 2002, 2007, Rushton *et al.* 2004a). When studying animals in modified landscapes, habitat selection models describing the relationship between species distribution and habitat factors provide an essential tool to predict responses of species to modification and identify critical habitat. The central question in studying species-habitat relationships is identifying the appropriate sampling scale, which may not be immediately known. In this case sampling at more than one scale is necessary.

This study examined the distribution of three taxa of black cockatoo in response to different forms of habitat modification in south-west Western Australia at the local, landscape and regional scales. For the purpose of the study, local scale was defined as the area within 50-100 m from the study transects, landscape scale refers to the 400 km^2 study areas while the regional scale refers to the northern jarrah forest in which the study areas were embedded, roughly between Perth in the north-west and Dwellingup in the south-eastern corner.

3.1.2 The use of habitat selection models for conservation planning in modified landscapes: The importance of spatial scale

The distribution of animals is non-random. No animal species occurs in every possible habitat and most animals have relatively narrow habitat requirements (Ehrlich 1995). Understanding how animals use their environment is central to the study of animal ecology (Johnson 1980). In the light of the substantial and ongoing changes to natural systems worldwide, brought about by human activity, conservation planning is dependent on a proper understanding of how different species respond to habitat changes (Coreau & Martin 2007), as well as being able to identify critical habitat (Gibson *et al.* 2004c).

Given the speed at which many landscapes have been or are being modified, relative to the response times of most organisms (Fahrig 2001), empirical evidence on the long-term effects of modification on species and communities is limited (Fahrig 2002). However, increasingly sophisticated modelling techniques are available that can offer a good alternative (Austin 2002, 2007, Johnson & Omland 2004, Rushton *et al.* 2004). In essence these species-habitat models describe the process of habitat selection in animals, of which an extensive literature is available (for an overview see George & Zack 2001, Bowyer & Kie 2006, Austin 2007). Species-habitat models offer insight into the factors responsible for observed distribution patterns (Johnson & Omland 2004) and can be used to predict unknown distribution patterns, either in other areas or in the same area following habitat modification (Pulliam *et al.* 1992, Austin 2002, 2007, Coreau & Martin 2007).

The literature on species-habitat modelling shows how spatial models can be applied across a wide spectrum of purposes. At the most basic level, models serve to identify relationships between animal distribution and spatial habitat factors such as, for instance, the extent, pattern and type of modification (Thompson & McGarigal 2002, Seddon *et al.* 2003, Westphal *et al.* 2003, Cameron & Cunningham 2006, Manning *et al.* 2006, De Frutos, Olea & Vera 2007). For the purpose of protecting important habitat, spatial models enable one to identify critical habitat for single species (Gibson *et al.* 2004b) or a community of species (Gibson *et al.* 2004a) and to locate areas of potentially suitable habitat in other landscapes without having to survey these directly (Stoms *et al.* 1993, Gibson *et al.* 2004c). Models constructed with distribution data from one landscape can also be used to predict occurrence of a species in other landscapes (Lindenmayer *et al.* 2002, Graf *et al.* 2006). Finally, a few studies are able to incorporate a temporal factor as well, either by surveying the same changing landscape across time (Coreau & Martin 2007) or through the construction of simulation models (Pulliam *et al.* 1992).

One of the major issues in modelling studies of species-habitat relationships is obtaining data that is of the correct spatial (or temporal) scale, hence identifying the appropriate scale on which to sample is critical (Levin 1992, Rushton *et al.* 2004). The scale required depends on question one wishes to answer, as well as the ecology of the study species (Wiens 1989, Austin 2007). In many cases, more than one scale is needed to properly explain observed distribution patterns.

Habitat selection in animals is often viewed as a hierarchical process (Johnson 1980). For instance, an animal first chooses a region or landscape to

settle in, then selects a home range and finally chooses particular locations within the home range to feed or nest (Johnson 1980, George & Zack 2001).

The actual geographical size of what constitutes the local, landscape or regional scale varies widely between species, depending on their body size and dispersal capabilities (George & Zack 2001). Consequently, there are about as many definitions of "local" and "landscape" as there are species-habitat studies (McGarigal & McComb 1995, Trzcinski *et al.* 1999, Cushman & McGarigal 2002, 2004, Westphal *et al.* 2003, Koper & Schmiegelow 2006, Manning *et al.* 2006, DeFrutos *et al.* 2007). At the same time, the relative impact of local, landscape or regional scale habitat characteristics and whether or not animals respond to habitat characteristics at multiple scales also differs between species (Bowyer & Kie 2006, Koper & Schmiegelow 2006, Manning *et al.* 2006). For instance, some species only become established when conditions at the landscape scale are suitable, while others mainly depend on local conditions to get established (McGarigal & McComb 1995, Coreau & Martin 2007).

A wide range of studies has shown that for many species more than one scale is needed to explain distribution patterns and that information from only one scale would have yielded incomplete or even misleading results (McGarigal & McComb 1995, Lindenmayer *et al.* 2002, Cushman & McGarigal 2004, Dussault *et al*. 2005, Bowyer & Kie 2006, Cameron and Cunningham 2006, Koper & Schmiegelow 2006). Hence, to properly understand how habitat selection operates, it is often necessary to sample at a range of spatial scales. Ideally, the choice of scale(s) should be determined by the scale(s) on which the species of interest perceives variation in its habitat (Wiens 1989, Austin 2007, Coreau & Martin 2007). However, it is often difficult to determine *a priori* what the most appropriate scale is and in this case sampling across a larger range of scales is recommended (Fuhlendorf *et al.* 2002).

Modification of landscapes, either due to human impact or natural succession, brings about changes in the amount and/or quality of habitat available to animals (Pulliam *et al.* 1992, Brawn & Robinson 1996, Fuhlendorf *et al.* 2002). These changes often occur on a range of scales simultaneously, while the magnitude and direction of change may differ between them (Coreau & Martin 2007).

Different species inhabiting the same area or landscape can respond very differently to landscape modification (McGarigal & McComb 1995), and sensitivity to change at particular scales can be related to a species' specific ecology (Bowyer & Kie 2006, Coreau & Martin 2007). For instance, species with limited dispersal

capabilities tend to respond more strongly to local-scale modifications and species that combine low mobility with high habitat specialisation tend to suffer greatly (Fahrig 2002, Gibson *et al*. 2004c, Coreau & Martin 2007). Conversely, generalist species tend to be more versatile in their use of habitat types and are often able to make use of modified parts of the landscape, while very mobile species are able to move large distances across areas with less suitable habitat (Coreau & Martin 2007).

Mobile animals, particularly birds, are able to respond relatively quickly to changes at different spatial scales (Coreau & Martin 2007). Birds also tend to be very visible and relatively easy to survey (Bibby *et al.* 2000). Hence, birds form particularly suitable study subjects to examine the impacts of habitat changes at multiple spatial scales. The literature on bird-habitat relationships generally shows that larger avian species respond to habitat variability at the scale of several kilometres (Thompson & McGarigal 2002, Cushman & McGarigal 2004, Manning *et al.* 2006, Westphal *et al.* 2006) and studies not including scales of this size often fail to find effects for larger bird species (Cameron & Cunningham 2006, Seddon *et al.* 2003).

Given that wide-ranging species often have home ranges that include a greater variety of habitat types (Pulliam *et al.* 1992), the effects of mobility and versatility cannot easily be distinguished. However, in order to develop sound management plans, it is important to know whether species are utilising a wide variety of land use types within their range or utilise only one or two while only traversing the others. Models for the superb parrot (*Polytelis swainsonii*) indicate that this species views the modified landscape it lives in as a continuum of usable habitat (Manning *et al.* 2006). In contrast, glossy cockatoos (*Calyptorhynchus lathami*) are reported to fly large distances between critical resources such as feeding and nesting sites, while ignoring the surrounding habitat (Cameron & Cunningham 2006).

In the light of progressive landscape modification, it seems likely that more generalist species would be able to persist longer, i.e. at higher degrees of modification, than mobile species as the latter are greatly dependent on the distance between and connectivity of critical resources. The importance of connectivity was demonstrated clearly for a population of Carnaby's cockatoo breeding in the wheatbelt. As their habitat became more and more reduced and fragmented, the population eventually was unable to "connect the pieces" and disappeared (Saunders 1977b, 1980, 1990).

The above examples underline that for mobile, wide ranging species it is important to adopt a landscape-scale approach but that data must also be collected at smaller scale in order to understand the observed patterns. As a general rule, study areas should be large enough to enable data collection at a scale relevant to the life-history aspects one wishes to study (Bowyer & Kie 2006), as well as one scale level above to provide context and one scale level below to examine potential mechanisms (Levin 1992, Wiens 1989).

3.1.3 Black cockatoos in modified landscapes

This study examined the distribution patterns of black cockatoos in south-west Western Australia in relation to variation in land use characteristics at both the local scale, in the vicinity of the study transects, and the wider landscape scale of the entire study area(s). The forest red-tailed cockatoo (*Calyptorhynchus banksii naso*), Baudin's cockatoo (*C. baudinii*) and Carnaby's cockatoo (*C. latirostris*) are associated with forests and woodlands. Over the past century their natural habitat in the Southwest Australia Ecoregion has experienced major changes since European settlement, with most of the native vegetation removed or significantly modified (Saunders 1985, 1986, Gole 2006). Black cockatoos have disappeared from areas where the native vegetation has been completely cleared, but they appear to persist in modified landscapes of varying degrees (Abbott 2001, Johnstone & Storr 1998). All three taxa are currently facing extinction. Knowledge on how they use the land use types available in their remaining range is essential to identify critical habitat and guide restoration efforts.

Black cockatoos are large and mobile species, with a daily foraging range of several km (Johnstone & Kirkby 1999, T. Kirkby *pers. comm.* February 2008). Given that black cockatoos are highly dependent on native forest, they may be considered mobile rather than generalist species. This suggests that they may be very sensitive to modification of their preferred habitat (native forests and woodlands) beyond a certain threshold level, but this it is hard to estimate what this threshold level is for black cockatoos. There is no common threshold across species of how much native vegetation must remain in order for species to persist, because this depends on their ecology (Fahrig 2001). However, simulation models suggest that particular aspects of a species' ecology can have strong effects on the minimum amount of native vegetation required. Species with a slow reproductive rate and a large range, like black cockatoos, need larger areas of suitable habitat (native vegetation), while

the ability of species to utilise alternative habitat types (modified parts of the landscape) reduces the amount of native habitat required (Fahrig 2001).

This study addressed how variation in land use characteristics affects distribution patterns of black cockatoos, in order to identify critical habitat and guide conservation efforts. As described earlier (Chapter 1, Section 1.4) the study focuses on distribution patterns related to foraging behaviour. The distribution and abundance of the three taxa was compared between natural landscape and two different modified landscapes in the northern jarrah forest. The northern jarrah forest region is important for post-breeding white-tailed species while forest red-tailed cockatoo is present year-round (Johnstone & Storr 1998).

All three taxa are large and mobile birds. In non-breeding season their daily foraging range is up to 4 or 5 km around their roost trees (Johnstone & Kirkby 1999, T. Kirkby *pers. comm*. June 2006). The study was designed to survey at scale large enough to encompass several home ranges. Habitat information was collected at a range of scales, both smaller and much larger than home range scale. Habitat selection at the smallest scale, i.e. the scale of individual food trees, will be addressed elsewhere (Chapter 5).

The aims of the study were to: (1) Examine the distribution patterns of black cockatoos within the three study areas; (2) Investigate whether observed distribution patterns can be related to specific land use types; (3) Address whether differences in distribution patterns relative to the different land use types can be related to life-history characteristics of the taxa. The answers to these questions will contribute to developing management strategies for each taxon of black cockatoo.

3.2 Methods

The distribution and abundance of the forest red-tailed black cockatoo, Baudin's cockatoo and Carnaby's cockatoo was recorded during extensive transect surveys in three study areas conducted every second month over a 12 month period. The study areas were selected on the basis of each containing a different combination of land use types. The Pickering Brook area contained a mixture of native forest, orchards and pasture, the Wungong area held a mosaic of native forest and revegetated mine sites of various ages, while the Karnet area consisted primarily of native forest (see Chapter 2 for more detail).

Given the ecology of the study species and the limited time available, transect surveys were considered to be the most appropriate method. This is because transects are a quick and efficient means to survey a large area in a short period (Bibby *et al.* 2000). Some of the land use types in the study areas were very dense with limited access roads and/or occur only on private land. Therefore, distributing survey points randomly across the landscape was considered to be impractical and too time consuming for the scope of this study.

Information on land use was prepared from existing GIS data for three spatial scales: the 400 km^2 landscape scale, the local scale within a 100 m radius from each 500 m section of transect and the smallest observation point scale within a 5, 25 and 50 m radius surrounding each observed group of cockatoos. For the purpose of exploring whether how the proportions of land use types change between the local and the landscape scale, land use data was also prepared for a series of intermediate scales centring on the transect lines.

3.2.1 Collecting cockatoo distribution data

Transect surveys for black cockatoos were conducted every second month over the whole year of 2007, starting in February and finishing in December. All three study areas were sampled three times per study month, yielding a survey effort of 9 days per month or 54 days for the whole study year.

In each of the three study areas two 15 km transects were positioned using a map and a GPS (Garmin GPSMAP 60CSx). Transects followed existing roads and tracks and were carefully placed to include all the dominant land use types and sample equally across slopes, hillcrests and valleys. The combined length of all transects together was 90.5 km.

In Wungong and Karnet the presence of an extensive network of unsealed forest tracks, made it possible to select two consecutive 15 km routes (Chapter 2, Figures 2.3, 2.4). In Pickering Brook the presence of many dead-end roads and roads with a speed limit of 80 km/h or higher formed a limitation to where transect routes could be located. Consequently, one of the two transects in Pickering Brook consisted of four disjunct segments with a combined length of 15.5 km (Chapter 2, Figure 2.2). For data recording purposes all transects were subdivided in 500 m sections. The start and end point of each section was stored in the GPS as a

waypoint and marked in the field with flagging tape. This yielded a total of 181 transect sections. All flagging tape was removed in the last survey round.

On a given survey day, one 15 km transect was surveyed in the morning, and the other in the afternoon. Care was taken to randomise the order in which both transects in an area were visited, as well as the direction in which they were driven. This ensured that over the study year as a whole, the numbers of morning and afternoon visits and clockwise and counter clockwise survey rounds were more or less equal for all transects. Within study months the order in which the study areas were visited was alternated to ensure no area was surveyed two days in a row.

Since the aim was to record distribution patterns related to foraging, surveys were timed to avoid the time of day when cockatoos are moving to and from their roost sites. Hence, survey days started in the second hour after sunrise, when roosting flocks had completely fanned out across the landscape and finished at least one hour before sunset when birds begin to congregate in flocks to and fly back to their roosts (Johnstone & Kirkby 1999). If day length permitted, surveying during the middle part of the day was avoided, since this is a time when bird activity tends to be low, especially on hot summer days (Bibby *et al.* 2000). Sunset and sunrise times were obtained from the Australian Bureau of Meteorology (http://www.bom.gov.au).

Surveys were conducted by slowly (20 km/h) driving a four wheel drive vehicle along the transect roads and tracks, and looking and listening for cockatoos. The time to complete an individual 15 km transect varied from two to four hours, depending on how often black cockatoos were encountered. In every 500 m section two 2-3 minute stops were held to listen for black cockatoos with additional stops whenever birds were heard or seen while driving. Consequently, on days when many cockatoos were encountered, a survey took longer than when there were only few.

For safety reasons, surveys in Wungong and Karnet which were heavily forested and relatively remote, were carried out by a team of two people; the author (M. Weerheim) and a field assistant. In Pickering Brook, where transects ran close to built-up areas, all surveys were conducted by the author only. Since most field assistants were unable to recognise the calls of the target species, the effects of their presence on cockatoo detection was deemed to be negligible. To further minimise potential differences in survey effort between Pickering brook and the other two areas, only the author left the vehicle to look and listen for birds.

Whenever black cockatoos were seen or heard, the taxon was identified based on sight and calls, and group size and location were established as accurately as possible. Location of black cockatoos was recorded as the estimated distance to the transect road along a perpendicular line, as well as the position on the transect where this line intersected the road. Additional information was recorded of relevant observations on feeding and breeding related behaviour. Breeding considered to be related to breeding included birds entering tree hollows, adults feeding chicks, chick begging calls and the distinct male courtship call of the forest red-tailed cockatoo. The three taxa could be easily distinguished on tail colour, bill shape and call.

When birds were within 50 m from the road, the author approached them as closely as was possible without causing disturbance and observed them with binoculars. In these instances the exact group size as well as the location of individual birds (if sitting in different trees) could be recorded. For cockatoos further from the road, often only estimates of group size were possible. Distance was estimated based on loudness of calls and recorded to the nearest 100 m, i.e. birds between 50 and 150 m away were classified as 100 m. The following distance categories were recognised: 100, 200, 300, 400 and 500 m.

In a pilot study it was established that the greatest distance at which cockatoo calls could still be heard through the forest was about 500 m. For this reason all calls heard very far away were assigned to the 500 m distance class, leading to an effective detection zone of 1 km wide. Group size was estimated based on both distance and call frequency and recorded as belonging to one of six possible categories: 1-2 birds, 3-10, 10-20, 20-50, 50-100 and 100-200 birds. No groups greater than 200 birds were encountered during the surveys.

The ability to distinguish individual birds or family groups as discrete data points decreased with increasing distance to the transect roads. Consequently, at greater distances, larger numbers of birds were recorded as a single data point. It was established in the field that family groups that were 15-20 m apart could still be distinguished as separate units, based on the direction from which calls were heard, at a distance of 50 m from the road. Following this as a rough rule of thumb, it is estimated that birds that were 100 m away had to be 30-40 m apart to be recorded as separate units, and birds that were 500 m away had to be 150-200 m apart.

Black cockatoos are very mobile birds, foraging over several kilometres in a day. This induced the risk of double counting birds flying from one transect section

to another over the course of a survey day. Measures to avoid double counting included keeping track of where birds were and in which direction flying birds were moving. In addition, great care was taken not to disturb birds foraging close to the road to ensure they stayed put while the survey vehicle moved past. Black cockatoos were used to cars driving along on the roads and did not flee from them. Hence, although double counting could not be avoided completely, the above measures did ensure that it was kept to a minimum.

In addition to within-day double counts, there was a chance that the same birds were counted on more than one day within the same survey month because it was not possible to recognize cockatoos individually. This form of double counting, however, did not affect the quality of the data. Rather than absolute population size, within-month abundance data must be interpreted as reflecting levels of bird activity near the transects. With respect to the individual transect sections, the total number of birds counted in a section in one study month, or over the whole study year, reflected intensity of usage. This measure is more meaningful than the number of birds that happen to be counted during a single visit, since the variable is less sensitive to chance effects. Because the number of birds recorded was a function of both activity levels and absolute abundance and the relative influence of either is hard to estimate (Bibby *et al.* 2000), the word abundance will continue to be used in the remainder of this chapter. However, when interpreting results, the influence of activity levels or usage intensity on bird counts will be kept in mind.

3.2.2 Digitising cockatoo records in a GIS map

Following fieldwork all individual cockatoo observations, based either on sightings or on calls, were entered into an ArcGIS map which already showed transect roads and waypoint data collected in the field by GPS (Figures 3.1, 3.2, 3.2). An aerial photograph (see Section 3.2.3) was also available, but was switched off during digitizing to minimise bias, mainly due to the temptation to place cockatoo observations into particular land use patches. Instead, all observation points were entered blindly by using the ArcView map ruler available in the ESRI ArcMap program.

Each observation was digitized on screen into a vector point file (shown on screen as a dot point), hereafter referred to as an observation point. An individual observation point could represent any group size, from one or two cockatoos to a

hundred or more. However, most groups were relatively small with an average of 6 birds per group for all taxa combined.

Observation points were not weighted according to group size for the following reason: When groups of birds were encountered close to a transect it was possible to determine the individual locations of the separate units (often family groups) that made up this larger group, hence each unit received its own observation point. At greater distances, only the rough location of the group as a whole could be estimated (see Section 3.2.1) and the group received one single observation point. Since weighting for group size and weighting for distance (i.e. uncertainty) would in effect cancel each other out, weighting was deemed unnecessary.
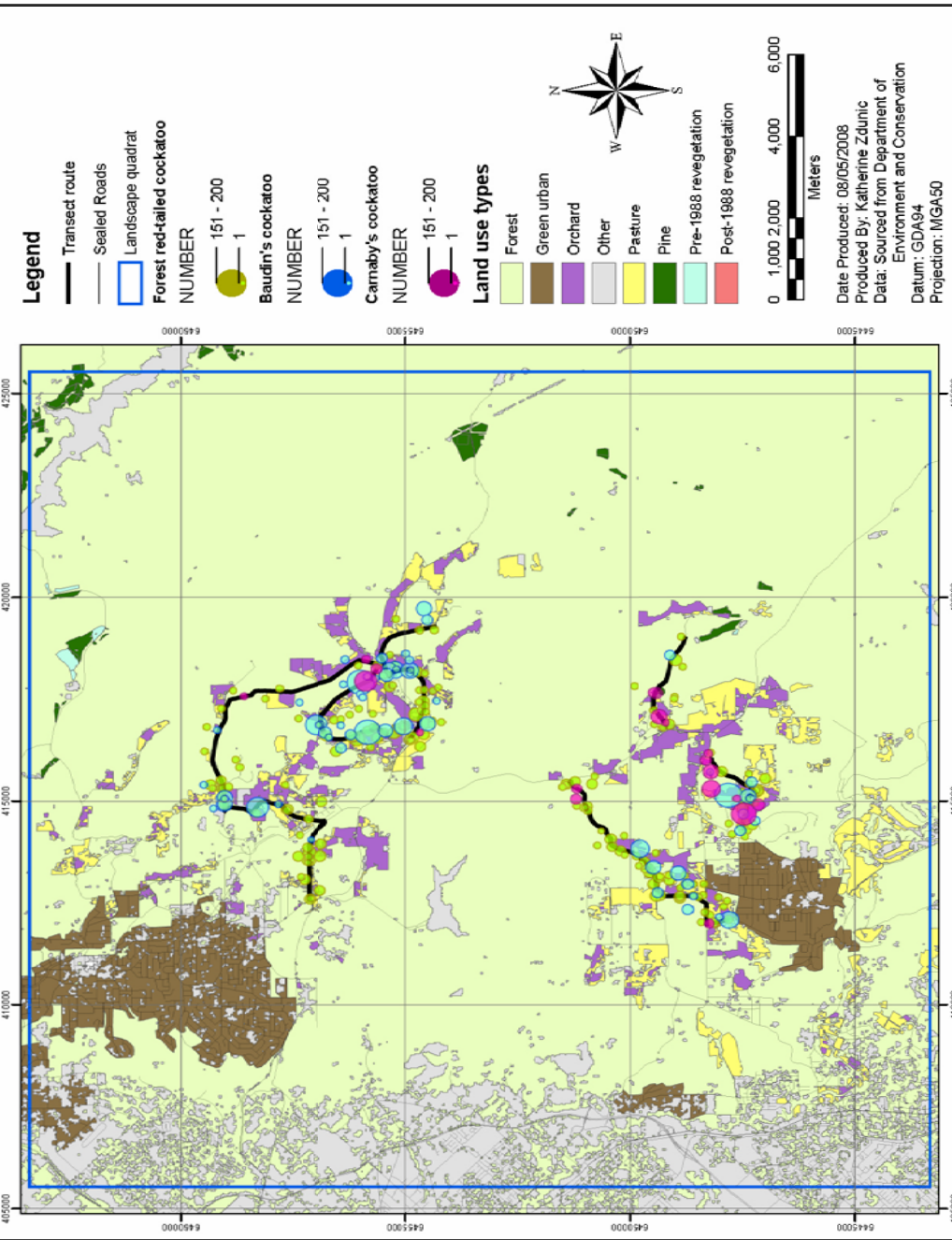
Figure 3.1 – Pickering Brook study area showing locations of black cockatoos recorded over the whole 2007 study year. Different colours depict different taxa. Size of the dot point represents group size. Blue square encompasses the 400 km^2 landscape quadrat. Also shown are the various land use types. The location of the road transects is depicted by bold black lines.

Legend

— Transect route

Sealed Roads

☐ Landscape quadrat

Forest red-tailed cockatoo

NUMBER

151 - 200

1

Baudin's cockatoo

NUMBER

151 - 200

1

Carnaby's cockatoo

NUMBER

151 - 200

1

Land use types

Forest

Green urban

Orchard

Other

Pasture

Pine

Pre-1988 revegetation

Post-1988 revegetation

N
W E
S

0 1,000 2,000   4,000   6,000
Meters

Date Produced: 08/05/2008
Produced By: Katherine Zdunic
Data: Sourced from Department of
Environment and Conservation
Datum: GDA94
Projection: MGA50

Figure 3.2 – Wungong study area showing locations of black cockatoos recorded over the whole 2007 study year. Different colours depict different taxa. Size of the dot point represents group size. Blue square encompasses the 400 km^2 landscape quadrat. Also shown are the various land use types. The location of the road transects is depicted by bold black lines.
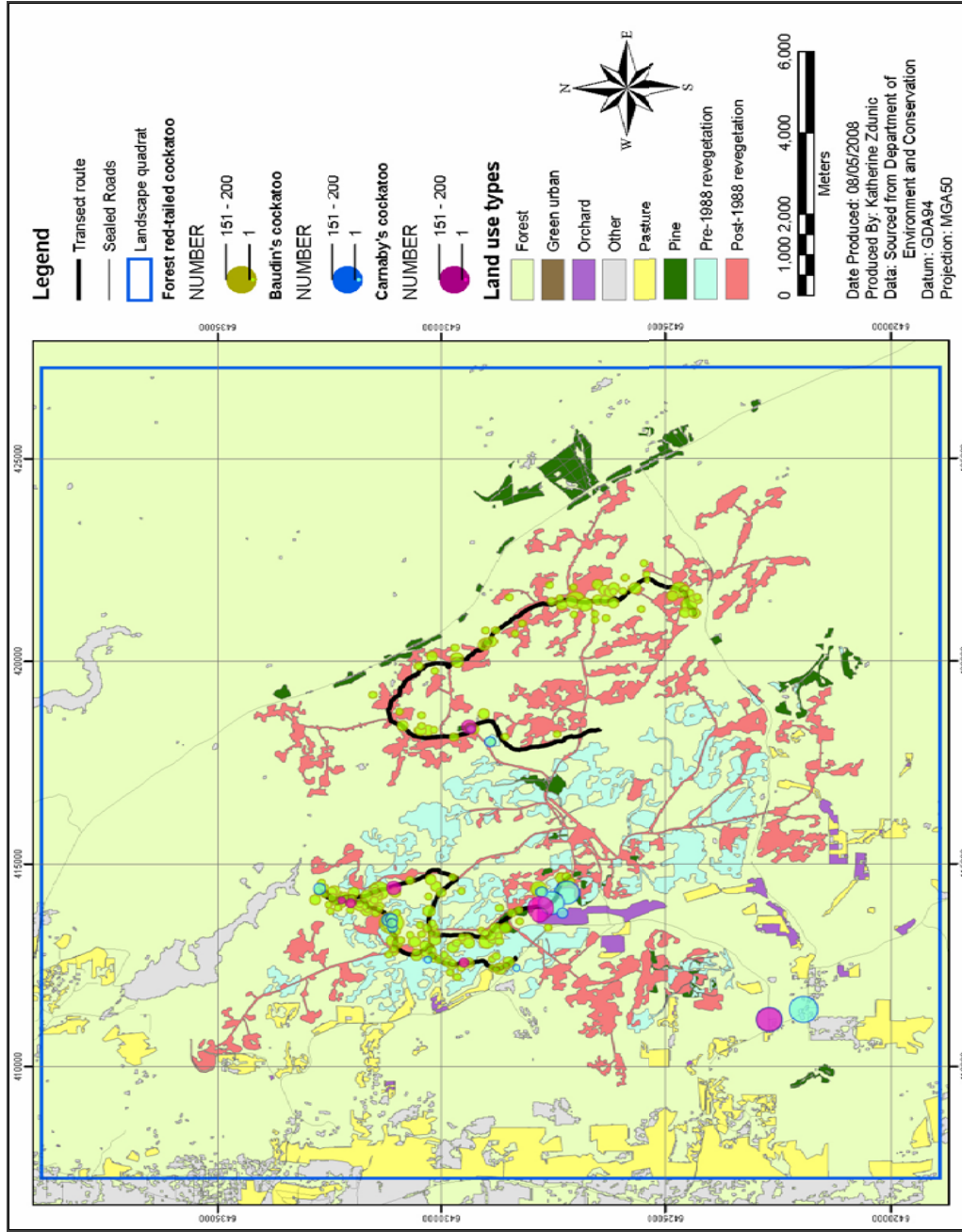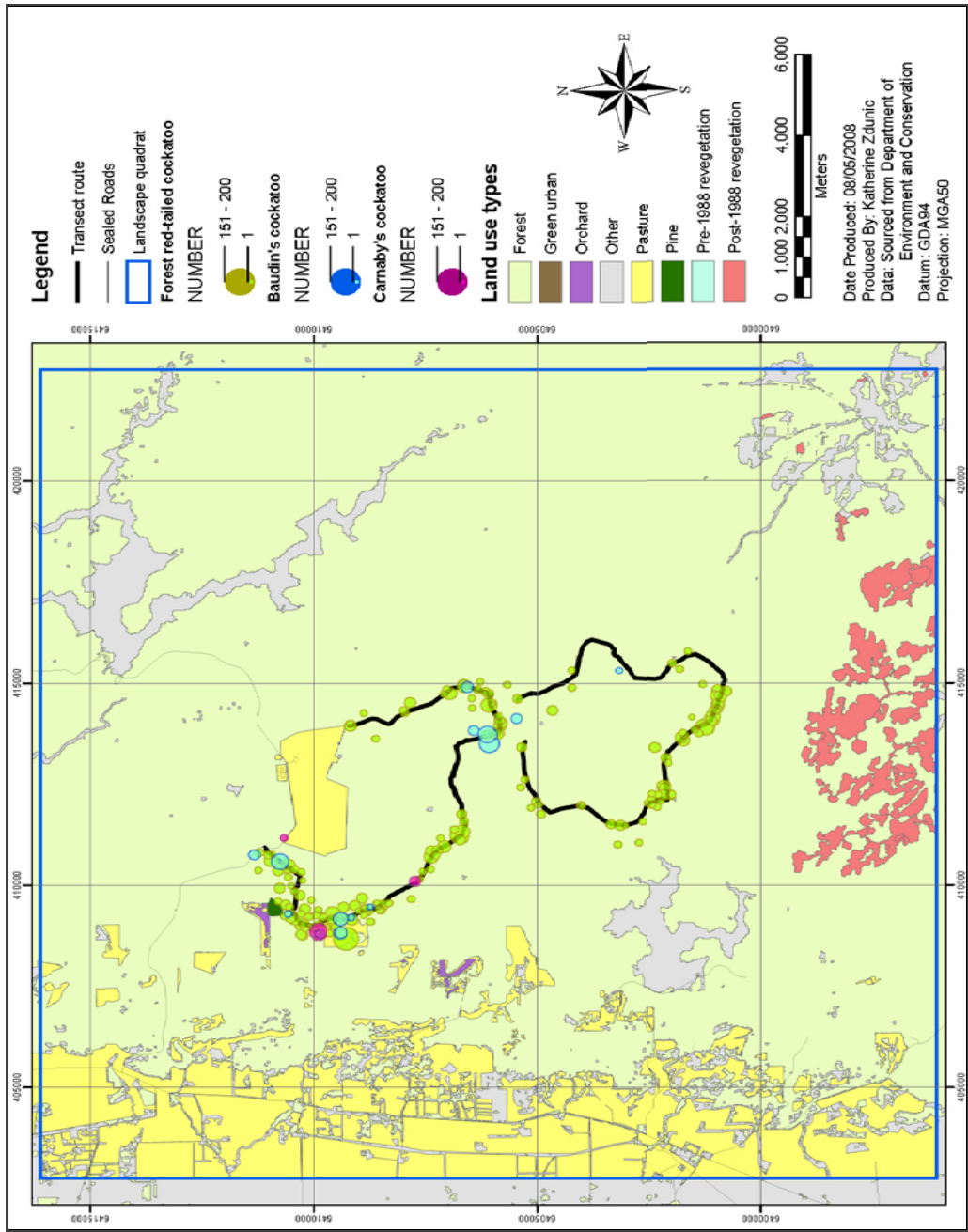
Figure 3.3 – Karnet study area showing locations of black cockatoos recorded over the whole 2007 study year. Different colours depict different taxa. Size of the dot point represents group size. Blue square encompasses the 400 km² landscape quadrat. Also shown are the various land use types. The location of the road transects is depicted by bold black lines.

3.2.3 Obtaining land use data

Land use data for both the local (section) and landscape scale was obtained from existing digital aerial and satellite imagery that was turned into a land use data layer in ArcGIS. Within each 400 km^2 (20x20 km) landscape quadrat roughly every 25 m^2 was assigned as belonging to one of eight land use types (Table 3.1).

Table 3.1 – Description of land use types present in the three study areas, Pickering Brook, Wungong and Karnet used to sample cockatoo presence and abundance.

Name	Description
Forest	Native vegetation with >1 tree per 10 m^2 and/or dense shrub cover.
Orchard	Apple, pear or stone fruit orchards
Pasture	Vegetated surface with <1 tree per 10 m^2 and very little shrubs. Includes pastures, natural grassland, parks, and sports grounds.
Pine	Commercial pine plantation.
Other	Houses, bare ground, large water bodies, roads.
Green urban	Areas with >1 tree per 10 m^2 and/or dense shrub cover, situated within the boundaries of urban area.
Pre-1988 revegetation	Revegetated mine site containing mainly exotic eucalypt species and very little understorey.
Post-1988 revegetation	Revegetated mine site containing native jarrah and marri trees and range of native understorey species.

Spatial data for the forest variable was obtained from the Land Monitor project (Allen & Beetson 1999, www.landmonitor.wa.gov.au). The Land Monitor Project classified Landsat digital imagery (www.landsat.org) into a bush / non bush layer with a pixel size of 25 m^2. The bush layer formed the basis for the forest variable.

Orchards, pastures and pine plantations were digitized on screen from a set of digital colour aerial photographs obtained from Landgate (www.landgate.wa.gov.au). The photographs were taken in December 2004 and had a resolution of 0.2 m and an accuracy of 0.4 m^2. Using the same photographs, the green urban land use type was cut out from the forest layer. This land use type was only identified in the Pickering Brook area where large patches of native vegetation occurred within the boundaries of town sites. It represents an intermediate type between forest and other. In the other study areas the dichotomy between native forest and modified land was generally sharper and this intermediate type did not occur. Spatial data on revegetation was provided by Alcoa. All remaining areas were automatically classified under the "other" variable, which encompassed a wide variety of non-vegetated land use types.

Photo-interpreted land use classifications were ground truthed for all areas adjacent to the transects as well as for a large number of random locations within the 400 km^2 landscape quadrats in the vicinity of the transects. Due to the size of the study areas, it was not feasible to conduct systematic on-ground vegetation surveys to obtain more detailed local scale habitat variables (cf. Westphal *et al.* 2003).

3.2.4 Calculating land use variables at a range of spatial scales

For analyses purposes, land use statistics were calculated for a range of different scales (areas) using ArcGIS: the landscape scale, the local or section scale, a range of scales intermediate between landscape and local scale, and the very local or observation point scale. The procedure for each scale was the same. First, a series of concentric buffers was drawn around the area(s) of interest. Second, ArcView calculated the area covered by each land use type within the buffer zone(s).

At the landscape scale, land use variables were calculated within each 400 km^2 landscape quadrat (Chapter 2, Figures 2.2, 2.3, 2.4). At the local scale, land use variables were calculated within 100 m buffers surrounding each individual transect section; this will be discussed in more detail below. The daily foraging range of black cockatoos can be up to 4 or 5 km (Johnstone & Kirkby 1999, T. Kirkby *pers. comm*. June 2006) which is intermediate between the local and landscape scale.

In order to explore how the proportions of land use types changed with increasing scale, land use variables were calculated within a series of concentric buffers surrounding each individual transect. The smallest buffer had a radius of 500 m followed by a 1000, 2000 and 4000 m buffer. Since 500 m was also the maximum distance at which calls could be heard, the area inside the 500 m transect buffers represented the "detection zone" for black cockatoos. Only in this zone could presence or absence of observations be considered a reliable estimate of presence or absence of black cockatoos. The detection zone was important for the analyses of land use at the smallest scale, surrounding observation points (see below).

Local-scale land use variables were calculated within 100 m radius buffers surrounding each 500 m long transect section (Figure 3.4).

Figure 3.4 – Example of 100 m buffer zone around transect sections, used to calculate land use characteristics per section. (Location of close-up area is the western start/end point of the northernmost transect in Pickering Brook).

45
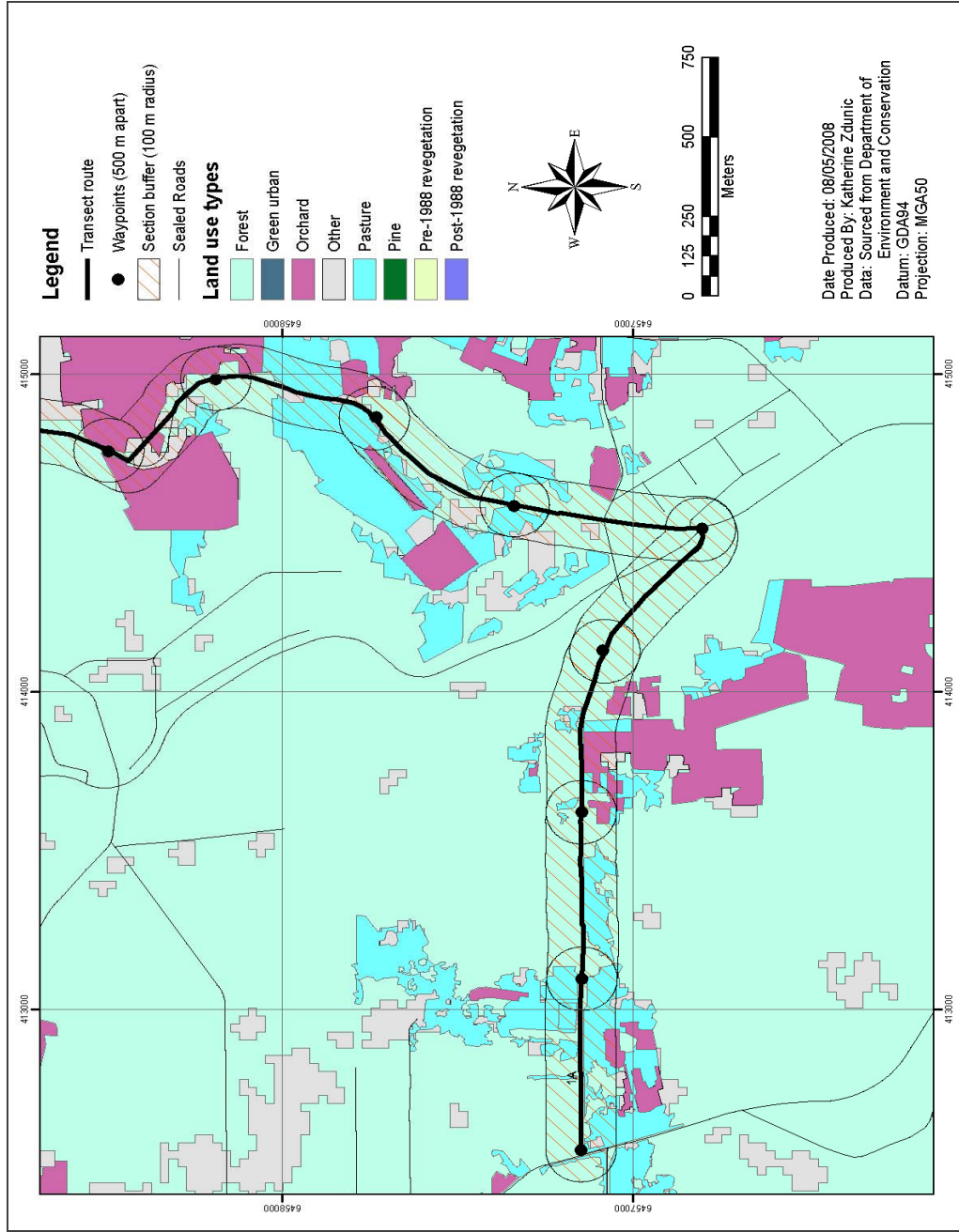
The 100 m buffer size represented a trade-off between maximising the number of observations that could be included in the analyses, and minimising the overlap between buffer zones of adjacent sections, while keeping the quality of observation data high.

Because the total number of observation records over the whole study year was relatively low, it was important to include as many observations into the analyses as possible. Since cockatoos were recorded anywhere between 0 and 500 m from the transects, the 500 m buffer scale included all cockatoo sightings, and would have yielded the largest possible dataset. However, because buffer zones of adjacent sections overlapped, the land use variables within them became increasingly interdependent with increasing buffer size.

At the 500 m scale, sections with one neighbour (the end sections of the transects) shared 61% of their buffer zone with the neighbouring section, while sections with two neighbours shared 98% of their area with both neighbours combined. At the 100 m scale the overlap with one neighbour was 24% and with two neighbours 48% (Figure 3.4). Buffers with a 50 m radius overlapped only 14% with one neighbour and 27% with two. Hence, the 50 m scale yielded the least interdependent land use variables. However, this scale excluded 90% of the area in which cockatoos could have been recorded (detection zone).

A third consideration, however, was quality (reliability) of observation data. Since the likelihood that a cockatoo was detected decreased with increasing distance from the transect (Bibby *et al.* 2000), the reliability of observation records as a true representation of the cockatoos that were actually present decreased accordingly. This principle was demonstrated by the fact that 50% of all records were within 50 m from the transects, while 70% were within 100 m. Taking into account the importance of data quality and data independence, as well as the need for a sufficiently large sample size, the 100 m scale was considered to be the most appropriate.

Cameron and Cunningham (2006) found that glossy cockatoos selected feeding sites based on habitat quality in the immediate vicinity (within 20x20 m quadrat) while ignoring the quality of the surrounding habitat. For this reason, land use variables were also calculated at the very local scale, inside a series of concentric buffers surrounding each observation point for the forest red-tailed cockatoo (n = 585). Buffer radii were 5, 25 and 50 m (Figure 3.5).

Since Baudin's and Carnaby's cockatoo were only recorded in 90 and 34 locations, respectively, the data for these species were considered insufficient to warrant any statistical tests. The aim of calculating land use variables at the very local scale was to investigate which land use types the birds were actually 'sitting in'. Since surveys were conducted at a time of day when black cockatoos were foraging, the birds were presumed to be sitting in a particular tree or bush because they were feeding there, or had been feeding nearby. Observations on birds that could be seen from the road confirmed this assumption.

For the forest red-tailed cockatoo the combined area inside all 5, 25 and 50 m radius buffers surrounding the 585 observation points represented respectively 0.05, 1.25 and 5.00 % of the total 500 m detection zone. To investigate whether the land use data within the observation point buffers (observed data) differed from data that could have been obtained within buffers around randomly distributed points (expected data), a set of random points was created by ArcView within the 500 m detection zone. The number of random points was equal to the number of observation points and land use variables were calculated within a similar sized series of buffers.

Figure 3.5 – Example of 5, 25 and 50 m buffers around observation points, used to calculate land use characteristics at the very local scale. Shaded area represents the 500 m wide detection zone surrounding transect roads. (Location of close-up area is the western start/end point of the northernmost transect in Pickering Brook).

48
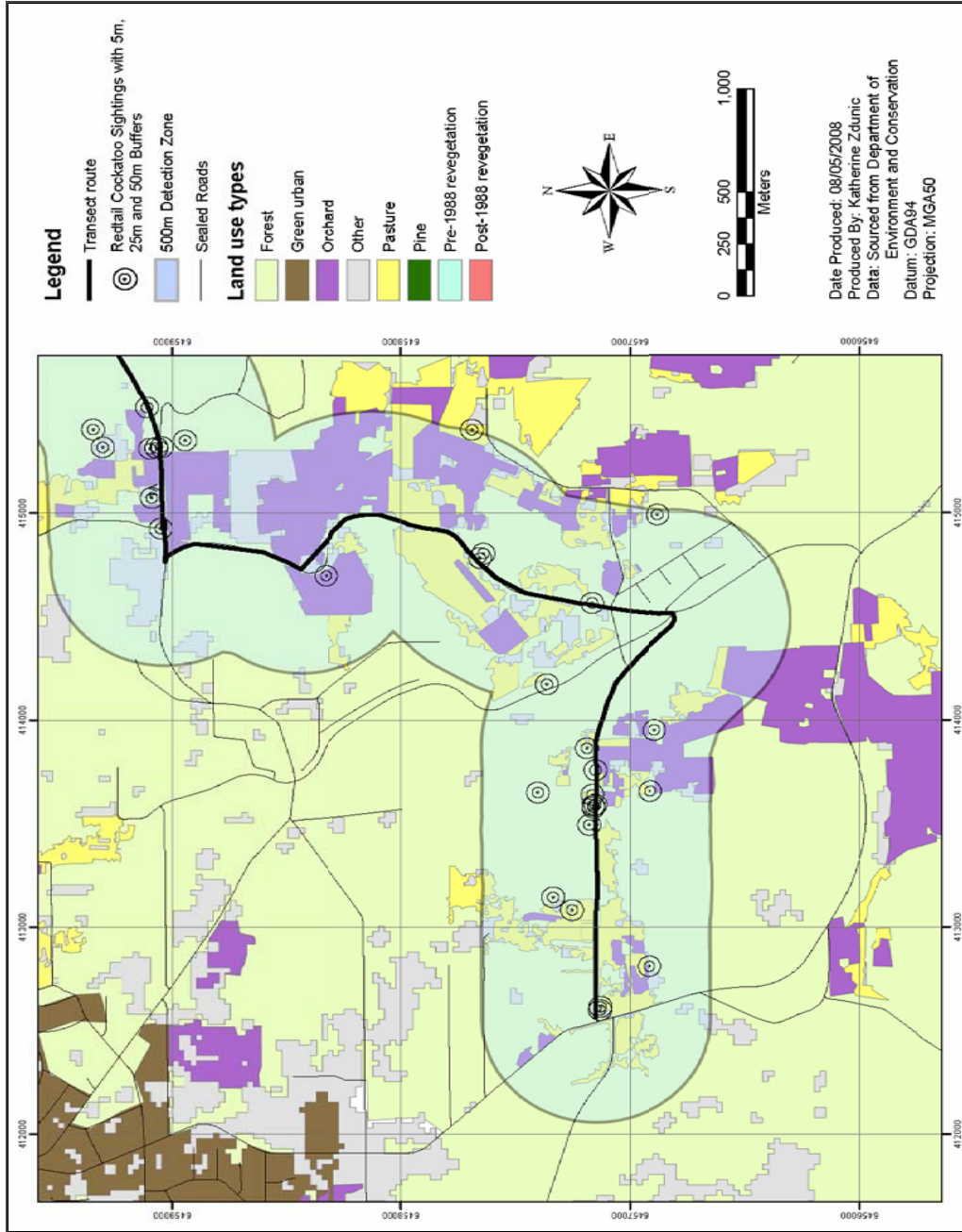
3.2.5 Data analyses

The Statistica 7 software package (Statsoft 2007) was used for all analyses. In the initial exploratory analyses, presence and count data were compared between months and study areas using chi-square tests, and between the morning and afternoon surveys using two-tailed paired samples t-tests.

For all subsequent analyses, data over the whole study year was pooled into a single dataset for each taxon. This was done due to the low number of cockatoos (bird activity) recorded in each individual survey month. Although this procedure reduced the detail of information available, because between-month comparisons would not be possible, it greatly increased the power of tests and thus improved the likelihood of detecting meaningful patterns.

The relationship between cockatoo distribution and land use variables was explored from two different angles: "from the landscape to the birds" and "from the birds to the landscape".

In the first approach, the sampling unit was the 100 m buffer zone surrounding each section. Models were run in Statistica 7 using a generalised linear-nonlinear (GLM) routine with a Poisson link function. Model building followed a best-subsets approach, with models selected based on the Akaike Information Criterion (AIC). The dependent variable entered into the models was either presence (1 or 0) or abundance (number of birds counted) of black cockatoos within the 100 m buffer surrounding each section; the independent variables were the land use variables within the same 100 m buffer.

In the second approach, the sampling unit was the observation point, i.e. the location where each cockatoo or group of cockatoos was recorded in the landscape, and the data entered into the analyses was the number of times each land use type was present in the vicinity of an observation point. Pearson chi-square tests were employed to determine whether certain land use types occurred more often in the vicinity of observation points than expected by chance, with expected frequencies determined using land use data surrounding a set of random points created in ArcView. This analysis could only be conducted for the forest red-tailed cockatoo.

3.2.5.1 Comparisons between study areas, months and time of day

The number of sections each taxon was recorded in was compared between study months (n = 6) and between study areas (n = 3) using a Pearson chi-square test. The same test was also used to compare for each individual taxon the total number of birds recorded (bird activity) between months and between study areas.

Since birds tend to be most active in the early morning, with a second briefer peak in activity in the late afternoon (Bibby *et al.* 2000), the usefulness of afternoon surveys was assessed by comparing the number of birds counted in mornings and afternoons. For each taxon the number of birds recorded in each study area and month during either the morning or afternoon surveys were compared with two-tailed paired samples t-tests (n = 18 for each taxon).

3.2.5.2 Regression models

GLM is the most commonly used approach to link the occurrence and abundance of species to habitat variables (Rushton *et al.* 2004, Austin 2007). It has the advantage of dealing very well with presence/absence data (Austin 2007). Models were run in Statistica 7 using a generalised linear-nonlinear (GLM) routine with a Poisson link function. Model building followed a best-subsets approach, with models selected based on the Akaike Information Criterion (AIC).

Since black cockatoos were relatively rare at the section level, a two-stage modelling design was employed as recommended by Cunningham and Lindenmayer (2005) (see also Cameron & Cunningham 2006). In the first modelling stage, GLM was used to explore which land use variables best explained the presence of a particular taxon over all available sections (n = 181). The dependent variable was presence/absence (1 or 0) of the taxon being modelled in each section, linked to the land use variables in the same section. In the second stage, GLM was used to explore which land use variables best explained abundance (intensity of usage) of the taxon in the subset of sections where it was recorded as present. The data entered into the models was the total number of birds recorded in each section, given presence, linked to the land use variables in these same sections. The land use variable green urban did not occur within 100 m from the transects in any of the three study areas and was therefore not included in the GLM process.

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For the forest red-tailed cockatoo, three two-stage models were constructed: first with the combined dataset from all study areas, and subsequently with the individual datasets from the Pickering Brook and Wungong study area. No separate model could be constructed for Karnet because in this study area the land use variable forest occupied 99.9% of all sections. For Baudin's cockatoo only two two-stage models could be constructed: one for all areas combined and one for the Pickering Brook area. Since Baudin's cockatoo was only recorded in 5 sections in Wungong, no individual model could be constructed for this area. No models could be constructed for Carnaby's cockatoo, given the fact that the species was recorded in only 24 sections over the full 12 month study.

Because the forest variable was dominantly present in all study areas and the purpose of modelling was to discover the effect of the modified land use types, this variable was not included in the modelling process.

The best models were selected using the Akaike Information Criterion (AIC) (Anderson *et al.* 2001, Burnham & Anderson 2004, Johnson & Omland 2004, Gibson *et al.* 2004a, 2004b, Rushton *et al.* 2004, Westphal *et al.* 2003). AIC is a measure of model fit, based on both Kullback-Leibner information loss and statistical maximum likelihood (Anderson *et al.* 2001, Westphal *et al.* 2003). Individual AIC values are arbitrary and only have meaning in a relative sense, allowing a ranking of models from best to worst. The model with the lowest AIC has a high likelihood of being the 'best' model, within the total set of available models, while higher values indicate decreasing likelihood (Burnham & Anderson 2004). AIC penalises for addition of parameters, thus promoting selection of more parsimonious models Westphal *et al.* 2003). The formula for calculating the AIC is:

$$AIC = -2\ln(\lambda(\hat{\theta}|data)) + 2k$$

Where $\ln(\ell|\hat{\theta}|data)$ is the maximized log-likelihood over the unknown parameters (θ) and k is the number of parameters in the model, i.e. independent variables plus the intercept. The log-likelihood reflects the overall fit of the model, with smaller values indicating worse fit (Burnham & Anderson 2004). As a rule of thumb, AIC should only be used whenever the sample size or number of observations n is at least 40 times the number of parameters k, or in other words when $n / k \geq 40$ (Burnham & Anderson 2004, Anderson *et al.* 2001). If this is not the case, the second order Akaike Information Criterion (AIC$_c$) should be used instead (e.g. Gibson *et al*. 2004a,

2004c). In this study the largest possible n was 181, using data from all study areas combined, while the smallest k for this dataset was 7. Hence, AIC_c was calculated for each model. The formula for obtaining the AIC_c is:

$$AIC_c = AIC + \frac{2k(k+1)}{(n-k-1)}$$

As the sample size n increases, the last term will approach zero. The AIC_c penalises even stronger for over-parameterisation than AIC. The lower the AIC or AIC_c, the better the model explains the observed data. However, simply choosing the model with the lowest AIC (AIC_{min}) is not sufficient as other models may have AIC values close to AIC_{min} and can be considered equally parsimonious. This is referred to as model selection uncertainty (Johnson & Omland 2004). The strength of evidence in favour of each alternative model can be assessed by calculating Δ_i which expresses the difference between the AIC of model i and the minimum AIC (Burnham & Anderson 2004, Westphal *et al.* 2003).

$$\Delta_i = AIC_i - AIC_{min}$$

All models with $\Delta_i \leq 2$ were considered equally likely as the model with the AIC_{min} (Westphal *et al.* 2003, Burnham & Anderson 2004) and all models that met this criterion were included in the final set of plausible models.

Akaike weights w_i were calculated for all plausible models. This measure is an alternative way of expressing the strength of evidence for each model. Although it is not truly a measure of probability, w_i can be interpreted as expressing approximately the probability that model i is the best model in the set of candidate models (Westphal *et al.* 2004).

$$w_i = \frac{\exp\left(\frac{-\Delta_i}{2}\right)}{\sum_{r=1}^{R} \exp\left(\frac{-\Delta_r}{2}\right)}$$

To determine the relative strength of effect that each independent variable had on the dependent variable, the summed Akaike weight for each variable (Σw_{var}) was calculated by summing w_i over all models that included that variable (Anderson *et al.*

2001). The effect strength of a variable can range from 0.00 to 1.00. However, the value of Σw_{var} is relative in nature and depends on the range of w_i values available. Hence, when the 'best' model or models contain of a number of variables, all of these can have effect strengths of 1.00 or alternatively all of them can have much lower effect strength. Hence the interpretation of Σw_{var} for a given variable depends on the effect strengths of all other variables included in the modelling process.

It is important to keep in mind that the AIC is not a significance test and does not yield a *p*-value. Instead it expresses the relative strength of evidence in favour of each model in the form of w_i and Δ_i (Anderson *et al.* 2001).

3.2.5.3 Chi-square tests on observation points

In order to establish whether forest red-tailed cockatoos utilised certain vegetation types more often than expected by chance, the land use characteristics in circular buffers centred on locations where the birds were recorded (observed dataset) where compared with those centred on random locations (expected dataset) using chi-square tests. Such methods are commonly used to analyse data for highly mobile species (Rushton *et al.* 2004). Since there were insufficient observation points available for Baudin's cockatoo and Carnaby's cockatoo, data for these species were not analysed. Three different observed and expected datasets were created, using circular buffers with a 5, 25 and 50 m radius.

Since chi-square tests require input data consisting of absolute numbers, it was not possible to analyse the total area or proportion of each land use type falling inside the circular buffers. Instead, the number of times a land use type was included in the circular buffers surrounding the set of observation points or random points was counted to obtain a figure of inclusion frequency.

Chi-square tests demand an expected frequency of at least 5 and therefore land use types whose inclusion frequency in the random point buffers was less than 5 (expected frequency) were pooled with another land use type to obtain a combined variable with an expected value of at least 5. Land use types were pooled preferably with those which also had a low inclusion frequency, in order to obtain as large a number of separate variables as possible.

For each buffer size (5, 25 and 50 m radius) the observed and expected inclusion frequencies of each land use type (or pooled type) were compared within all three study areas combined, and for each study area separately, yielding a total of 12 chi-square tests.

3.2.5.4 Notes on spatial autocorrelation

Spatial autocorrelation (SA) was likely to occur in both the independent and dependent data due to both the sampling method and the ecology of the study species. First, in transect surveys, sampling points (sections) are not randomly distributed but all lie on the same line. Consequently, the likelihood of having similar land use types in adjacent sections is high since a land use type present in one section is likely continue into the next. This effect was exacerbated by the fact that

buffers of adjacent sections partially overlapped (see Section 3.2.4). Second, black cockatoos are gregarious birds (Johnstone & Kirkby 1999) and individual foraging groups keep in contact by constant calling. Hence, the presence of black cockatoos in one section may well have influenced the likelihood of finding birds of the same taxon in nearby sections.

Due to the nature of the data, it was not possible to run statistical tests for SA. Two commonly used methods to test for SA are constructing corellograms which plot Moran's coefficients against spatial distance (DeFrutos *et al.* 2007, Cushman & McGarigal 2002) or by running Mantel tests (Westphal *et al.* 2003). The Moran's Index quantifies the ecological similarity between locations as a function of geometric distance, whereas Mantel tests describe the correlation between ecological and geographical distance. Both these tests are designed for data recorded with a stratified random or grid-based sampling technique where sampling points themselves are not spatially autocorrelated (only the data within might be). Since all observation points by definition clustered around the transects, the dataset in of this study was not suitable for these tests.

One of the consequences of having a spatially correlated dataset is a reduced freedom of the data to vary. In other words, the dataset contains less information than if it had been obtained from spatially uncorrelated points (King 2002). Second, increasing levels of SA lead to stronger covariance between sampling points (Dormann 2007), which means that true variance in the dataset is underestimated. These two effects may lead to overestimation of the importance of covariates (e.g. land use variables) in explaining species distribution (Coreau & Martin 2007). Indeed, a study that compared between spatial and non spatial models constructed with the same datasets, invariably found that the regression coefficients were different (Dormann 2007). Nonetheless, simulation studies using datasets with SA set at a much higher level than normally reported in ecological field studies, found only modest effects of SA on the models constructed (King 2002).

When SA in the dependent variable is believed to be due to endogenous population processes such as aggregation or dispersal, it is possible to correct for SA by incorporating an autocovariate term in the model (Coreau & Martin 2007, McPherson & Jetz 2007). Such autocovariate terms may reflect for instance how much a species' probability of occurrence at one site is affected by its presence or absence at neighbouring sites (McPherson & Jetz 2007). However, autologistic models have only limited predictive value due to their high susceptibility to starting conditions (Dormann 2007). To date no study has yet attempted to evaluate whether

models incorporating a spatial component are actually less biased than much simpler non spatial models (Dormann 2007).

In this study no compensation for SA was made. First, because the nature of the dataset meant it was not possible to assess the magnitude of any effects of SA and consequently define correction factors. Second, because including correction factors might not actually improve the quality (realism) of models constructed and would certainly not improve predictive value of any models developed. However, presence and possible effects of SA will be taken into consideration when interpreting and discussing the results.

3.3 Results

3.3.1 Number of cockatoos recorded

There were clear differences in abundance between the three taxa under study and also between study months for each taxon separately (Table 3.2). Forest red-tailed cockatoos were present in more transect sections (x^2 = 384.781, *d.f.* = 2, *p* < 0.001) and in greater abundance (x^2 = 1332.094, *d.f.* = 2, *p* < 0.001) than the two white-tailed species.

Table 3.2 – Number of transect sections containing forest red-tailed cockatoos, Baudin's cockatoos and Carnaby's cockatoos and actual bird abundances recorded in 181 transect sections across all three study sites over the 2007 study year.

	Number of sections with taxon present			Percentage of sections with taxon present			Number of birds recorded		
	Red	*Bau*	*Car*	*Red*	*Bau*	*Car*	*Red*	*Bau*	*Car*
Year	**156**	**52**	**24**	**86%**	**29%**	**13%**	**2608**	**1174**	**380**
February	26	5	5	14%	3%	3%	277	15	64
April	67	17	4	37%	9%	2%	575	265	72
June	47	25	6	26%	14%	3%	704	599	92
August	33	19	4	18%	10%	2%	217	260	29
October	79	5	6	44%	3%	3%	379	25	115
December	86	1	4	48%	1%	2%	452	10	8

Numbers refer to all cockatoos seen and heard 0-500 m from transects.

There was no difference between bird numbers recorded in either the morning or afternoon surveys in any of the study areas or months (*n* = 18, compared using a two-tailed paired samples t-test). This was true for both the forest red-tailed cockatoo (*t* = -1.374, *d.f.* = 17, *p* = 0.187), Baudin's cockatoo (*t* = 0.931, *d.f.* = 17, *p* = 0.365) and Carnaby's cockatoo (*t* = -0.255, *d.f.* = 17, *p* = 0.802).

Forest red-tailed cockatoos occurred in smaller groups than the other two taxa. The average group size for the forest red-tailed cockatoo was 4 ± 0.2 birds (*n* = 585) ranging from one to 50 birds. For Baudin's cockatoo the average group size was 13 ± 2 birds (*n* = 90) ranging from one to 100 birds, while Carnaby's cockatoo had an average group size of 11 ± 2 birds (*n* = 34) ranging from two to 60 birds. These figures do not include three large foraging flocks of white-tailed cockatoos recorded outside the transect surveys, which are discussed elsewhere (Chapter 4).

Records for the forest red-tailed cockatoo varied between months both in terms of sections the taxon was present in (x^2 = 54.308, $d.f.$ = 5, p < 0.001) and in absolute counts (x^2 = 389.279, $d.f.$ = 5, p < 0.001). In February and August the presence and abundance of forest red-tailed cockatoos was lower compared to the other months.

For Baudin's cockatoo presence (x^2 = 40.296, $d.f.$ = 5, p < 0.001) and abundance (x^2 = 1380.728, $d.f.$ = 5, p < 0.001) also varied significantly between months. Their numbers peaked in June, with tails on either side in April and August. In June the number of Baudin's cockatoos was almost equal to the number of forest red-tailed cockatoos for that month, but Baudin's cockatoo was recorded in only half as many sections. This finding reflects the fact that the species occurred in larger flocks than the forest red-tailed cockatoo.

Carnaby's cockatoo was present in low numbers throughout the year. The number of sections it was recorded in was similar between study months, although their abundance varied (x^2 = 92.416, $d.f.$ = 5, p < 0.001) being lower in August and December compared to the other months.

The three study areas differed in the total number of cockatoos recorded over the whole 2007 study year (Figure 3.6). This variation was significant for all three taxa, forest red-tailed cockatoo (x^2 = 41.469, $d.f.$ = 2, p < 0.001), Baudin's cockatoo (x^2 = 698.877, $d.f.$ = 2, p < 0.001), and Carnaby's cockatoo (x^2 = 213.309, $d.f.$ = 2, p < 0.001).

In Pickering Brook Baudin's cockatoos actually outnumbered forest red-tailed cockatoos, which themselves were least abundant in this area. Forest red-tailed cockatoos were recorded in equal numbers in Wungong and Karnet, areas with respectively a high level of revegetated forest and containing mature forest. Carnaby's cockatoo was most numerous in Pickering Brook, followed by Wungong and with lowest numbers recorded in Karnet (see also Figures 3.1, 3.2, 3.3).
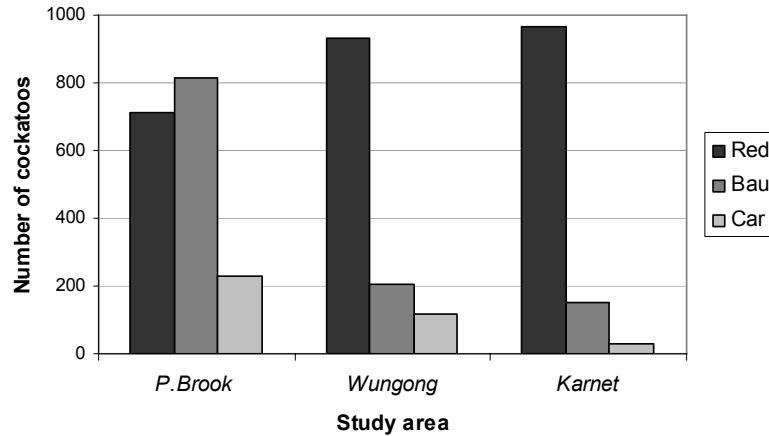
Figure 3.6 – Total number of cockatoos recorded in each study area over the whole study year of 2007

When comparing monthly count data for each study area separately, the lower numbers of forest red-tailed cockatoos observed in February only occurred in Wungong (Figure 3.8).

In Pickering Brook and Karnet (Figures 3.7 and 3.9) the numbers for February and April and for October and December, respectively the first and the last two survey periods were very comparable; between 120 and 170 birds per area per study month. Only in these two study areas there was a clear lower number of birds in August, whereas in Wungong the lowest number of birds was seen in October. Peaks of 300 or more forest red-tailed cockatoos seen in a single month were observed in April and June in Wungong and in June in Karnet, while no such peak was apparent in Pickering Brook.

The peak in Baudin's cockatoos in June (Table 3.2) was primarily due to a dramatic increase in Pickering Brook (Figure 3.7) although a small increase was also recorded in Wungong (Figure 3.8), but not in Karnet (Figure 3.9).

No strong patterns appeared for Carnaby's cockatoo. In Pickering Brook numbers fluctuated between study months as birds were either encountered as one or two pairs or in flocks of 12 to 60 birds. In Wungong most Carnaby's cockatoos were seen in April, which was mainly due to one large flock of 60 birds. No Carnaby's cockatoos were seen in Karnet in the first four study periods, but in October a flock of 26 birds appeared.
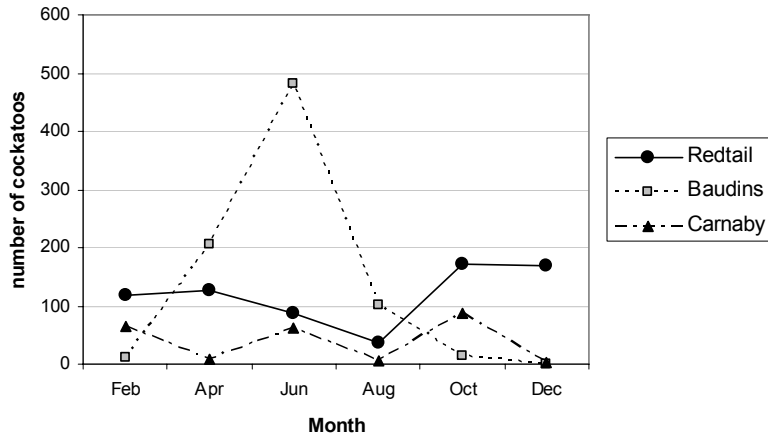
Figure 3.7 – Pickering Brook: Number of black cockatoos recorded within 500 m from transects at two-month intervals over the 2007 study year.
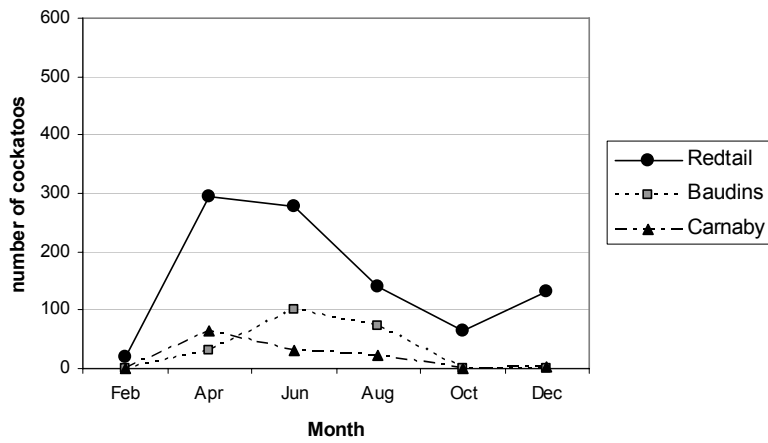
Figure 3.8 – Wungong: Number of black cockatoos recorded within 500 m from transects at two-month intervals over the 2007 study year.
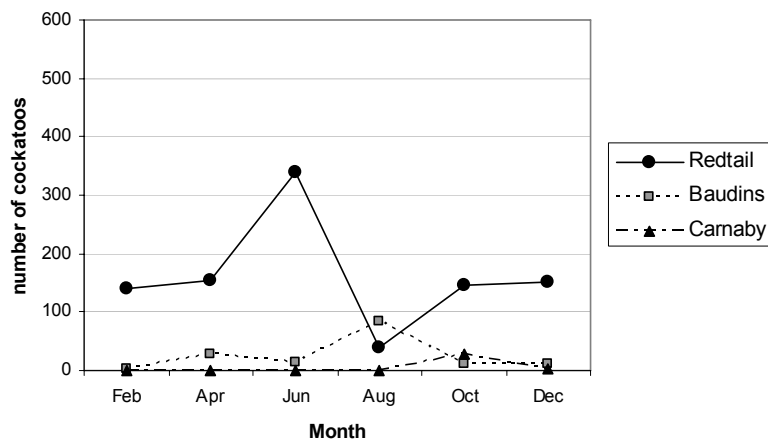
Figure 3.9 – Karnet: Number of black cockatoos recorded within 500 m from transects at two-month intervals over the 2007 study year.

3.3.2 The proportion of land use types at increasing scales

In each study area the proportions of land use types varied with increasing buffer radius around the transects (Figures 3.10, 3.11 and 3.12). At the smaller scales, orchards and pasture had high proportions in Pickering Brook, but were virtually absent in both other areas. On the other hand, revegetation occupied a high proportion of the smaller buffer areas in Wungong, but this land use type was completely absent from Pickering Brook and only marginally present in Karnet.
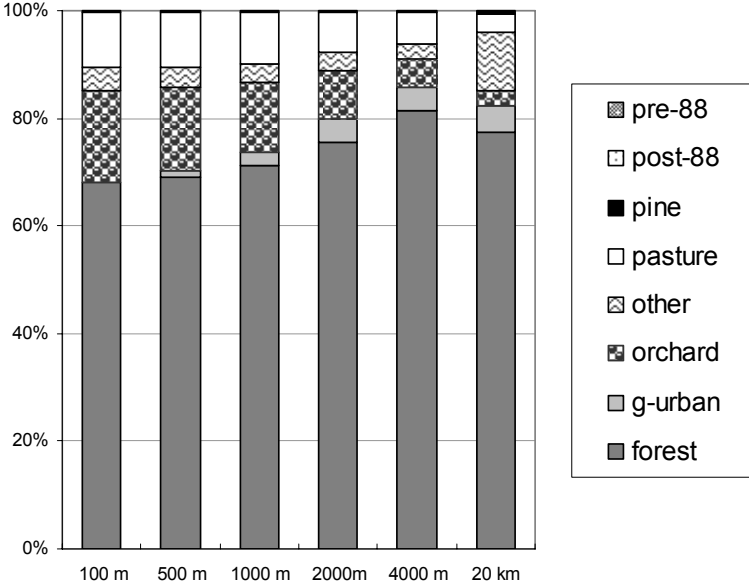
Figure 3.10 – Pickering Brook: Percentage cover of each land use type within transect buffers of increasing radius
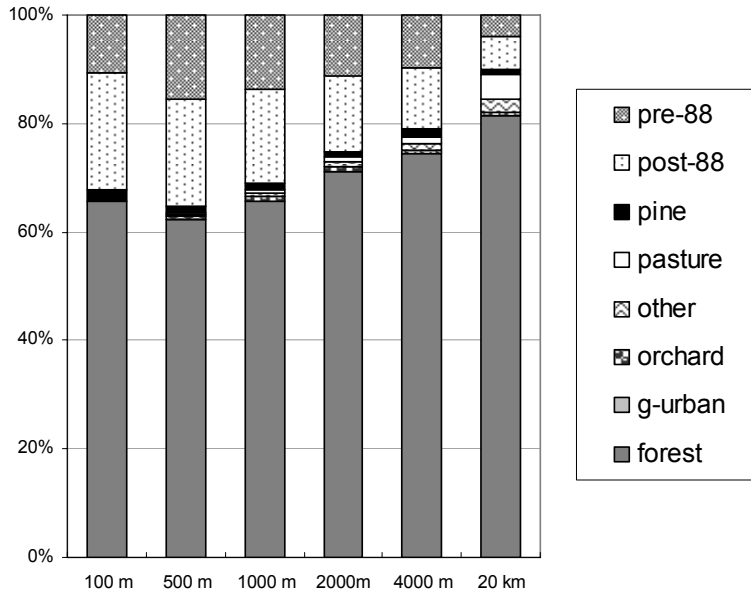
Figure 3.11 – Wungong: Percentage cover of each land use type within transect buffers of increasing radius
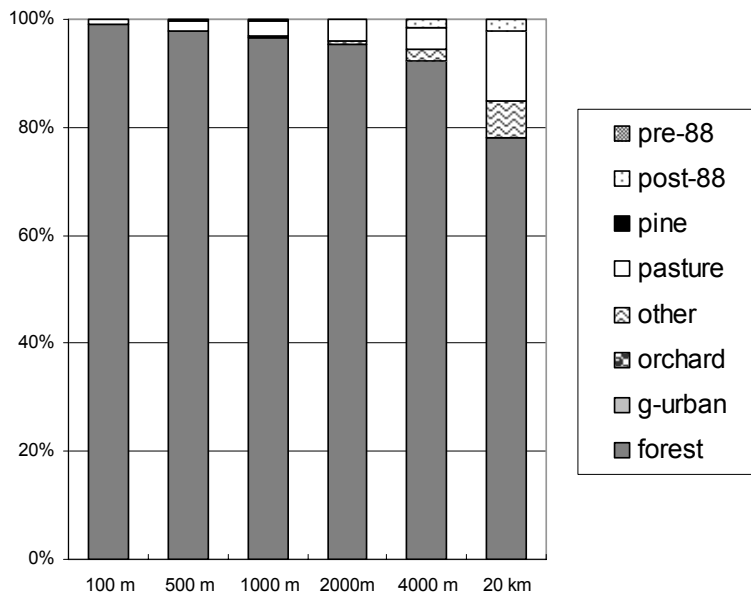
Figure 3.12 – Karnet: Percentage cover of each land use type within transect buffers of increasing radius

Study areas were selected to sample a range of different land use types. The transects were positioned to directly traverse these modified land use types and for Pickering Brook and Wungong this was reflected in slowly diminishing proportions of orchards, pasture and revegetation as with increasing buffer size.

The Karnet study area was selected for containing a large proportion of native forest, and within the smallest buffer areas forest was nearly 100%. However, with increasing buffer scales the forest percentage decreased, and at the scale of the entire 400 km^2 study area the forest proportion was 80%. This figure is similar to the proportion of forest in the other two study areas. Hence, with respect to the forest fraction, the study areas as a whole were very similar.

At the scale of the entire study area, the land use types for which Pickering Brook and Wungong were selected still occupied a reasonable proportion while in Karnet pasture occupied 12%, reflecting the presence of extensive grazing land west of the jarrah forest. The relatively large proportion of other at the study area, which was most noticeable in Pickering Brook and Karnet, reflects the inclusion of large water bodies present in these areas, while in Pickering Brook the eastern suburbs of Perth also contribute to the high figure for other (Chapter 2). Hence, although at the study area scale the proportion of forest was very similar for each of the three study areas, they continued to differ with respect to the non forest fraction.

3.3.3 GLM analyses

The results of the two-stage GLM analyses for forest red-tailed cockatoos and Baudin's cockatoos are described below. Only candidate models with Δi < 2.0 are shown, which means that all models presented in the same table section can be considered to be the most parsimonious models explaining presence or abundance of cockatoos.

3.3.3.1 Models for forest red-tailed cockatoo

Regression models for presence of the forest red-tailed cockatoo in all three study areas combined, based on both cockatoo count data and vegetation data within 100 m from the transects, suggest a negative response of this taxon to post-1988 revegetation. In models constructed with the combined data of all three study areas, post-1988 revegetation appeared in all candidate models that were the most likely in explaining cockatoo presence and its effect was negative (Table 3.3).

Post-1988 revegetation also had the highest effect strength (Σw_{var}) on presence of forest red-tailed cockatoos. When post-1988 revegetation was excluded from the modelling process (results not shown in the table), the set of plausible models included all available variables, which all had very similar effect strength.

Table 3.3 – Results of GLM analyses on presence of forest red-tailed cockatoos and vegetation data within 100 m buffers around transects in three study areas combined. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ$_i$	w$_i$
Variables in analysis: orchard, other, pasture, pine, post-1988, pre-1988				
Variables excluded: forest				
181	-Po88	345.71	0.00	0.25
	-Po88 +Pr88	346.84	1.13	0.14
	-Po88 -Oth	347.24	1.54	0.11
	-Po88 -Pas	347.48	1.77	0.10
	-Po88 +Pin	347.69	1.98	0.09

Σw_{var} = Orc 0.26   Oth 0.28   Pas 0.26   Pin 0.22   Po88 0.72   Pr88 0.35

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ$_i$) and Akaike weight (w$_i$), and for each variable the summed w$_i$ over all models that included that variable (Σw_{var}). Only models with Δ$_i$ < 2 are shown.
Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

In the second stage of model building, the set of models explaining abundance of forest red-tailed cockatoos over all study areas combined did not indicate a strong response to any of the individual land use variables. The most plausible candidate models together contained all variables that were available for analysis (Table 3.4).

However the effect strength of orchard and other were higher than the other variables. Both had a negative effect on abundance of forest red-tailed cockatoos.

Table 3.4 – Results of GLM analyses on abundance of forest red-tailed cockatoos and vegetation data within 100 m buffers around transects in three study areas combined. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ$_i$	w$_i$
	Variables in analysis: orchard, other, pasture, pine, post-1988, pre-1988			
	Variables excluded: forest			
129	-Orc -Oth +Pas	1498.15	0.00	0.14
	-Orc –Oth	1498.32	0.17	0.12
	-Orc -Oth -Po88	1498.64	0.49	0.11
	-Orc -Oth +Pas -Po88	1498.96	0.81	0.09
	-Orc	1498.87	0.73	0.09
	-Orc -Po88	1499.29	1.15	0.08
	-Orc -Oth +Pas +Pr88	1499.69	1.54	0.06
	-Orc +Pas	1499.41	1.26	0.07

Σw$_{var}$ = Orc 0.99   Oth 0.60   Pas 0.46   Pin 0.24   Po88 0.52   Pr88 0.34

n	Candidate Models	AICc	Δ$_i$	w$_i$
	Variables in analysis: other, pasture, pine, pre-1988, post-1988			
	Variables excluded: forest, orchard			
129	-Oth	1507.72	0.00	0.19
	-Oth +Pr88	1508.82	1.10	0.11
	-Oth +Pas	1508.85	1.13	0.11
	-Oth -Po88	1509.03	1.31	0.10

Σw$_{var}$ = Oth 1.00   Pas 0.41   Pin 0.30   Po88 0.29   Pr88 0.36

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ$_i$) and Akaike weight (w$_i$), and for each variable the summed w$_i$ over all models that included that variable (Σw$_{var}$). Only models with Δi < 2 are shown. Variables: For: forest, Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

In models for presence of forest red-tailed cockatoos in Pickering Brook, no single land use variable appeared to be the strongest predictor (Table 3.5). The set of plausible models all had AIC$_c$'s very close to each other while the effect strengths of the individual variables (Σw$_{var}$) were also very similar.

Table 3.5 – Results of GLM analyses on presence of forest red-tailed cockatoos and vegetation data within 100 m buffers around transects in Pickering Brook. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ_i	w_i
	Variables in analysis: orchard, other, pasture, pine			
	Variables excluded: forest			
61	-Oth	119.82	0.00	0.16
	+Orc	119.89	0.07	0.15
	-Pin	119.90	0.08	0.15
	-Pas	119.93	0.11	0.15
	-Oth -Pin	121.37	1.55	0.07
	+Orc -Oth	121.48	1.66	0.07
	+Orc -Pin	121.50	1.68	0.07
	-Pas -Pin	121.50	1.68	0.07
	+Oth -Pas	121.68	1.86	0.06
Σw_{var} =	Orc 0.37 Oth 0.38 Pas 0.36 Pin 0.40			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown. Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

In abundance models for the Pickering Brook area, pasture and pine were both included in all plausible models (Table 3.6). However, the complete set of plausible models included all land use variables present in the Pickering Brook area, suggesting that their effects on the abundance of forest red-tailed cockatoos can not be ignored. In fact, the effect strengths of all variables were very similar.

Table 3.6 – Results of GLM analyses on abundance of forest red-tailed cockatoos and vegetation data within 100 m buffers around transects in Pickering Brook. Models built using a generalised linear-nonlinear routine with a Poisson link function

n	Candidate Models	AICc	Δ_i	w_i
	Variables in analysis: orchard, other, pasture, pine			
	Variables excluded: forest			
43	+Pas -Pin +Orc	415.08	0.00	0.35
	+Pas –Pin	415.61	0.53	0.27
	+Pas -Pin -Oth	416.09	1.01	0.21
	+Pas -Pin +Orc -Oth	416.45	1.37	0.17
Σw_{var} =	Orc 0.37 Oth 0.38 Pas 0.36 Pin 0.40			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown. Variables: For: forest, Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

Models constructed for the Wungong area showed that post-1988 revegetation, had a negative effect on both presence (Table 3.7) and abundance (Table 3.8) of forest red-tailed cockatoos. The post-1988 variable also had the greatest effect strength in presence models, while in abundance models both post-1988 and pasture had very high but equal effect strength.

The effect of pasture was also negative. Hence, forest red-tailed cockatoos appeared to avoid areas with post-1988 revegetation, while occurring in lower numbers in areas with post-1988 revegetation and/or pasture.

Table 3.7 – Results of GLM analyses on presence of forest red-tailed cockatoos and vegetation data within 100 m buffers around transects in Wungong. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ_i	w_i
	Variables in analysis: other, pasture, pine, post-1988, pre-1988			
	Variables excluded: forest			
60	-Po88	112.84	0.00	0.33
	-Po88 +Pr88	114.71	1.87	0.13
$\Sigma w_{var} =$	Oth 0.25 Pas 0.25 Pin 0.25 Po88 0.79 Pr88 0.30			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown. Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

Table 3.8 – Results of GLM analyses on abundance of forest red-tailed cockatoos and vegetation data within 100 m buffers around transects in Wungong. Models built using a generalised linear-nonlinear routine with a Poisson link function

n	Candidate Models	AICc	Δ_i	w_i
	Variables in analysis: other, pasture, pine, post-1988, pre-1988			
	Variables excluded: forest			
41	-Pas -Po88	571.25	0.00	0.32
	-Pas -Po88 –Oth	571.59	0.34	0.32
$\Sigma w_{var} =$	Oth 0.45 Pas 1.00 Pin 0.23 Po88 1.00 Pr88 0.23			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown. Variables: For: forest, Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

3.3.3.2 Models for Baudin's cockatoo

Models for the presence of Baudin's cockatoos, constructed over all study areas together, indicated a positive response to orchards (Table 3.9). The orchard variable also had much greater effect strength than the other variables. When orchard was excluded from analyses, the set of plausible models included all possible variables entered into the modelling process. Therefore, apart from orchard, none of the other variables had a noticeable effect on the dependent variable.

Table 3.9 – Results of GLM analyses on presence of Baudin's cockatoos and vegetation data within 100 m buffers around transects in all three study areas combined. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ_i	w_i
	Variables in analysis: orchard, other, pasture, pine, post-1988, pre-1988			
	Variables excluded: forest			
181	+Orc	167.84	0.00	0.12
	+Orc +Oth	168.32	0.48	0.09
	+Orc +Pas	168.37	0.53	0.09
	+Orc +Oth +Pas	168.97	1.12	0.07
	+Orc -Pr88	169.44	1.60	0.05
	+Orc -Po88	169.53	1.69	0.05

Σw$_{var}$ = Orc 0.99   Oth 0.43   Pas 0.41   Pin 0.26   Po88 0.25   Pr88 0.33

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw$_{var}$). Only models with $\Delta i < 2$ are shown. Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

In the second modelling stage, abundance models for Baudin's cockatoos over all study areas combined showed no clear effect of any of the land use variables (Table 3.10). Regardless of which variable was excluded from the analyses, the most plausible models contained all of the remaining land use variables, with most of them having high (but meaningless) effect strength.

Table 3.10 – Results of GLM analyses on abundance of Baudin's cockatoos and vegetation data within 100 m buffers around transects in all three study areas combined. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ_i	w_i
Variables in analysis: orchard, other, pasture, pine, post-1988, pre-1988				
Variables excluded: forest				
34	+Orc -Oth -Pas -Pin +Po88	598.90	0.00	0.56
	+Orc -Oth -Pas -Pin +Po88 -Pr88	599.64	0.74	0.39
Σw_{var} =	Orc 1.00 Oth 0.98 Pas 0.97 Pin 1.00 Po88 1.00 Pr88 0.41			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown. Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

Presence models for Baudin's cockatoo in Pickering Brook showed a strong and positive effect of orchard (Table 3.11).

Table 3.11 – Results of GLM analyses on presence of Baudin's cockatoos and vegetation data within 100 m buffers around transects in Pickering Brook. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ_i	w_i
Variables in analysis: orchard, other, pasture, pine				
Variables excluded: forest				
61	+Orc	90.80	0.00	0.86
	+Orc -Pin	91.49	0.68	0.61
	+Orc +Oth	92.17	1.37	0.43
Σw_{var} =	Orc 0.81 Oth 0.28 Pas 0.20 Pin 0.37			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown. Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

Models on abundance of Baudin's cockatoo contained all available variables (Table 3.12) and these all had similar effect strengths. Hence, no clear effect of any variable on the abundance of Baudin's cockatoos in Pickering Brook was apparent.

Table 3.12 – Results of GLM analyses on abundance of Baudin's cockatoos and vegetation data within 100 m buffers around transects in Pickering Brook. Models built using a generalised linear-nonlinear routine with a Poisson link function.

n	Candidate Models	AICc	Δ_i	w_i
Variables in analysis: orchard, other, pasture				
Variables excluded: forest				
23	+Orc -Oth -Pas	475.37	0.00	1.00
Σw_var =	Orc 1.00 Oth 0.99 Pas 1.00			

Shown are for each candidate model the adjusted Akaike score (AICc), difference in AICc with the top model (Δ_i) and Akaike weight (w_i), and for each variable the summed w_i over all models that included that variable (Σw_{var}). Only models with $\Delta i < 2$ are shown.
Variables: Orc: orchard, Oth: other, Pas: pasture, Pin: pine, Po88: post-1988 revegetation, Pr88: pre-1988 revegetation. Sign refers to effect on dependent variable.

3.3.4 Chi-square tests on observation points of forest red-tailed cockatoos

There were significant differences between the observed and expected inclusion frequencies of land use types in circular buffers surrounding observation points for forest red-tailed cockatoos and a set of random points, respectively (Table 3.13).

Table 3.13 – Results of Chi-square analyses comparing land use types in circular buffers around locations where forest red-tailed cockatoos were recorded over whole study year (observed) with those surrounding a random set of points (expected). Shown are study areas in which circular areas were measured and radius of circles (R). Land use types occurring less than 5 times in expected dataset were pooled.

Study area(s)	R	Land use types compared*	χ^2	d.f.	p	Difference**
All	5	1 2 3 4 5 6 7	20.657	6	0.002	-1 +2 +3 +7
	25	1 2 3 4 5 6 7	20.135	6	0.003	+3 +4 -7
	50	1 2 3 4 5 6 7	18.112	6	0.006	+3 +4 -7
Pickering	5	1 2 3 4 5	9.483	4	0.050	+1 -2 -3 +4 -5
Brook	25	1 2 3 4 5	13.746	4	0.008	-1 +3 +4 -5
	50	1 2 3 4 5	16.224	4	0.003	-1 +3 +4 -5
Wungong	5	1 (2,3,4,5) 6 7	19.016	3	<0.001	+1 -7
	25	1 (2,3,4,5) 6 7	11.010	3	0.012	+1 -7
	50	1 (2,3,4,5) 6 7	9.671	3	0.022	+1 -7
Karnet	5	1 (2,3,4,5,6,7)	0.512	1	0.474	
	25	1 (2,3,4,5,6,7)	11.596	1	0.001	+(2,3,4,5,6,7)
	50	1 (2,3,4,5,6,7)	17.274	1	0.001	+(2,3,4,5,6,7)

* 1: Forest, 2: Orchard, 3: Other, 4: Pasture, 5: Pine/GreenUrban, 6: pre-1988 revegetation, 7: Post-1988 revegetation. Pooled land use types between brackets.
** Difference between observed and expected frequencies with + indicating land use type occurred more in observed dataset than in expected and - that it occurred less.

Comparisons of data from all study areas combined showed that within buffers of 5 m radius, locations where forest red-tailed cockatoos were observed contained less forest than expected from the random dataset and more orchard, other and post-1988 revegetation. However, data from the 25 and 50 m radius buffers surrounding the same points showed a different result, with forest included as often as expected by chance while other and pasture were included more often and post-1988 included less often.

In Pickering Brook data from the 5 m radius buffers also yielded a different pattern than data from the two larger buffers. In 5 m radius buffers around observation points, forest and pasture were included more often than expected while orchard, other and pine were included less often. In 25 and 50 m radius buffers

forest and pine were included less often, while other and pasture were included more often.

In Wungong the low inclusion frequencies of orchard, other, pasture and pine meant that these had to be combined into one pooled land use type. Results were similar for all buffer sizes, showing that forest was included more often while post-1988 revegetation was included less often.

In Karnet all modified land use types were pooled to reach the required minimum expected inclusion frequency of 5. In the 25 and 50 m radius buffers around observation points the pooled land use type was included more often than expected by chance. Forest was included as often as expected. However, in the 5 m radius buffers there was no difference.

3.4 Discussion

3.4.1 Comparison of study areas

The study areas were selected for their differences, each containing a different combination of the most important land use types in the study region. Comparisons of the land use proportions within increasing buffers around the study transects indicated that the intended differences in land use were maintained up to the highest buffer radius of 4 km, and were also present at the largest scale of the 400 km^2 study area.

Forest red-tailed cockatoos forage within 1 to 4 km from their roost sites (Johnstone & Kirkby 1999), while only slightly larger foraging distances have been recorded for both white-tailed species (T. Kirkby *pers. comm*. June 2006). Hence, although birds could only be detected within 500 m from transects, the land use proportions at this scale were a good representation of those present within the home range of the birds. This means that it can be assumed that most cockatoos recorded during the transect surveys were indeed responding (positively or negatively) to the range of land use types present in the study areas since patterns at the local scale were similar to those at the home range scale.

At the 400 km^2 scale the three areas were in fact very similar with respect to the forest variable, which in each area occupied roughly 80% of the available land surface. In addition, since virtually all land use types that were not forest could be considered modified, the three study areas also contained the same amount of modified land surface. Hence, any clear differences between the study areas at the 400 km^2 scale depended on the nature of the modified land use types within, and this is what cockatoos selecting between the three landscapes may have been responding to.

3.4.2 Distribution and abundance of forest red-tailed cockatoos

Forest red-tailed cockatoos were present in high numbers year-round in each of the three study areas, although the numbers recorded were slightly lower in Pickering Brook compared to Wungong and Karnet. Since cockatoos could not be recognized individually, abundance data reflected patterns of bird activity as well as population size at the time of the study. The influence of activity levels on the number of birds

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recorded must be kept in mind when comparing bird counts between study areas and study months.

In August and February the number of forest red-tailed cockatoos recorded in each of the three study areas was lower than in the other study months, and chi-square tests on between-month variability suggest this difference was significant. In August the significantly lower number of observations was probably due to reduced activity of the birds because of bad weather. August is the last month of the Australian winter and the weather was cold, rainy and at times very windy. Such weather conditions are known to affect the behaviour of black cockatoos. During times of bad weather, the birds still, call less and fly around less (Johnstone & Kirkby 1999, T. Kirkby *pers. comm*. June 2006). Since the August surveys were of equal duration to the other months, reduced activity by the birds meant that a lower number of birds moved into or past the transects during a survey. Another effect of weather on detection of birds is the fact that wind scatters the sound of calls while the sound of rain on the rooftop of a vehicle muffles it. Hence, although lower numbers were recorded in August, this can not be interpreted as a reduction in the actual number of birds present in the study areas.

Regression analyses showed a strong negative response of forest red-tailed cockatoos to post-1988 revegetation, which they avoided. This effect was also demonstrated in the chi-square analyses at the observation point scale, which showed that post-1988 revegetation was included in observation point buffers less often than expected by chance. The post-1988 revegetation was established relatively recently with the youngest trees planted in 2001. Hence at the time of the study most trees and shrubs in this land use type were still quite small. On the ground post-1988 revegetation resembled shrubland rather than a forest. This may explain why a forest-dependent cockatoo avoids such areas.

No avoidance was found for the more mature pre-1988 revegetation, despite the fact that this land use type contained many exotic eucalypt species. Outside the study areas forest red-tailed cockatoos have been observed feeding on spotted gum (*Corymbia maculata*) (Johnstone & Kirkby 1999) and lemon-scented gum (*C. maculata citriodora*) (T. Kirkby *pers. comm.* June 2006*). Both of these eastern state eucalypt species are present in the pre-1988 revegetation, which suggest that this land use type may be a suitable feeding habitat. However, no feeding on eastern-state species was observed during this study. More importantly, the trees in the older revegetation were 20 to 40 years old at the time of the study and had a closed canopy of similar height to the surrounding native forest. This may be important in

the light of predation risk from the wedge-tailed eagle (*Aquila audax*), a known predator of black cockatoos (Brooker & Ridpath 1980, Saunders 1979), and other birds of prey. Glossy cockatoos (*Calyptorhynchus lathami*) avoid open areas and feed preferentially in trees with a dense canopy where they are better hidden from aerial predators (Cameron & Cunningham 2006). Similarly, forest red-tailed cockatoos also feed primarily in the canopy and appear quite uncomfortable on the ground (Johnstone & Kirkby 1999). During the study forest red-tailed cockatoos were twice observed responding to a bird of prey. In Karnet the sudden appearance of a wedge-tailed eagle caused a flock of 30 cockatoos to flee. The birds flew away from the raptor at great speed, just above the tree tops, while calling loudly. In Pickering Brook a group of 6 cockatoos responded to the approach of a square-tailed kite (*Lophoictinia isura*) by sitting still deep in the canopy and calling. This observation especially supports the view that the canopy offers the birds protection from raptors. Forest red-tailed cockatoos tend to fly just above the tree tops (*pers. obs.*) and from a birds-eye perspective, the canopy continued unbroken across native forest and older revegetation. Hence, even if forest red-tailed cockatoos did not exploit the older revegetation for food, its closed canopy would offer them a safe passage from one native forest patch to another as the birds could easily retreat down into the canopy when was raptor is spotted. Younger revegetation, being low and lacking a canopy, does not offer such refuge.

Despite the negative response of forest red-tailed cockatoos to younger revegetation, the total number of birds recorded in the Wungong study area was not different from the numbers recorded in Karnet, an area with almost exclusively native forest. These results suggest that although the taxon may have avoided certain parts of the Wungong area, it did not select against study areas containing young revegetation. This observation agrees with abundance models which showed that post-1988 only negatively affected abundance within the Wungong area, but not over all study areas together. A possible explanation why there appeared to be no selection against the landscape containing post-1988 revegetation may lie in the fact that at the 400 km^2 landscape scale the study areas were very similar, with all three containing 80% native forest which is the primary habitat for the forest red-tailed cockatoo (Higgins 1999).

Presence models for Pickering Brook and to a lesser extent Wungong as well showed a positive response to pasture. These findings agree with chi-square analyses at the observation point scale, which showed that forest red-tailed cockatoos in Pickering Brook utilised pasture more often than expected by chance.

Other than the inland red-tailed cockatoo (*C. b. samueli*), forest red-tailed cockatoos do not readily feed on the ground (Ford 1980, Johnstone & Kirkby 1999) and during the study the birds were never observed feeding in pasture. However, pasture almost invariably bordered native forest, which suggests that the pasture variable in effect reflected the presence of edge trees. Studies on glossy cockatoos suggest that edge trees produce greater seed crops than trees deeper inside a forest stand (Koch 2005) and this may well be true for jarrah and marri trees bordering pasture. Therefore, the positive effect of pasture on presence of forest red-tailed cockatoos, as well as the higher than expected inclusion frequency of pasture in buffers around observation points, may both be reflecting a tendency to feed in edge trees. Conversely, abundance models for Wungong showed a negative effect of pasture. A possible explanation for the seemingly conflicting results for presence models and observation point analyses compared to abundance models is that cockatoos feeding in edge trees may be more exposed to aerial predators and would do well to keep quiet. Since the survey protocol did not allow the observer to approach the birds so close that the flock might take flight, it is possible that the group size of flocks feeding in edge trees was underestimated. This would explain the negative effect of pasture (i.e. edges) on the recorded abundance of forest red-tailed cockatoos.

At the time of the study, all three areas appeared to be suitable for the forest red-tailed cockatoo. Although aimed at recording feeding behaviour, the surveys allowed for many *ad libitum* behavioural observations of forest red-tailed cockatoos indicative of breeding. In all three study areas juvenile birds were encountered frequently, easily recognised by their submissive behaviour and incessant begging calls that could be heard from far away. Furthermore, male courtship displays were observed in all three areas, especially in October. The conspicuous courtship displays of the forest red-tailed cockatoo, accompanied by a distinct call, are performed by the male only and always in the vicinity of a nest tree (R. Johnstone & T. Kirkby *pers. comm.* March 2008). The frequent observations of breeding behaviour indicate that forest red-tailed cockatoos were breeding successfully in all three study areas.

In conclusion, the forest red-tailed cockatoo appears capable of persisting in modified landscapes of various forms. However, it is important to realize that even in the direct vicinity of the transects, both of the modified landscapes still contained between 60-70% native forest. Forest red-tailed cockatoos are highly dependent on native forest for food, nest trees and roost trees. A reduction in forest cover in any of

the study areas is likely to have negative effects on the taxon, given that it has disappeared from parts of its former range where forests and woodlands were cleared extensively.

3.4.3 Distribution and abundance of Baudin's cockatoos

Baudin's cockatoo was most numerous in the Pickering Brook study area, which had the highest proportion of orchards. The proportion of orchards in this area was especially high in the vicinity of the transects, where this land use type occupied 17% of the area within 100 m from the road. Given the known tendency Baudin's cockatoo to feed on the seeds and juice of apples (Chapman 2007), the large number apple orchards in Pickering Brook is a likely explanation for their high abundance in this area.

With the exception of one or two individual records (Johnstone & Kirkby 2008), Baudin's cockatoos do not breed in the study areas. Instead, their stronghold of breeding is in the southern jarrah forest (Higgins 1999). The literature reports large seasonal movements with birds moving into the area where the study sites were located after they have finished breeding (Johnstone & Storr 1998, Saunders 1974b). The gradual build-up in numbers over April, which peaked in June, most likely reflected this seasonal migration. The peak manifested itself almost exclusively in Pickering Brook and only in the months when apples were ready for harvesting, which further supports the importance of apples for this species.

In regression analyses based data from on all three areas together, the presence of Baudin's cockatoo showed a positive response to orchards and to a lesser extent also to other. The category other includes a variety of land uses, such as large water bodies, houses, sheds, roads, small dams and bare ground, all of which are often associated with orchards. Hence, a positive response to other may actually have been due to a response to orchards instead. Analyses on abundance of Baudin's cockatoos did not yield any meaningful models, as all variables entered into the analyses were also present in the set of most plausible models.

Interestingly, in presence models constructed with data for the Pickering Brook area alone, the response to the orchard was weak, while abundance models for Baudin's cockatoo in Pickering Brook did not show clear effects of any of the land use variables. Hence, the distribution of Baudin's cockatoo in the Pickering Brook area appeared unaffected by any of the land use variables recorded.

In conclusion, the most plausible models for all areas together support the view that orchards are an important factor for Baudin's cockatoos when selecting between study areas. However, models for Pickering Brook alone suggest that once present within an area with abundant orchards, bird distribution patterns are unrelated to the distribution patterns of land use types.

3.4.4 Distribution and abundance of Carnaby's cockatoos

Throughout the year Carnaby's cockatoos were recorded in low numbers in all three study areas. Although based on a small number of observations, this pattern does not seem to agree with pre- and post-breeding movements reported for this species (Saunders 1974a, Higgins 1999, Johnstone & Storr 1998). However, the available literature on seasonal movements of Carnaby's cockatoo is based on data collected one or more decades ago. The observation that at least some birds may have year-round residents supports the view that Carnaby's cockatoo is shifting its distribution south-westwards and matches with evidence that it is currently breeding much closer to the study areas than it did thirty years ago (Johnstone & Cassarchis 2003, 2004, 2005). However, individual birds were not marked, nor were groups followed around throughout the day, so it was not possible to determine whether the cockatoos seen over the different study months were the same individuals, and whether they were indeed breeding nearby.

Only low numbers of Carnaby's cockatoo were recorded throughout the year. Carnaby's cockatoo is a species of the woodlands (Saunders & Ingram 1995, Abbott 2001) and as such the study areas may well have contained too much forest to the liking of this species. Another factor may be the low proportion of pine in each of the study areas, which has become a major food source for this species (Saunders 1974a, 1974b, 1980).

3.4.5 Conclusions

Understanding a landscape requires information on the broader region and on the finer scale local ecosystems (Forman 1995). Indeed, for both the forest red-tailed cockatoo and Baudin's cockatoo the full picture only emerged when the results from

both combined (regional) and separate (per landscape) analyses on the study areas were considered together.

On the larger, regional scale, the forest red-tailed cockatoo appeared to perceive all three areas as similar, but exercised selection on a finer scale, i.e. against young revegetation. For Baudin's cockatoo this seemed to be reversed. On the regional scale the birds selected strongly in favour of areas containing orchards but once there their distribution patterns appeared random.

The difference between how the forest red-tailed cockatoo and Baudin's cockatoo selected between and within landscapes was probably due to the different demands they placed on the study areas, and possibly also to differences in the detail of spatial knowledge they were able to obtain of the study region and the landscapes within.

Baudin's cockatoo arrived in the study areas after breeding and was primarily concerned with finding enough food (Saunders 1974b, Johnstone & Storr 1998). Given that the species in the post-breeding season tends to forage in large flocks, the food source must not only be large but also sufficiently concentrated (clumped) to be exploited by many birds simultaneously. The Pickering Brook area, offering a mix of abundant apples and marri fruits, fit this description very well.

Forest red-tailed cockatoos on the other hand are much more sedentary and for them the study areas formed their home range throughout the year. This means that in order to support a population of forest red-tailed cockatoos, an area should offer a stable year-round food source and also provide sufficient nest trees. The fact that behaviour indicative of breeding was observed in all study area, including courtship displays typically performed near a nest hollow, suggests that nest trees were available in all areas. Marri and jarrah trees, the main food species for this taxon (Johnstone & Kirkby 1999), were also present in abundance in all three areas.

A second explanation of the difference in habitat selection patterns between the forest red-tailed cockatoo and Baudin's cockatoo may be that both taxa have different abilities to learn about and remember details of the foraging habitat in the study region. The forest red-tailed cockatoo, like the glossy cockatoo (Crowley & Garnett 2001), is believed to have detailed knowledge of its foraging habitat (Johnstone & Kirkby 1999). Given that individual birds of this taxon are resident year round, they are in the position to learn and keep track of where sources of drinking water and high quality feeding areas are located as well as the stage of fruit ripening. Foraging time is determined by both handling time and search time

(Benkman 1987, Shuman *et al.* 1990) and being able to remember where the high quality food sources are, or are likely to be in the near future, can greatly improve foraging efficiency (Searle *et al*. 2006).

Baudin's cockatoo, in contrast, arrives after the breeding season. Although individual birds may have visited the same areas in earlier years, the quality of their spatial knowledge would undoubtedly be lower than that of the resident forest red-tailed cockatoos, while they also lacked the opportunity to keep track of the fruiting stages of localised food sources. Hence, Baudin's cockatoo probably requires a food source that is not only abundant but also predictable from one year to the next.

Given the different opportunities of both taxa to acquire spatial knowledge of food resources in a landscape, it is likely that to the forest red-tailed cockatoo the landscape is predictable on a much smaller spatial and temporal scale than for Baudin's cockatoo. In other words, the forest red-tailed cockatoo may be able to predict food availability at the patch scale, while Baudin's cockatoo can only predict this on the landscape scale. This may explain why Baudin's cockatoo appeared clumped in the same orchard-rich area, while the forest red-tailed cockatoo was able to spread out over and within all three study areas.

The forest variable did not appear as a strong predictor in any of the models for the forest red-tailed cockatoo, while the response of Baudin's cockatoo to forest was ambivalent and weak. These findings conflict with the knowledge that both species are highly dependent on native forest (Higgins 1999, Johnstone & Storr 1998). There are several possible explanations for this.

First, the forest variable may have been too course-grained and the distribution of black cockatoos was in fact driven by variability in quality within the original forest variable (Trzcinski *et al.* 1999, Westphal *et al.* 2003). Within-forest variability that might affect cockatoo distribution could be patchy distribution of food species other than eucalypts such as banksias (*Banksia* spp.) and Fraser's sheoak (*Allocasuarina fraseriana*), differences in fruit crop quality between individual eucalypt trees, or availability of drinking water.

Since all cockatoos need to drink at least once a day (Cameron 2007) the locations of water sources may have influenced the distribution patterns of black cockatoos recorded in this study. However, as addressed earlier (Chapter 1, Section 1.4), sources of drinking water tend to be ephemeral and hard to map in detail over areas as large as those used in this study. Without knowledge on the location of water sources and their availability year-round, the effect of drinking water on

between- and within-landscape distribution patterns of black cockatoos cannot be determined.

A second explanation for not finding an effect of forest on the presence and abundance of black cockatoos may be that the birds have a daily foraging range large enough to encompass all available land use types. A study on the performance of models for a large number of bird species showed that model accuracy is reduced for species with a large range or species that are able to utilise a broad range of habitat types (McPherson & Jetz 2007). Because large ranges generally include a wider variety of land use types (Pulliam *et al.* 1992), the effects of mobility and versatility cannot easily be distinguished.

For the forest red-tailed cockatoo, data on land use types in the vicinity of observation points do not suggest that the birds were making extensive use of any of the modified land use types, with the association with pasture most likely due to the birds feeding in edge trees bordering pasture. However, similar analyses could not be performed for the other two taxa due to limited number of observation points.

More detailed studies are needed to determine distribution patterns at a finer scale and identify whether and how the black cockatoos utilise (or avoid) other modified land use types. In this study, a limited exploration of finer scale utilisation of land use types by black cockatoos was possible in the form of direct and indirect records of feeding behaviour for all three taxa. This very basic dataset was analysed and the results are described in the following chapter (Chapter 4). Nonetheless, even though regression analysis in this study could only examine broad scale interactions between black cockatoos and their landscape, clear responses to particular land use types still emerged.

A small aspect of within-forest variability, namely a possible difference in fruit crop quality between individual marri trees, was investigated in another part of this study and will be discussed in a later chapter (Chapter 5).

Despite the *caveats* mentioned above, this study identified how two of the three taxa under study use their landscape and make selections at very large scales indeed. For Baudin's cockatoo the response was only apparent at the largest possible scale, when examining all three areas together. Any small scale habitat study would not have been able to identify this pattern. Pragmatically, within the scope of a MSc project one has to make the choice between detailed studies in a small area, and coarse-grained studies in a larger area, with the risk of missing

some important details. With respect to this study, choosing the latter option appears well justified.

Chapter 4 – Feeding Observations

4.1 Introduction

Black cockatoos have a specialised diet and leave distinctive feeding signs such as discarded eucalypt fruits with species-specific bill markings (Saunders 1974b), chewed off twigs and leaves (Saunders 1974a) and "grubbing trails" in the bark of a tree (Johnstone & Kirkby 1999, Cameron & Cunningham 2006).

These feeding traces or "chewings" (*cf.* Joseph 1982) allow one to record food choice and locate foraging areas and also form indirect evidence of species presence and abundance (Bibby *et al.* 2000, Cameron & Cunningham 2006, Saunders 1974a). Chewings offer a time efficient means of gathering a large amount of information on foraging behaviour of black cockatoos, which can supplement feeding observations. Given that flocks of black cockatoos may fly distances of up to 4 or 5 km from their roost sites to their foraging locations (Johnstone & Kirkby 1999), following flocks around through the landscape is very time consuming and often frustrating as it is remarkably easy to "lose 200 cockatoos" (T. Kirkby *pers. comm.* June 2007).

The northern jarrah forest, situated south-east of Perth (McKenzie *et al.* 2003), is an important foraging habitat for three taxa of black cockatoo; the forest red-tailed cockatoo (*Calyptorhynchus banksii naso*), Baudin's cockatoo (*C. baudinii*) and Carnaby's cockatoo (*C. latirostris*) (Higgins 1999). All are endemic to south-west Western Australia. The forest red-tailed cockatoo is present in the northern jarrah forest year-round, while the other two visit the area in large flocks during the non breeding season (Johnstone & Storr 1998, Saunders 1974b, 1980).

The forest red-tailed cockatoo feeds primarily on eucalypt seeds. The seeds of marri (*Corymbia calophylla*) form a major component of the diet as fruits of this species are available year-round (Johnstone & Storr 1998, Higgins 1999, Johnstone & Kirkby 1999,). Studies on foraging behaviour report that the seeds of jarrah *(Eucalyptus marginata*) and other native species become important in March and June when marri is less abundant (Johnstone & Kirkby 1999). Forest red-tailed cockatoos also feed on the introduced cape lilac (*Melia azedarach*) (Johnstone & Kirkby 1999, Stranger 1999).

Baudin's cockatoo is also a forest-dependent species whose main food is the seeds of marri (Saunders 1974b). The species breeds in the southern jarrah forest

(Higgins 1999, Johnstone & Storr 1998). Outside the breeding season, from January to July, Baudin's cockatoos congregate in large flocks and move north-east searching for food (Johnstone & Storr 1998, Saunders 1974b). During this period they come within range of commercial fruit orchards, where they feed on the seeds and juices of apples (*Malus domestica*) and pears (*Pyrus communis*) although they also continue to feed on marri (Saunders 1974b, Chapman & Massam 2005, Chapman 2007a) and are occasionally reported to feed on pine (*Pinus* spp.) (Johnstone & Cassarchis 2005).

Carnaby's cockatoo breeds in the wheatbelt east and north-east of the northern jarrah forest, in remnants of its original woodland habitat (Johnstone & Storr 1998). In the breeding areas it feeds almost exclusively on the seeds of native vegetation, primarily proteaceous scrubs and heath and marri (Saunders 1974a, 1974b, 1980, 1986, Johnstone & Storr 1998). At the end of the breeding season, birds move south-west towards the coast to feed in pine plantations around metropolitan Perth. The main pine species planted are *Pinus pinaster* and *P. radiata* (Saunders 1974a). Numbers of Carnaby's cockatoo in pine plantations increase from December onwards and decrease after July (Saunders 1974a, 1980). Crop content studies have shown that during this time pine seed is the main food item consumed by Carnaby's cockatoo (Saunders 1974a).

This chapter describes opportunistic feeding observations as well as systematic records of chewings found on the roads during a 2007 year-round study on distribution patterns of black cockatoos in the northern jarrah forest south-east of Perth. These records serve to complement the results obtained from regression analyses on habitat use by black cockatoos (Chapter 3) and provide an opportunity to check modelling predictions against observed foraging patterns. The aims of the study were: (1) to compare observed foraging patterns with those reported in the literature and (2) to compare presence and abundance data obtained from chewings with those obtained from direct bird counts.

4.2 Methods

Data on foraging behaviour and chewings was collected during transect surveys conducted in three study areas, Pickering Brook, Wungong and Karnet. Additional data on feeding behaviour was recorded by taking notes whenever foraging birds were encountered within 5 km from the nearest transect. These incidental observations were used to supplement the list of food species consumed by each taxon, but were not included in any statistical analyses.

The study areas were selected for containing different combinations of the most common land use types. Pickering Brook had a mixture of native forest, orchards and paddocks, Wungong contained native forest and post mining revegetation of various ages while the Karnet area contained a large amount of native forest as well as pasture and some revegetation (Chapter 3, Figures 3.1, 3.2, 3.3). Transect surveys took place every second month, from February until December 2007, over a total of six survey periods. In each survey period all transects were searched three times, yielding a monthly survey effort of 271.5 km of transect over a period of nine days. Detailed descriptions of the study areas and the transect methodology are given in chapters 2 and 3, respectively.

In each survey period only fresh chewings, i.e. those that had been produced in the month preceding the survey were recorded. Fresh chewings could be recognized by the colour of discarded fruits and the presence of fresh leaves. Double counting of chewings was avoided by comparing chewings found with those recorded in previous survey periods, or recorded earlier in the same survey period. To achieve this, detailed records of location and number of chewings were made and these records were taken into the field during subsequent surveys.

Identity of the bird taxon that had produced the chewings was established by examining species-specific bill marks (Figure 4.1). Not all feeding traces could be assigned to a particular taxon. Feeding on eucalypt flowers looked similar for parrot and cockatoo species alike. In addition, both Baudin's and Carnaby's cockatoo feed on pine cones (Johnstone & Cassarchis 2005), and the discarded cones were indistinguishable. Grubbing traces in the bark of trees could also not be distinguished due to lack of experience at the start of the study, and limited time to observe grubbing behaviour in detail. When birds were seen chewing the bark off branches in the canopy, it was not clear whether they were in search of invertebrates or whether the chewing served beak maintenance (e.g. Higgins 1999). These results have been omitted from the feeding records.
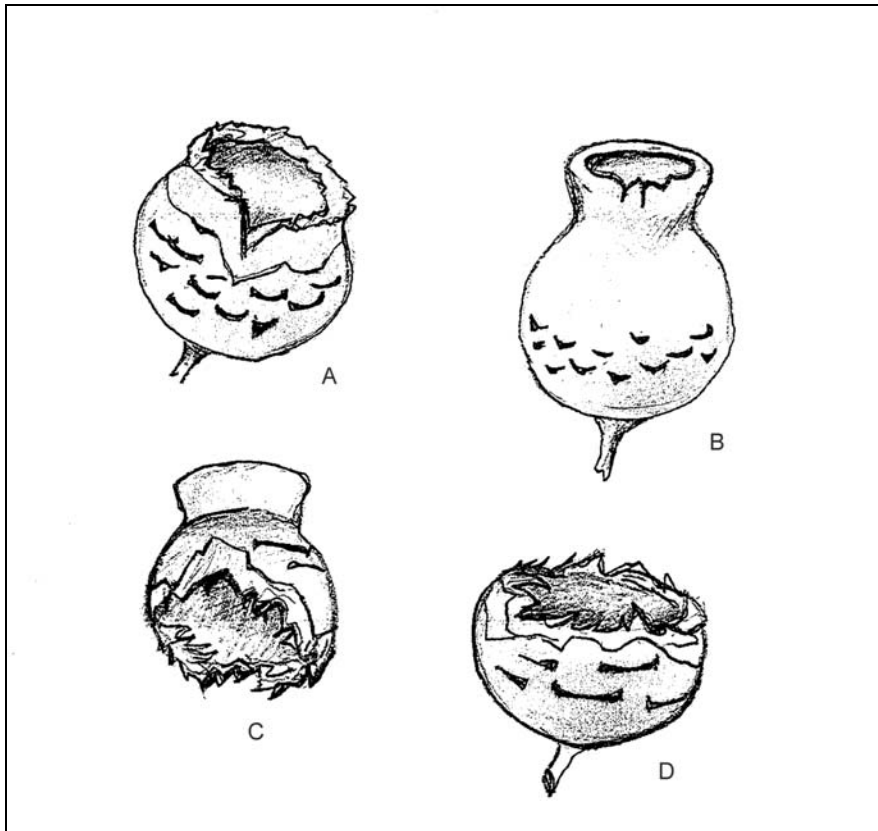
Figure 4.1 – Chewings on marri fruits by (A) Carnaby's Cockatoo, (B) Baudin's Cockatoo, (C) forest red-tailed cockatoo "bottom entry type", (D) forest red-tailed cockatoo "top entry type".

Carnaby's cockatoo: Rim of fruit partially and often completely removed. Indentations from lower mandible 6-7 mm wide. Often many indentations all over the fruit, indicating many bites needed to access seeds.

Baudin's cockatoo: No or very few damage to the rim. Indentations from lower mandible 4-5 mm wide and more triangular in shape than Carnaby's. Often only side of mandible used to place pressure so most indentations smaller than that. Most indentations near bottom of fruit.

Forest red-tailed cockatoo: Fruit severely damaged. Seeds accessed either from the bottom or from the top. Indentations from lower mandible 8-9 mm wide.

It is important to note that chewings were only recorded when they occurred on or directly next to the transect roads and that no active searches were made for them further away from the road. A second point is that the relative abundance of chewings from the various plant species was strongly dependent on the proximity of these species to the road. For instance bullich (*Eucalyptus megacarpa*) grows along creek lines while most transect roads ran parallel to creeks rather than crossing them, while pine blocks tended to be 10 m or more from the edge of the road. In addition, decay speeds for the various fruits differ. Chewings on marri could be found and readily identified to bird taxon at least one year after they were dropped on the road, whereas chewed cones of Fraser's sheoak (*Allocasuarina fraseriana*) disappeared very rapidly.

Given that each transect was visited only three days in each survey period, and that survey periods were two months apart, no conclusions on the size of feeding flocks could be drawn from the abundance of chewings. Marri fruits dropped on the road change colour over the course of about one week; hence the number of chewings produced by one pair of birds feeding in a tree for several days looked similar to those produced by a large flock feeding in the same tree for one hour.

However, the number of chewings counted in a particular location over the three monthly survey days did give an indication of feeding activity (usage) of that location per study period (Bibby *et al.* 2000). Similarly, counts of cockatoos seen during the transect surveys also reflected monthly bird activity rather than absolute abundance (Chapter 3). This is because cockatoos could not be identified individually. Therefore, one pair seen on each of the three days in a survey period (i.e. very actively foraging near the transects) was counted three times and thus contributed as much to the figure of monthly bird activity (abundance) as a less active group of six cockatoos. For this reason, estimates of bird activity based on either chewing abundance or bird counts were deemed to be very comparable.

The degree to which the number of chewings found in each study area per month predicted the number of birds counted in that area in the same month was tested using linear regression. Chewing counts were entered as the independent (predictor) variable and bird counts as the dependent (response) variable. Statistical analyses were conducted in SPSS for Windows version 14.0 (SPSS Inc. 2006).

Data on foraging behaviour and chewings were combined into a record of feeding events. A feeding event was defined as either an observation of one or more birds feeding in a particular location on a particular day, or each time when fresh

chewings were found on the road. To avoid double counting, all instances where chewings were found while the feeding bird(s) were still present were excluded from the combined record. Although information on foraging flock size and abundance of chewings was lost in this figure, it allowed records on feeding observations and chewings to be combined in order to paint a more complete picture of feeding frequency in a particular month and the range of food items taken by each taxon. The above mentioned limitations make clear that the foraging data collected *ad libitum* during transect surveys may not paint the full picture of all foraging behaviour by black cockatoos that occurred in the study areas in 2007. These limitations are recognized when discussing the results.

4.3 Results

A total of 13 different plant species fed on by black cockatoos were recorded over the whole 2007 study year (Table 4.1). Some additional food species could not be identified, primarily because feeding events on non native species often occurred on private land and because the survey protocol dictated that birds should not be approached so closely that this would cause disturbance.

Most feeding events involved forest red-tailed cockatoos, which were encountered more frequently than the other two taxa (Chapter 3). Feeding on the nectar of marri flowers was recorded in February in all study areas, but nearly always in the form of chewed off flowers on the road which could not be identified to bird species. Only once was nectar feeding observed directly, involving a small group of forest red-tailed cockatoos. This one record was included in the total number of feeding events on marri.

Pine cones that had been fed on by either Baudin's or Carnaby's cockatoo were discovered on or near the transect road on 11 occasions. Most pine cones were first found in the first survey period in February and did not change much in appearance over the course of the study year. For this reason it cannot be presumed that the cones found in February had been dropped in that month or perhaps many months earlier.

Table 4.1 – Number of feeding events by black cockatoos over the whole 2007 study year. Figures represent combined counts of all instances a flock was observed feeding on a food type and each time newly opened fruits were found on the road. First number is total feeding events over all three areas; individual counts for respectively Pickering Brook, Wungong and Karnet are shown between brackets.

Plant species	Forest red-tailed cockatoo	Baudin's cockatoo	Carnaby's cockatoo
Marri *Corymbia calophylla*	221 * (85, 47, 89)	108 (72, 16, 20)	1 (0, 0, 1)
Jarrah *Eucalyptus marginata*	76 (11, 53, 12)	1 (0, 1, 0)	4 (2, 2, 0)
Bullich *E. megacarpa*	12 (0, 1, 11)		
Blackbutt *E. patens*	2 (0, 0, 2)		
Bull banksia *Banksia grandis*			1 (0, 0, 1)
Parrot bush *Dryandra sessilis*	1 (1, 0, 0)		
Fraser's sheoak *Allocasuarina fraseriana*	13 (4, 5, 4)		
Snottygobble *Persoonia longifolia*	1 (0, 1, 0)		
European oak *Quercus* spp.		2 (0, 2, 0)	
Cape lilac *Melia azedarach*	2 (2, 0, 0)		
Apple *Malus domestica*		1 (1, 0, 0)	
Pine *Pinus* spp.		6 (4, 2, 0)	9 (4, 5, 0)
Cape weed *Arctotheca calendula*			1 (0, 0, 1)

* This figure includes one instance of forest red-tailed cockatoos feeding on marri flowers, all other feeding events concern feeding on marri seeds.

Black cockatoos were recorded drinking water from three different sources. On two occasions, in February and in April, forest red-tailed cockatoos drank from a puddle on the road after a night of heavy rains. This was during the day and involved only 4 and 6 birds. All other observations of drinking birds were at the end of the day, and involved groups of birds congregating around a water source. In April a group of 29 Baudin's cockatoos drank from a water trough in a paddock in Pickering Brook and similar behaviour was recorded in a paddock in Karnet in October, involving 10 birds. In Wungong, one particular creek in an area of mature native forest attracted individuals of all three taxa. Forest red-tailed cockatoos and Carnaby's cockatoos were recorded drinking from this creek or sitting in trees lining the creek throughout the year while Baudin's cockatoo was seen there in June. In April a flock of 33 forest red-tailed cockatoos gathered at the creek to drink, and this was the largest foraging

flock recorded for this taxon over the entire study year. If the survey protocol had allowed staying longer, the final group count would probably have been even greater.

The average size of a foraging flock of forest red-tailed cockatoos was 6 ± 0.4 birds (*n* = 152 feeding flocks), with group size ranging from one to 33 birds. In contrast, Baudin's and Carnaby's cockatoo often appeared in large flocks. The average size of a foraging flock of Baudin's cockatoos was 27 ± 8 (*n* = 30 feeding flocks), ranging from one to 200 birds. Carnaby's cockatoo had an average group size of 19 ± 5 birds (*n* = 15 feeding flocks), ranging from two to 60 birds. These figures were calculated over feeding flocks only, and did not include group counts of birds that were not feeding.

4.3.1 Feeding records of forest red-tailed cockatoo

Forest red-tailed cockatoos fed on marri throughout the year in all three study areas. Marri seeds were the most commonly consumed food item, with 67% of all feeding events being on this species, while jarrah, Fraser's sheoak and bullich seeds featured in respectively 23, 4 and 4% of all feeding events (Table 4.1).

In February and June groups of respectively 12 and 8 forest red-tailed cockatoos fed in cape lilac trees in two private gardens in Pickering Brook. The trees grew about 10 m away from the road and therefore no chewings were recorded. In addition a few feeding events were observed on blackbutt (*Eucalyptus patens*), parrot bush (*Dryandra sessilis*) and snottygobble (*Persoonia longifolia*) but none of these individual plants grew close to the road.

In all three study areas, the frequency of feeding events on the one hand, and the abundance of chewings on the other painted slightly different pictures of feeding activity and species fed on.

The difference was only minor for Pickering Brook. Marri and to a lesser degree jarrah were fed on most frequently (Figure 4.2) and this was reflected in the number of chewings found (Figure 4.3). Based on chewings alone it would appear that marri and jarrah were the only species fed on in Pickering Brook while records of feeding events show that sheoak was fed on throughout the first half of the study year. Furthermore, no chewings were found in August, while some feeding events (observations) were recorded in Pickering Brook for that month.
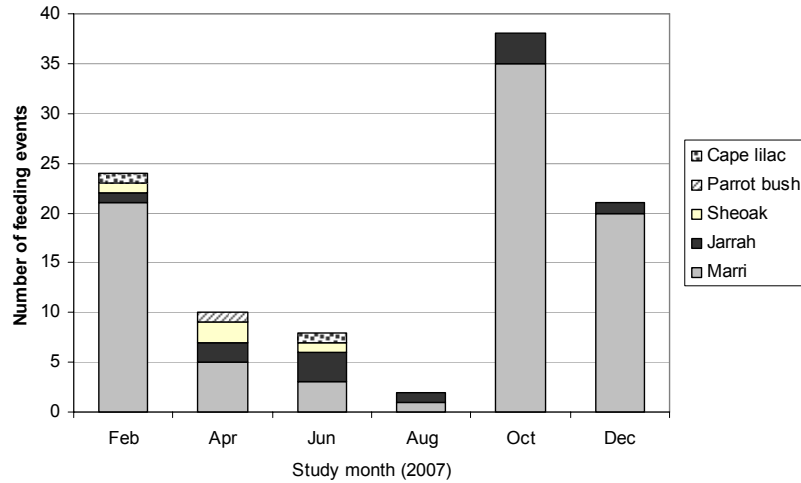
Figure 4.2 – Pickering Brook: Number of feeding events by forest red-tailed cockatoos on marri, jarrah, sheoak, parrot bush and cape lilac recorded in each study month in 2007. Figures represent combined counts of all instances a flock was observed feeding on a particular food type and each time newly opened fruits were found on the road.
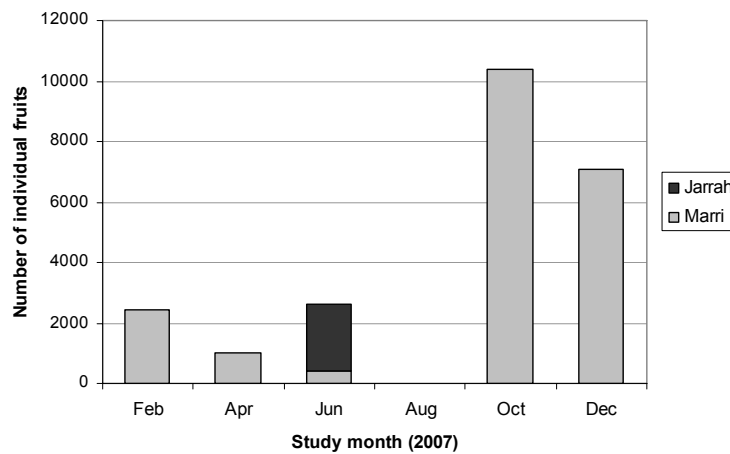
Figure 4.3 – Pickering Brook: Number of opened fruits dropped by forest red-tailed cockatoos on transects in each study month in 2007.

In Wungong jarrah appeared to be as important a food item to forest red-tailed cockatoos as marri. Especially in April and June, jarrah was the most frequently utilised food species (Figure 4.4) and was also the species for which the most chewings were found (Figure 4.5).

Forest red-tailed cockatoos were observed feeding on jarrah in every study period, but there were no chewings recorded of this food species in August and December. Similarly, some feeding on bullich was observed in December, but no chewings were found on the road.

The greatest discrepancy between feeding activity patterns suggested by feeding events (observation) and chewings data occurred in August. In this month the number of feeding events in Wungong was the second highest of all study months, but only very few chewings were recorded.
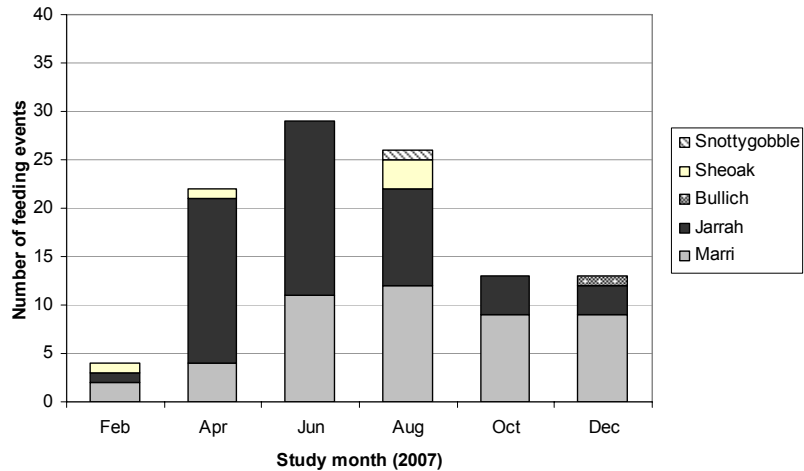
Figure 4.4 – Wungong: Number of feeding events by forest red-tailed cockatoos on marri, jarrah, bullich, sheoak and snottygobble recorded in each study month in 2007. Figures represent combined counts of all instances a flock was observed feeding on a particular food type and each time newly opened fruits were found on the road.
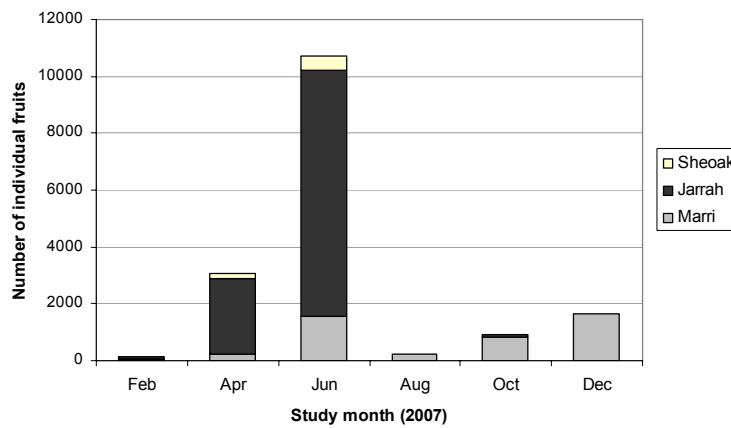
Figure 4.5 – Wungong: Number of opened fruits dropped by forest red-tailed cockatoos on transects in each study month in 2007.

In Karnet the number of feeding events was similar to the other study areas (Figure 4.6) but the amount of chewings was much lower, especially in February and April when fewer than 500 chewed fruits were found (Figure 4.7).

Nearly all chewings in Karnet were on marri, while a reasonable number of sheoak chewings appeared in June. Small numbers of bullich chewings were found in April, October and December. The frequency of feeding events on bullich was greater than suggested from the few discarded bullich fruits found. Forest red-tailed cockatoos in Wungong were seen feeding on blackbutt and jarrah, but no chewings of these tree species were found.
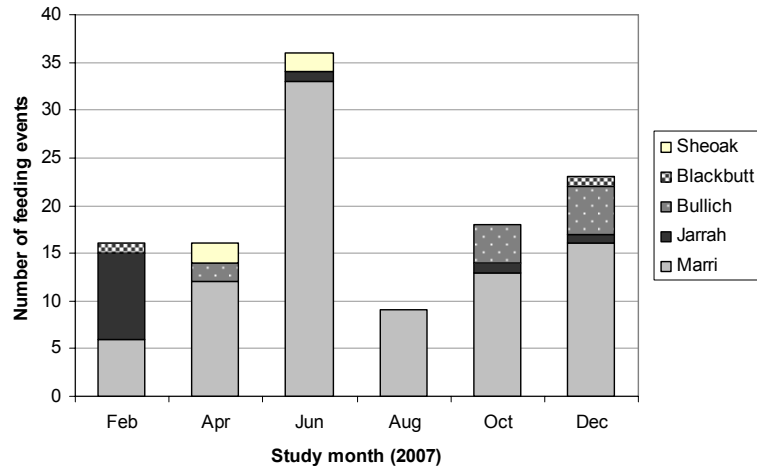
Figure 4.6 – Karnet: Number of feeding events by forest red-tailed cockatoos on marri, jarrah, bullich, blackbutt and sheoak recorded in each study month in 2007. Figures represent combined counts of all instances a flock was observed feeding on a particular food type and each time newly opened fruits were found on the road.
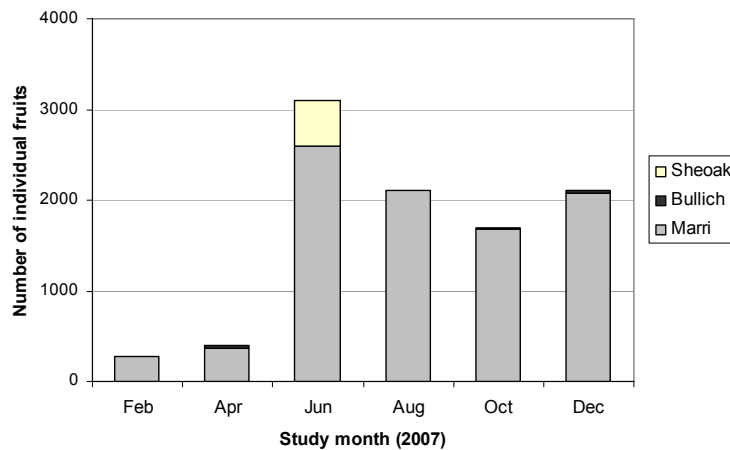
Figure 4.7 – Karnet: Number of opened fruits dropped by forest red-tailed cockatoos on transects in each study month in 2007. (Note: y-axis only one third as high as Figures 4.5 and 4.6)

In all study areas, more than half of all feeding events by forest red-tailed cockatoos were recorded where foraging birds were observed, often in pairs or flocks (Figure 4.8). Feeding observations always yielded more food species than suggested from chewings alone.
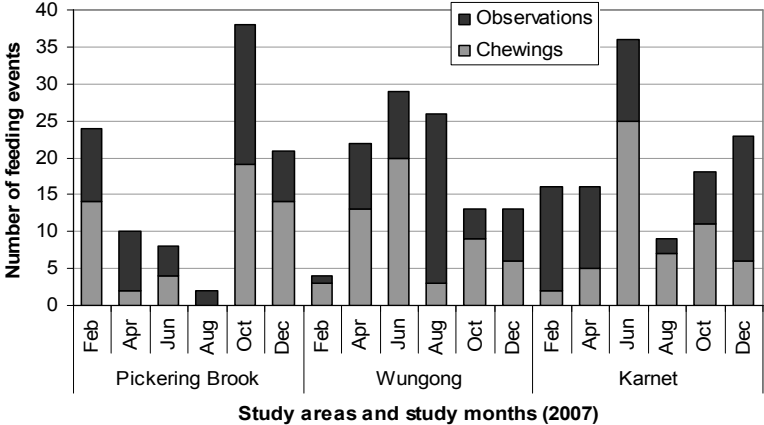
Figure 4.8 – Number of feeding events by forest red-tailed cockatoos in Pickering Brook, Wungong and Karnet that were either based on observations of foraging birds or on chewings found on the transect roads in each study month in 2007.

4.3.2 Feeding records of Baudin's cockatoo

Marri was the main food species for Baudin's cockatoo, with 92% of all feeding events recorded on marri seeds (Table 4.1). The greater majority of all feeding events over the whole study year occurred in Pickering Brook in June (Figure 4.9), which was also where and when the greatest abundance of marri chewings was found (Figure 4.10).
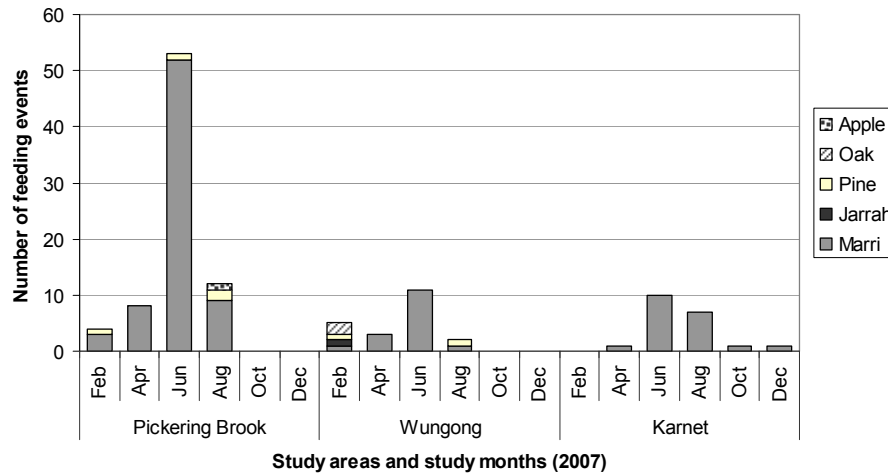
Figure 4.9 – Number of feeding events by Baudin's cockatoos in Pickering Brook, Wungong and Karnet in each study month in 2007.
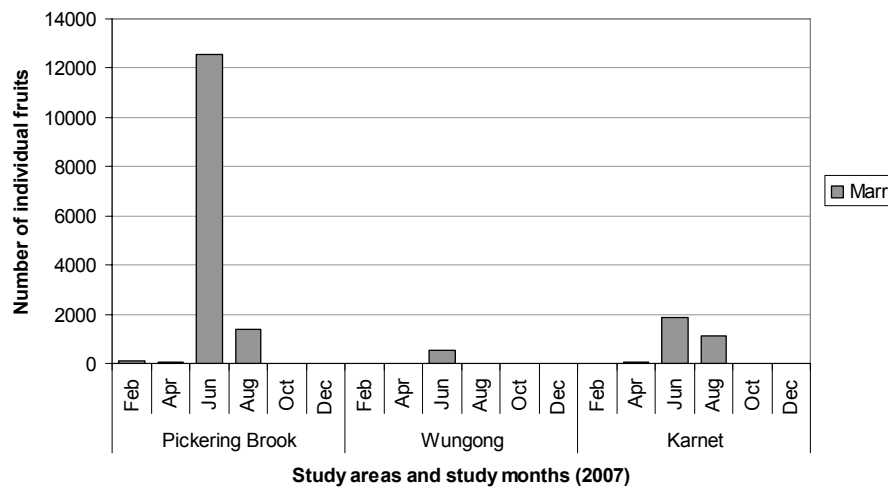
Figure 4.10 – Number of opened marri fruits dropped by Baudin's cockatoos on transects in Pickering Brook, Wungong and Karnet in each study month in 2007.

During the surveys, Baudin's cockatoo was never observed feeding in apple trees, despite the fact that the species was most abundant in June when the apples were ripe for harvest, and several orchardists mentioned in that month that groups of 100 or more birds had been feeding in their orchards at sunrise. However, since the survey protocol dictated that surveys should commence at least one hour after sunrise (see Chapter 3) none of these feeding events were recorded. Although no direct observations of feeding in apple trees were made, there were several instances when Baudin's cockatoo was seen feeding or sitting in marri trees on the edge of orchards. In June a group of at least 100 birds fed in marri trees adjacent to an orchard and on two other occasions groups of 14 and 35 cockatoos sat in trees next to an orchard but did not feed. In August after the apples had been harvested, 20 Baudin's cockatoos fed on fallen apples on the ground in an orchard early in the morning (Figure 4.8). Later that day another group of 24 birds flew out of an orchard into a group of marri trees on which they began to feed.

Pine seed was the second most frequently consumed food item for Baudin's cockatoo (Figure 4.9). The birds were recorded feeding in pine plantations on six occasions from February through to August. Each feeding event occurred in a different small pine block in both Pickering Brook and Wungong, nearly always in a mixed flock with Carnaby's cockatoo. The largest group of Baudin's cockatoos feeding on pine was recorded in February and involved at least 100 birds, while all other instances involved smaller groups of between two and 14 birds.

In February a group of 200 Baudin's cockatoos fed for several days on the fruits (acorns) of introduced European oak trees (*Quercus* sp.) in the town site of Jarrahdale. Since this occurred within 5 km from the nearest transect in the Wungong study area, these records have been included in the feeding events for Wungong (Table 4.1). This was the first time that feeding on acorns was ever recorded for Baudin's cockatoo (T. Kirkby *pers. comm*. February 2007).

4.3.3 Feeding records of Carnaby's cockatoo

Feeding observations on Carnaby's cockatoo were made throughout the year. Pine seeds were the most frequently consumed food (Table 4.1). The birds fed on pine from February through to August, utilising all the pine blocks present on or near the transects in Pickering Brook and Wungong. There were no pine blocks within 100 m from the transects in Karnet, so neither chewings nor feeding observations were

recorded in this area. The size of foraging flocks recorded in pine during the study varied from six to up to 60 birds, with the largest group size recorded twice in Wungong, once intermixed with 100 Baudin's cockatoos. Because pine plantations are dense and the birds feed high in the trees, the exact size of foraging flocks was hard to determine and could easily have been greater than 60.

Other food species taken by Carnaby's cockatoo were jarrah, marri and bull banksia (*Banksia grandis*). In February six birds fed on an unidentified berry crop in an orchard in Pickering Brook, across the road from a pine block which they also utilised. In October a group of 30 birds fed on grasses and herbs in paddocks in Pickering Brook. Because these paddocks were private property and survey protocol dictated that the birds should not be disturbed, the plant species could not be identified.

In the same month a group of 26 birds was recorded feeding on grasses and herbs including cape weed (*Arctotheca calendula*) in a paddock in Karnet. In December only one feeding observation was made, involving a pair of Carnaby's cockatoo feeding on jarrah in Pickering Brook.

4.3.4 Relationship between chewings and bird counts

For the forest red-tailed cockatoo the monthly number of chewings recorded in a study area only explained 24% of the variation in bird counts (number of birds = 108.663 + 0.013 * number of chewings, r^2 = 0.243, n = 18, p = 0.037) (Figure 4.11).

In contrast, monthly chewings abundance of Baudin's cockatoo per study area explained 79% of the variation in bird counts (number of birds = 30.344 + 0.035 x number of chewings, r^2 = 0.793, n = 18, p < 0.001). Because the abundance of both chewings and birds recorded in Pickering Brook in June was much higher than in any other study area and month (Figure 4.12), the analysis was conducted a second time with the June data for Pickering Brook removed. Without this data, monthly chewings abundance per study area explained only 6% of the variation in bird counts and the relationship was no longer significant (number of birds = 33.908 + 0.023 x number of chewings, r^2 = 0.056, n = 17, p = 0.362).

No analysis was conducted for Carnaby's cockatoo because there were no chewings that could reliably be assigned to this species.
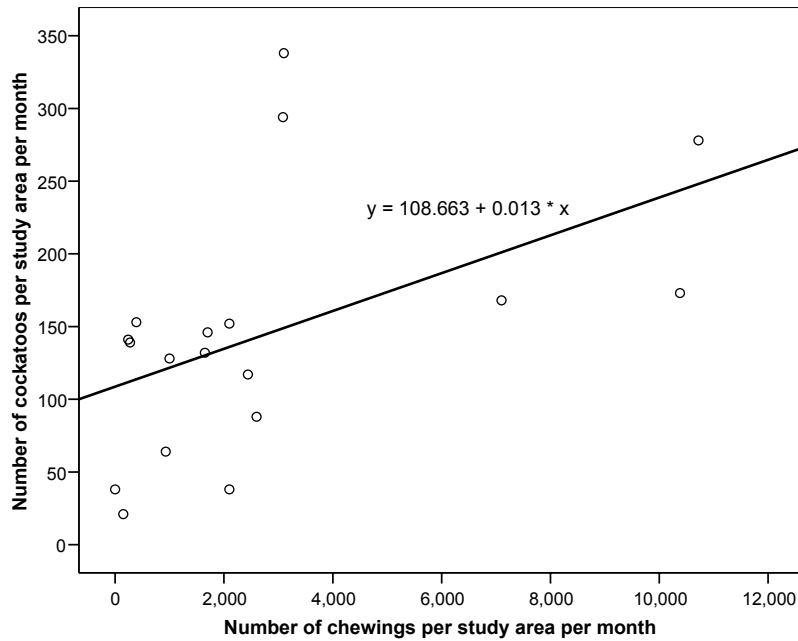
Figure 4.11 – The number of forest red-tailed cockatoos (y-axis) in relation to the number of chewings found on the road (x-axis) in each study area per month in 2007 (*n* = 18).
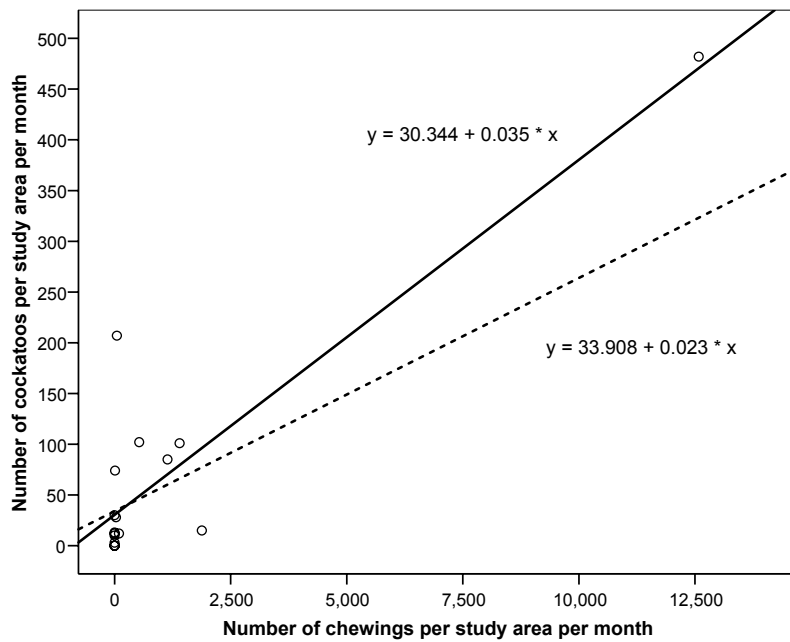
Figure 4.12 – The number of Baudin's cockatoos (y-axis) in relation to the number of chewings found on the road (x-axis) in each study area per month in 2007. Solid line shows regression line for all data (*n* = 18) while dotted line shows regression line for all data except Pickering Brook in June (*n* = 17).

4.4 Discussion

4.4.1 Do observed foraging patterns match with the literature?

The foraging behaviour of forest red-tailed cockatoos recorded in this study did not fully match year-round feeding patterns reported in an earlier published work on the feeding ecology of forest red-tailed cockatoos (Johnstone & Kirkby 1999). The earlier study reported that the birds made a switch around March and June from feeding predominantly on marri to feeding more intensely on jarrah and other native foods. With respect to jarrah, counts of chewings agreed with the earlier findings to a degree as the majority of jarrah chewings were found in April and June. However, feeding events on jarrah occurred throughout the year in all study areas and were especially frequent in Wungong. In this study area jarrah rather than marri appeared to be the dominant food item taken. Although in Wungong jarrah was most frequently consumed in April and June, which appears to fit with the earlier publication, jarrah was still fed on frequently in August and in this month featured in more than more than one third of all feeding events. In Karnet feeding events on jarrah were recorded most frequently in February rather than April or June. Feeding patterns on bullich also did not conform to the idea of a switch in March and June. Bullich featured in the diet of forest red-tailed cockatoos throughout the year and most especially in October and December. However, the paucity of records does not allow for strong conclusions to be drawn.

Forest red-tailed cockatoos fed on the seed of Fraser's sheoak from February through to August with the greatest number of chewings found in June. This observation does not agree with the earlier study which states that the seeds of sheoak are only abundantly available to forest red-tailed cockatoos in January and February (Johnstone & Kirkby 1999). Fraser's sheoak has a protracted flowering season (FloraBase 2007, Marchant *et al.* 1987) and is partially serotinous (Bellairs & Bell 1990). Hence, rather than a restricted availability of sheoak seeds to the first months of the year, fresh seeds should be available from November through to April, while at least part of the seed crop is retained on the trees over the rest of the year. The feeding observations in this study appear to fit this pattern.

The appearance of Baudin's cockatoo in the study areas from February onwards, with most birds disappearing again after August, concurs with the movement patterns reported for this species in the literature (Higgins 1999, Johnstone & Storr 1998, Saunders 1974b). Although the number of feeding events

and chewings peaked dramatically in Pickering Brook at the time the apples were being harvested in June, no birds were actually seen feeding on apple trees. Anecdotal evidence that the birds tended to feed in the orchards very early in the day, just after sunrise, is the most likely explanation for the lack of observations. When the birds began to arrive in February and probably earlier as well, the apple trees were still in bloom or carried only small unripe apples. It was in this month that the birds fed on the greatest variety of alternative food items including, unexpectedly, acorns from European oak trees. Feeding on acorns by Baudin's cockatoo has not been reported earlier and shows the ability of this species to learn to incorporate novel food items into its diet.

Like Baudin's cockatoo, the number of Carnaby's cockatoos present in the study areas was expected to increase from February onwards, with local abundance decreasing after July (Saunders 1974ab, 1980). However, the feeding observations made in this study, albeit sparse, did not suggest a noticeable increase or decrease in feeding activity by Carnaby's cockatoos over the year.

This finding appears to support observations that since the earlier studies were published the distribution of Carnaby's cockatoo has shifted considerably south-westwards (Johnstone & Storr 1998), with recent nests located as far south as Nannup (Johnstone & Cassarchis 2003, 2004, 2005). Hence, the birds encountered in this study, rather than being post-breeding migrants, may have been residents to the study areas (see Chapter 3).

The feeding data collected in this study supports the view that pine is an important food species for Carnaby's cockatoo (Saunders 1974a, 1980). The number of observations in pine is especially significant given the fact that Carnaby's cockatoo was only encountered 24 times over the whole study year (Chapter 3), of which 9 times it was recorded feeding in a pine block (Figure 4.13). The protracted period over which pine seeds were available, with feeding recorded from February through to August, indicates that pine forms a stable and reliable food source for Carnaby's cockatoo throughout the year. Given the low numbers of Carnaby's cockatoo present, and the fact that feeding traces on pine could not be identified to either species or month, it is possible that the birds continued feeding on pine after August, but this was not recorded. Future studies to quantify the importance of pine for Carnaby's cockatoo are urgently needed.
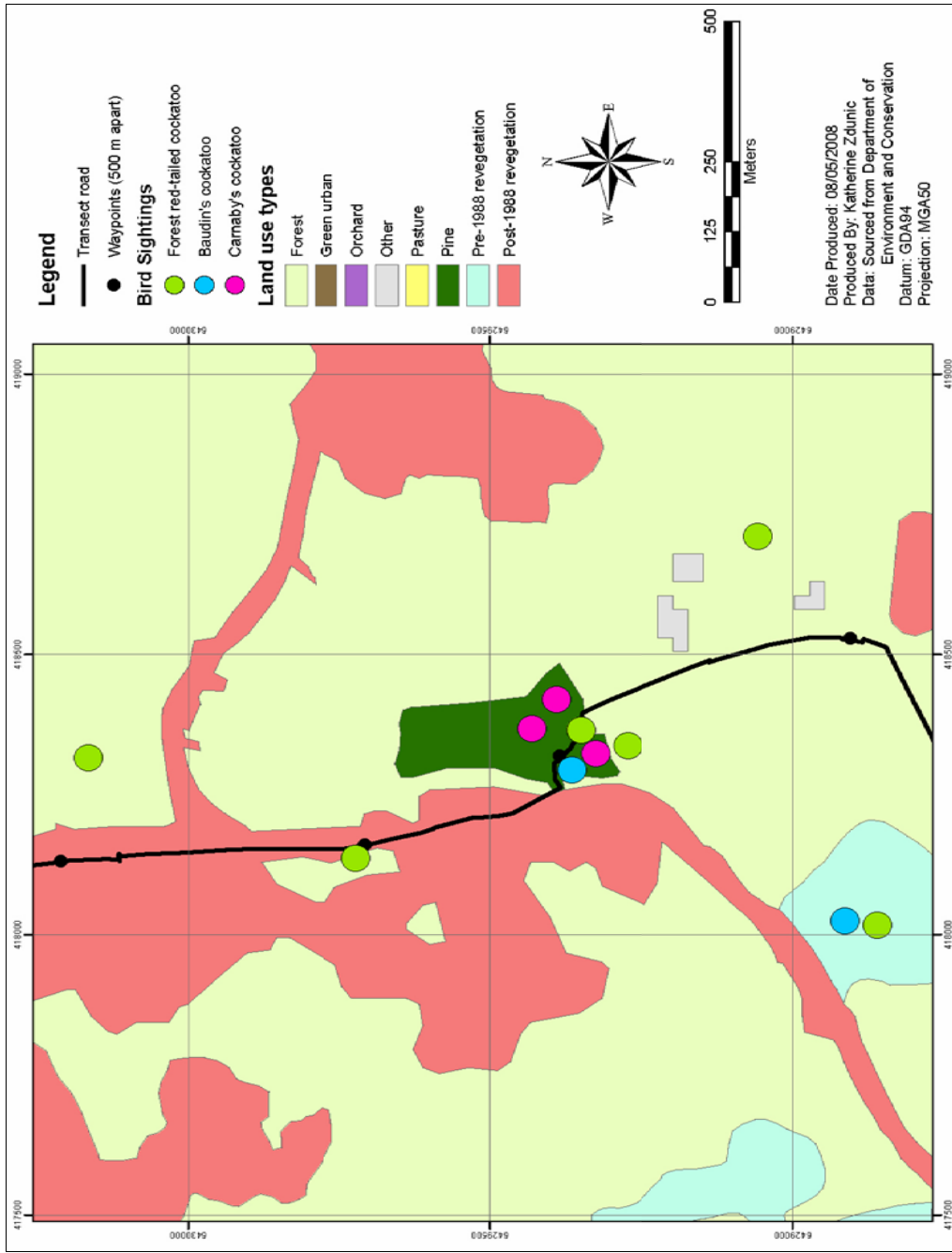
Figure 4.13 – Example of usage of pine blocks by Carnaby's and Baudin's cockatoo. Also shown is small group of forest red-tailed cockatoos utilising patch of native forest surrounded by post-1988 revegetation. (Location of close-up area is the centre of the Wungong study area, along the westernmost transect).

4.4.2 Comparisons between feeding data and bird observations

Comparisons of bird count data and the abundance of chewings suggest that both datasets can complement each other to paint a fuller picture of monthly bird activity in an area. For instance, although bad weather reduces movement and call rate of cockatoos (Johnstone & Kirkby 1999), this should not affect the number of chewings since the birds will continue feeding regardless of rain and wind (T. Kirkby *pers. comm.* June 2006).

The number of chewings found in a study area per month predicted 24% of the variation in the number of birds counted for the forest red-tailed cockatoo. Chewings data for forest red-tailed cockatoos suggested different monthly patterns of bird activity in each of the three study areas than those obtained from direct bird counts, although some matches can be found.

In Pickering Brook a peak in the abundance of marri chewings by forest red-tailed cockatoos in October and December (Figure 4.3) was not reflected in dramatically higher bird counts for these months compared to the rest of the year (Chapter 3, Figure 3.7). However, a drop in the number of forest red-tailed cockatoos counted in Pickering Brook in August did coincide with a complete absence of chewings for this month. In February about twice as many chewings were found in Pickering Brook compared to April, but this did not correspond with a clear difference in bird counts for these months.

In Wungong most forest red-tailed cockatoos were counted in April and June (Chapter 3, Figure 3.8), and these were also the months when the greatest number of chewings for this taxon was found (Figure 4.5). However, the number of chewings in June was very high even compared to April, and this was not matched by a similar peak in bird counts for this month. This finding could indicate that the actual number of forest red-tailed cockatoos in June was much higher than suggested by bird counts, hence that a great number of birds utilising the transect areas were somehow missed during the counts.

However, the fact that jarrah chewings made up 80% of the peak in June suggests that the actual increase in feeding activity may not have been as dramatic as the absolute chewings count suggests. This is because jarrah fruits are relatively small compared to marri fruits and cockatoos must open roughly six times as many jarrah fruits to gain the same amount of energy as they would when feeding on marri (Cooper *et al.* 2002, Johnstone & Kirkby 1999), thus creating six times as many

chewings. Records on the number of feeding events (Figure 4.4) indeed suggest a more modest peak in feeding activity in Wungong in June. In fact, the frequency of feeding events for all study areas appeared very similar to estimates of bird activity based on bird counts. However, since part of the feeding events data was based on observations of feeding birds, counts of which were also included in bird abundance data, this means that both datasets consisted of partially the same data. For this reason, comparisons between bird counts and feeding events are expected to yield a high match and would not offer any new information.

In Karnet the main difference between activity estimates based on counts or on chewings was a very low number of chewings found in February and April (Figure 4.7), while bird counts for those months suggest that bird activity in this month was not lower than in October and December (Chapter 3, Figure 3.9). In February and April, forest red-tailed cockatoos fed frequently on jarrah, and also on blackbutt, bullich and sheoak, species of which very few chewings appeared on the roads. This finding suggest that feeding in these months happened to occur quite often on trees and shrubs standing a little bit back from the road. Chewings from such non edge plants could not fall on the road and were therefore not recorded.

Bird counts in Karnet were much lower in August compared to the other months (Chapter 3, Figure 3.9), while chewings records did not suggest a drop in feeding activity. This may be due to the fact that August was a very cold and wet month. During bad weather cockatoos tend to be quieter and fly less (Johnstone & Kirkby 1999), which makes them less likely to be encountered or detected during surveys (see also Chapter 3). The fact that the number of chewings was the same between August, October and December strongly suggests that the low bird counts in August were due to reduced movements and call rates, rather than a reduction in the actual number of forest red-tailed cockatoos present in Karnet in that month.

For Baudin's cockatoo, the strength of the correlation between bird counts and chewings data depended entirely on the inclusion or exclusion of a single data point. In Pickering Brook both chewings abundance (Figure 4.10) and bird counts (Chapter 3, Figure 3.7) simultaneously peaked dramatically in the month of June. This peak had a strong influence on the correlation coefficient. Without this data point, monthly chewings abundance only explained 6% of the variation in bird counts and this relationship was not significant.

The difference between Baudin's cockatoo and the forest red-tailed cockatoo in the degree to which chewings data can predict variation in bird counts is probably

due to life-history differences between the taxa. Since the forest red-tailed cockatoo is relatively sedentary (Johnstone & Storr 1998), changes in both chewings records and bird abundance were mainly driven by variation in whether birds had been feeding next to a transect or further into the forest and where resident flocks happened to be relative to the transects during a survey. On the other hand, changes in abundance of Baudin's cockatoo were driven primarily by seasonal movements of birds into the study areas between February and June and back out between June and August (Higgins 1999, Johnstone & Storr 1998). Hence, between-month variation in chewings and bird counts for this species were due to a dramatic increase in the local population of Baudin's cockatoos in Pickering Brook.

Bird counts in Pickering Brook indicated that the number of Baudin's cockatoos present in April was approximately 40% as high as those recorded in June but this did not reflect in the abundance of marri chewings. Feeding observations in April show that the birds were feeding on marri, but the paucity of chewings suggests that most of the trees that were fed in stood away from the road.

In Wungong and Karnet the numbers of Baudin's cockatoos recorded were much lower than in Pickering Brook (Chapter 3, Figures 3.7, 3.8, 3.9) and this was reflected in a relatively low number of chewings for these areas (Figure 4.10). The greatest number of chewings in Karnet occurred in June but in this month only 15 individual cockatoos were encountered, compared to 85 birds seen in August when the number of chewings was much lower (Figure 4.10). In Wungong chewings were only found in June although birds were recorded from April through to August.

The discrepancies between bird counts and chewings records for Wungong and Karnet were probably due to the low number of Baudin's cockatoos present, combined with the fact that this species tends to forage in large groups. A reduction in the number of birds that can be encountered leads to a higher effect of chance on the actual bird numbers that will be counted. In addition, feeding in large, rather than small groups further reduces the encounter frequency because at similar absolute bird numbers, there will be less groups to encounter. When the frequency or likelihood of bird encounters is low, chewings data may actually provide a more reliable estimate of bird activity than observations, because chewings can accumulate over the course of a day or week, whereas bird encounters may be quite brief.

However, when absolute bird numbers are low, this also reduces the likelihood of finding chewings, as these can only be recorded when birds feed in trees next to

a road that happens to be selected as a transect route. Naturally, these trees make up only a minor percentage of all feeding trees available to the birds. Hence, at low population numbers, absence of chewings may not mean much at all. For instance, chewings data suggests that in Wungong no Baudin's cockatoos were present in August (Figure 4.3), while in fact 74 birds were counted in that month (Chapter 3, Figure 3.8), and the same occurred in Karnet October and December (Chapter 3, Figure 3.9).

Hence, when bird abundance is low, using a combination of count and chewings data to establish bird presence and activity is recommended. In order to better match both types of data, it may be desirable establish how many chewings one bird can produce per unit time. This may enable the development of conversion factors to gain a rough estimate of bird abundance based on changes in the number of chewings from one day to the next.

Over the whole 2007 study year no chewings were found that could indisputably be assigned to Carnaby's cockatoo. Hence, observation data only served to gain insight into the feeding behaviour of this species. The fact that pine blocks nearly always stood away from the roads meant that very few chewed pine cones were found. Given the low absolute abundance of Carnaby's cockatoo in the study areas, chewings collected during road transect were probably not a good way to establish activity patterns for this species.

4.4.3 Conclusions

Chewings records combined with feeding observations, provided a good indication of feeding activity and food items consumed by each taxon of black cockatoo throughout the study year. To an extent chewings abundance confirmed estimates of cockatoo abundance for both the forest red-tailed cockatoo and Baudin's cockatoo, although the match was better when bird abundance was high. No chewings were found for Carnaby's cockatoo, but observations of feeding flocks confirmed the importance of pine as a major food source for this species, forming a stable and reliable food source for most of the year.

Chapter 5 - Selective feeding by forest red-tailed cockatoos

5.1 Introduction

Optimal foraging theory predicts that animals forage in such a way that their rate of energy intake is maximised within a set of constraints such as predation, competition, requirements for specific nutrients or the necessity to perform other activities such as reproduction (Pyke *et al.* 1977). Selection of food items, i.e. what to forage on, constitutes the smallest hierarchical scale of habitat selection (Pyke *et al.* 1977, Johnson 1980, George & Zack 2001). This decision level fits in well with selection of where to forage, addressed in chapter 3, which is a higher scale of habitat selection.

Within their home range animals are expected to forage in patches with the most profitable food resources (Pyke *et al.* 1977, Cameron & Cunningham 2006) and the abundance of profitable patches is one of the factors determining where a home range can be established (Johnson 1980). However, food types within a patch may vary in profitability and animals can increase their foraging efficiency by discriminating between them (Christensen *et al*. 1991, Sallabanks 1993).

Food profitability has been the subject of many studies, with profitability often expressed as energy gain per unit handling time (Benkman 1987, 1989) or as the ratio between energy gained and energy invested to obtain the food (Crowley & Garnett 2001). However, animals also need to take in sufficient amounts of important nutrients (Pyke *et al.* 1977, Cooper *et al.* 2003). Studies from a wide range of species show that birds select between isocalorific (i.e. of similar calorific value) food items based on protein (Bosque & Calchib 2003, Valera *et al.* 2005), lipid (Stiles 1993, Lepczyk *et al.* 2000, Bairlein 2002, Xiao *et al.* 2006), or carbohydrate content (Schaefer *et al.* 2003a). However, not all studies support this view, finding instead that calorific value alone is the strongest factor driving food selection (Brodman *et al.* 1997) or that animals primarily select for food items which require the least handling time (Clark *et al.* 1986, Diaz 1996).

When animals choose between different food species (Benkman 1987, Cameron & Cunningham 2006) selectivity is obvious (cf. Maron & Lill 2004). However, profitability may also vary within a single food species, for instance between individual plants (Christensen *et al*. 1991, Summers & Proctor 1999) or between fruits on the same plant (Sallabanks 2003). Selection at such fine levels

may be particularly important for taxa with highly specialised diets (Pepper *et al.* 2000, Crowley & Garnett 2001, Maron & Lill 2004).

The forest red-tailed cockatoo (*Calyptorhynchus banksii naso*) can be considered a moderately specialised feeder. Its diet includes a variety of native food species (Johnstone & Storr 1998, Higgins 1999) but the seeds of marri (*Corymbia calophylla*) form the most important element of its diet (Saunders 1980, Saunders *et al.* 1985, Johnstone & Kirkby 1999). The tough woody fruits of marri are hard to open and the heavy bill of the taxon is believed be an adaptation to feeding on marri (Ford 1980). Despite the importance of marri to the forest red-tailed cockatoo and several other members of the Psittacidae (Robinson 1960, Long 1985, Higgins 1999), there are very few published studies describing the fruiting cycle of marri (Robinson 1960, Johnstone *et al.* 1999).

A complete cycle from flowering to dropping of seeds takes about 17 months (Johnstone & Kirkby 1999). A new fruit crop develops while last year's crop is still present and a tree often holds fruits of two different ages. Marri seeds are therefore available throughout the year, although the abundance varies significantly between years, driven by asynchronous mast flowering within the population (Robinson 1960, Johnstone & Kirkby 1999). Although the food quantity appears to be sufficient, it has been suggested that food quality may limit the number of forest red-tailed cockatoos capable of breeding (Johnstone & Kirkby 1999).

Forest red-tailed cockatoos are reported to have clear and consistent preferences for individual marri trees, termed "feed trees" (cf. Joseph 1982) to which they return for many days until the fruit crop is depleted (Johnstone & Kirkby 1999). Other trees nearby, termed "non-feed trees" remain untouched, despite having seemingly equally good fruit crops. This behaviour suggests that there may be differences in profitability between individual trees, possibly due to differences in seed quality (Johnstone & Kirkby 1999).

Consistent selection in favour of certain feed trees has also been recorded for glossy cockatoos (*Calyptorhynchus lathami*) and the south-eastern red-tailed cockatoo (*C. banksii graptogyne*). Like the forest red-tailed cockatoo, both taxa are specialised feeders (Higgins 1999). Glossy cockatoos feed almost exclusively on sheoak (*Allocasuarina* spp.) and appear to select trees with larger cone crops and more profitable cones (Clout 1989, Pepper *et al.* 2000, Crowley & Garnett 2001, Chapman & Paton 2005, Cameron & Cunningham 2006). The south-eastern red-tailed cockatoo depends heavily on buloke (*Allocasuarina luehmannii*) in summer

and early autumn and the birds select trees with more and heavier seeds per cone (Maron & Lill 2004).

Only one published study has addressed whether the reported selectivity in forest red-tailed cockatoos can also be related to morphological or chemical characteristics of marri trees and/or their fruits (Cooper *et al.* 2003). The results suggest that the birds select trees based on the energy yield in the fruits. Feed trees had fruits that were 10% larger than those from non-feed trees, had 25% more seeds per fruit and provided the birds with 34% more energy per fruit.

If there are indeed strong differences in profitability between individual marri trees and these are consistent from year to year, this implies that the jarrah forest consists of a mosaic of high and low quality trees. Glossy cockatoos concentrate their feeding efforts in areas where sheoak trees (*Allocasuarina* spp.) have the most profitable crop (Pepper 1997). Hence their distribution is believed to be limited not only by the availability of feeding habitat per se but also by the extent of highly profitable areas within that habitat (Pepper *et al.* 2000). For the conservation of the forest red-tailed cockatoo this suggests that recognizing high quality marri trees and possibly locating areas where such trees are abundant, is an important focus for management efforts.

Forest red-tailed cockatoos are reported to feed on both young green marri fruits and hard mature fruits (Johnstone & Kirkby 1999). Green fruits are softer and easier to open, which suggests that birds would require less handling time per fruit to extract the seeds. Similar to what is recorded for pine cones (Benkman 1987) seeds in green fruits may still be of low calorific value, which increases as they mature. For black cockatoos foraging on green fruits a lower energy gain per fruit may be compensated for the ability to process more fruits per unit time, leading to an overall similar profitability for young and mature fruits. To date, no studies have examined the correlation between fruit age and profitability in marri, while previous work on tree selection did not take fruit age into account (Cooper *et al.* 2003).

A study on seed development in two species of banksia showed that protein is loaded into the seed only in the last months before the cones harden, which may be defence strategy against seed predation by cockatoos (Stock *et al.* 1991). Given the high predation pressure on marri from forest red-tailed cockatoos and other birds, similar late loading of protein into seeds may occur. If this pattern exists, then cockatoos feeding on young green fruits would gain less protein than birds feeding

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on mature fruits. However, no published studies on nutrient loading in marri are currently available.

Selectivity for food quality is believed to be most important during the breeding season (Johnstone & Kirkby 1999). Indeed, studies on glossy cockatoos suggest that breeding birds are more selective than non breeding birds (Chapman & Paton 2005, 2006). Although these studies only focused on selectivity for calorific energy gain, sufficient uptake of protein and lipids may be especially important in the breeding season for the production of eggs (Ankney & Afton 1988) and development of growing nestlings (Valera *et al.* 2005).

This study aimed to determine whether there were morphological or nutritional differences between the fruits of marri trees that were fed in or ignored by forest red-tailed cockatoos. A second aspect of the study, which arose during fruit collection when fruits were found to belong to different age classes, was to compare the same characteristics between mature and young fruits to identify possible changes in profitability as fruits mature.

5.2 Methods

5.2.1 Collection of marri fruits

Since selectivity may be strongest in the breeding season, the study was conducted in November which co-insides with the period of egg laying and early chick rearing in forest red-tailed cockatoos (Saunders *et al.* 1985, Johnstone & Storr 1998, Higgins 1999, Johnstone *et al.* 2002).

For reasons of time management and human safety, trees were selected in the Karnet study area only. Of the three study areas, Karnet has the highest percentage of native forest and consequently the greatest number of mature marri trees, while levels of human activity are low.

Marri fruits were collected from 20 feed trees and 20 non-feed trees. Feed and non-feed trees were matched for size to ensure an equal representation of age classes in both groups. They were also matched for fruit crop abundance and shared a similar fire history. Tree size, measured as diameter at breast height (DBH) ranged from 40 cm to 335 cm. All trees carried a good fruit crop in the canopy

relative to tree size, ranging from a few hundred fruits in the smallest trees to several thousand in the largest trees.

A study on two eastern-state eucalypt species showed that edge trees had larger fruit crops than interior trees and were used more often as feed trees by south-eastern red-tailed cockatoos (Koch 2004). To control for possible edge effects in marri, only trees growing within 5 m from the edge of the road or other open space were included.

Feed trees were identified by showing clear signs of feeding by forest red-tailed cockatoos, which meant there were at least 50 recently opened fruits on the ground near the base of the tree. Marri fruits that were opened by forest red-tailed cockatoos could be easily distinguished from those opened by one of the other species of marri-feeding Psittacidae, Baudin's cockatoo, Carnaby's cockatoo, red-capped parrot and Australian ringneck parrot (Robinson 1960, Long 1984, Saunders 1985, Higgins 1999), as each taxon opens the fruits in a different manner and leaves a different feeding mark on the fruits (Johnstone & Kirkby 1999, Cooper *et al.* 2003) (Chapter 4, Figure 4.1). The age of feeding signs could be readily established from the colour of the fruits and the level of decay, as well as presence of freshly chewed leaves on the ground which indicated feeding had occurred less than a week previously.

Non-feed trees were selected preferentially within 50 m of a feed tree. However, due to the limited number of suitable trees available along the transect, that were both close enough to the road and that matched a feed tree in diameter and fruit crop size, the distance between feed and non-feed trees was often 100 m or more. Non-feed trees were recognized as having fewer than ten recently opened fruits near their base. Finding only a few opened fruits under a tree was not considered to be convincing evidence that the tree was in fact a feed tree for two reasons. First, glossy cockatoos are reported to sample a tree before accepting or rejecting it (Pepper *et al.* 2000) and a small number of opened marri fruits could well represent such a testing event. Second, forest red-tailed cockatoos were often observed carrying a marri fruit in their bill when flying away from a feeding tree and dropping it elsewhere.

Some non-feed trees did have a small number of flaky grey and decaying fruits at their base which might have been opened by forest red-tailed cockatoos several years earlier. However, for fruits of this age the cause of damage is hard to

determine and the large untouched fruit crop in the canopy was considered to be much more significant determining the current status of the tree as a non-feed tree.

Fruits were collected from each of the 40 marri trees by shooting down a branch which carried at least ten marri fruits with the valves still closed, indicating that seed was present inside. Branch selection was further constrained by diameter of the base of the branch – thinner branches take fewer bullets to break, but too thin a branch is harder to hit – as well as visibility of the base of the branch from the ground since a line of fire had to be possible. All shooting was carried out by a trained officer from DEC Jarrahdale using a 308 firearm.

Upon collection, it was found that many branches of the branches brought down carried fruits that appeared to be from different years. It was decided to collect fruits of each age class present on a branch, in order to allow comparisons between fruits of different age. Fruits were visually assigned to one of three age categories, young, mature and old. Young fruits appeared to be still ripening; they had a smooth outer surface and were bright green in colour. Mature fruits were dark green, often with patches of brown, and had a rougher surface. Old fruits were completely brown but had their valves still closed which meant that seeds were still present inside. Out of the 40 branches collected, 18 carried fruits from two different age classes. An attempt was made to collect at least ten fruits of each age category present, although this was not always possible. The average number of fruits collected per age category per tree was 6.5 ± 0.35 ranging from 2 to 10. Very small green fruits were ignored, as were old fruits on which the valves had already opened, meaning that the seed had dropped to the ground.

Fruits were placed in labelled paper bags and kept in cold storage until processing the next day.

5.2.2 Fruit and seed measurements

Marri fruits were weighed to the nearest 0.1 gram with an electronic balance and their height and width were measured with vernier callipers to the nearest mm. Height of a fruit was measured from the base of the fruit (excluding the pedicel) to the top of the rim (Figure 5.1) and width was measured as the diameter of the fruit. For very asymmetric fruits both the greatest and smallest height and width were measured and averaged.

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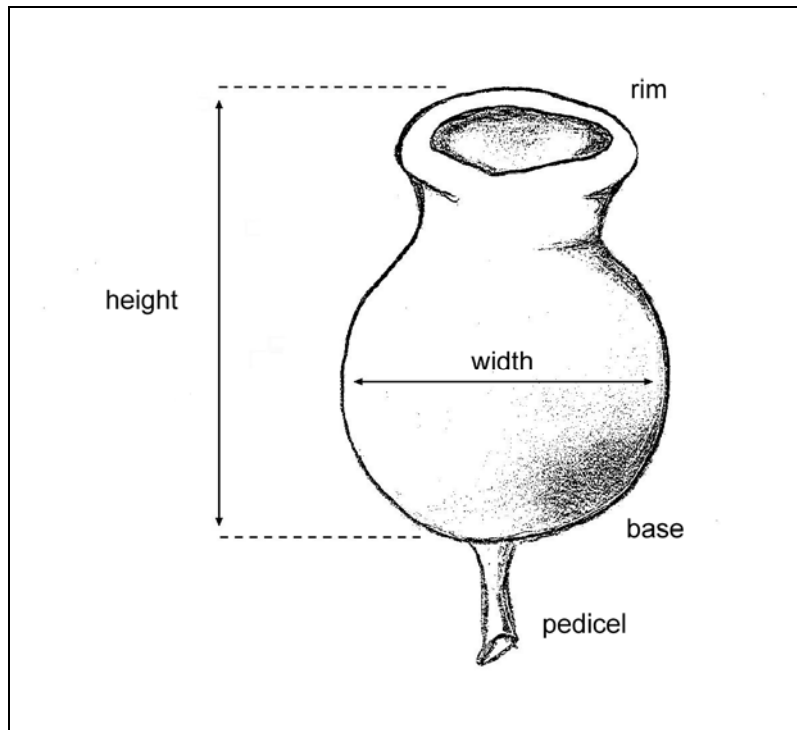
Figure 5.1 – Height and width measurements on fresh marri fruits.

Fruits were dried to constant weight in a forced-draft oven at a temperature of 40 °C. After drying fruits were weighed to the nearest 0.1 milligram using a fine scaled electronic Mettler balance. Seeds were subsequently removed from the fruits by shaking and scraping the inside with a thin metal rod. The total seed mass in each fruit was measured to the nearest 0.1 milligram.

Thirty seed samples were sent to the Chemistry Centre, Department of Industry and Resources, for analysis of nutrient composition. Seed samples were tested for moisture content (H_2O), ash, protein, lipid, neutral detergent fibre (NDF) and soluble carbohydrates in the form of nitrogen free extract (NFE). All seed samples were photographed prior to processing.

The group of 30 samples consisted of 15 samples from feed trees and 15 from non-feed trees and within each group there were 5 samples from young fruits, 5 from mature and 5 from old fruits. An individual sample consisted of the combined seed material from all fruits of a particular age class (i.e. young, mature or old) collected from a single tree and containing at least 1 gram of seed material. Seeds in the samples consisted of the whole seed: both endosperm and husk.

To avoid pseudoreplication, all samples were taken from different trees, hence when a tree yielded seed samples of two different age classes, only one age class

was used in analyses. The selection which fruit sample to use or discard was based both the number of fruits available in of each age class per tree and on the total availability of fruit samples of each feeding status and age class combination from all trees (n = 40). The aim was to maximise the number of fruits in all 30 samples without using two samples from the same tree. To obtain a sample of sufficient weight, the seeds from young fruits of two feed trees were combined. The average number of fruits included in a seed sample was 7.9 ± 0.42, ranging from 3 to 10.

5.2.3 Data analyses

All statistical tests were conducted in the software program SPSS for Windows version 14.0 (SPSS Inc. 2006). The ratios of young, mature and old fruits in the initial sample collected from the field (n = 40) were compared between feed non-feed trees using a Pearson chi-square test. A Pearson chi-squared test was also used to compare the frequency of occurrence of fruits with no seed material between feed and non-feed trees, and between age classes.

Only trees whose seeds were analysed for nutrient composition were included in the remainder of statistical analyses. If trees had yielded fruits of two age classes, only the morphological measurements on the fruits of the age class used for chemical analyses was included.

The mean values of morphological measurements were calculated for each fruit sample. For the two feed trees whose seed samples were combined, a mean was calculated over the combined morphological measurements, in effect treating them as a single tree. This procedure yielded a final sample size of n = 30 trees. The mean values were used as variables in statistical analyses.

Variables were tested for normality with a Kolmogorov-Smirnov test and if necessary transformed to achieve normality. The variables tree size (DBH), fruit crop in the canopy, number of seeds per fruit and water content of seeds (H_2O) were log transformed, and the variable soluble carbohydrates in seeds (NFE) was sine transformed.

The correlation between tree size (DBH) and fruit crop present in the canopy (before fruit collection) was analysed over all trees combined (n = 30) using a two-tailed Pearson test. The same test was used to investigate the correlation between tree size or fruit crop and each of the morphological and nutritional fruit variables.

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Correlations between all morphological variables of fresh fruits, i.e. those fruit features which cockatoos may be able to distinguish in the field were analysed using two-tailed Pearson correlation tests.

Fruit crop in the canopy was compared between feed and non-feed trees using a one-way ANOVA.

Morphological and nutritional characteristics of fruits and seeds (n = 30) were compared between feed and non-feed trees and between fruit age classes using a two-way between groups ANOVA. Tukey post hoc tests were performed when the results of the ANOVA indicated a significant difference between age classes.

5.3. Results

5.3.1 General observations

A total of marri 446 fruits were collected in the field; 41% of these were classified as young, 37% as mature and 22% as old (Table 5.1). The ratio of age classes in the initial sample, i.e. before fruits were selected for analysis, was similar for feed and non-feed trees (χ^2 = 4.715, *d.f.* = 2, *p* = 0.095).

Table 5.1 – Overview of all fruits collected in November 2008 from marri trees classified as feed and non-feed trees (*n* = 40), separated for the age classes young, mature and old. From this total sample a sub selection was used for statistical analyses (*n* = 31). Also shown are fruits that had no seed material present (*n* = 12).

Description	Fruit age	Feed	Non-feed	Total
All fruits collected	Young	102	82	184
	Mature	73	93	166
	Old	50	46	96
	Total	*225*	*221*	*446*
Fruits used in analyses	Young	45	36	81
	Mature	41	42	83
	Old	44	32	76
	Total	*130*	*110*	*240*
Fruits with no seed	Young	6	8	14
	Mature	2	4	6
	Old	1	3	4
	Total	*9*	*15*	*24*

Out of all fruits collected 24 did not have any seed material inside. One of these fruits contained pupae of an unidentified invertebrate species. Seedless fruits represented 5.4% of all fruits collected and came from 5 different feed trees and 7 different non-feed trees. The frequency with which seedless fruits were found in feed or non-feed trees or within a particular age class did not differ from expected frequencies (χ^2 = 0.483, *d.f.* = 2, *p* = 0.786).

There was a strong positive correlation between the log transformed values of tree size (DBH) and fruit crop in the canopy (*r* = 0.520, *n* = 30, *p* = 0.003). However, tree size and fruit crop in the canopy were not correlated with any of the morphological and nutritional characteristics of fruits and seeds.

Fruit wet weight was positively correlated with fruit size (height and width) and with total seed weight per fruit (Table 5.2). This indicates that larger and heavier

fruits offer cockatoos a greater calorific reward. Of the two measures of fruit size, only width was positively correlated with total seed weight, suggesting that choosy birds should select 'fatter' rather than 'taller' fruits. Total seed weight was strongly correlated with the (log transformed) number of seeds per fruit, but not with individual seed weight. However, seed number was negatively correlated with individual seed weight. This means that when the number of seeds increases, individual seeds tend to be smaller, but that overall fruits with more seeds would still offer a greater energy reward in terms of total seed mass.

Table 5.2 – Correlation matrix for morphological characteristics of fresh fruits (*n* = 30 trees), expressed as Pearson's *r*. Variables given are height, width and wet weight of fruits, individual seed weight, total seed weight and number of seeds per fruit. * = $p > 0.05$, ** = $p > 0.01$, *** = $p > 0.001$.

	Height	Width	Wet	TotSd	IndSd	SdNr
Height		0.691 ***	0.841 ***	0.292	0.138	0.185
Width			0.953 ***	0.446 *	0.206	0.228
Wet				0.421 *	0.216	0.208
TotSd					0.349	0.646 ***
IndSd						- 0.467 **
SdNr						

Variables: Height: height of fresh fruit, Width: width of fresh fruit, Wet: fruit wet weight, IndSd: average weight of individual seed, TotSd: weight of all seed material in a fruit, SdNr: number of seeds per fruit, this variable was log transformed

5.3.2 Morphological and nutritional comparisons of feed and non-feed trees

There was no interaction effect between tree feeding status (feed or non-feed tree) and fruit age for any of the variables tested. Feed and non-feed trees did not differ with respect to fruit crop present in the canopy (*n* = 30, *F* = 0.219, *p* = 0.643).

Non-feed trees had significantly heavier fruits than feed trees, both in terms of fresh wet weight and weight after drying (Table 5.3). This was reflected in similar ratios of wet to dry fruit weight, indicating that moisture contents in fresh fruits were also similar. Fruits from non-feed trees were also larger but this was not significant. Individual seeds from non-feed trees were significantly heavier than those from feed trees. However, this did not lead to a significant difference in total seed weight between the two classes, despite the fact that the number of seeds was similar. The ratio of dry seed to dry fruit was also similar.

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Table 5.3 – Morphological characteristics of fruits and seeds collected from marri trees classified as feed or non-feed trees. Values given as the mean ± standard error, *n* = 30, 15 trees per group, average of 8 fruits per tree. A * indicates significant difference at p < 0.05 (two-way ANOVA. No interactions were found between tree feeding status and fruit age).

	Feed	Non-feed
Fruit height (mm)	38.0 ± 0.93	40.8 ± 0.92
Fruit width (mm)	31.2 ± 0.59	34.0 ± 0.77
Fruit wet weight (g) *	20.2 ± 1.14	26.5 ± 1.68
Fruit dry weight (g) *	10.0 ± 0.60	13.6 ± 0.81
Fruit dry weight to wet weight ratio	0.50 ± 0.047	0.52 ± 0.014
Total seed weight (g)	0.31 ± 0.033	0.36 ± 0.026
Individual seed weight (g) *	0.10 ± 0.007	0.12 ± 0.008
Number of seeds per fruit	3.4 ± 0.39	3.1 ± 0.19
Total seed weight to dry fruit weight ratio	0.03 ± 0.009	0.03 ± 0.002

Feed and non-feed trees did not differ with respect to nutrient composition of seeds (Table 5.4). The variables water content of seeds (H_2O) and soluble carbohydrates (NFE) were log transformed and sine transformed, respectively.

Table 5.4 – Nutrient composition of seeds collected from marri trees classified as feed or non-feed trees. Values represent percentage of total seed sample made up by each compound and are given as mean +/- standard error, *n* = 30, 15 seed samples per group. None of the differences were significant (two-way ANOVA. No interactions were found between tree feeding status and fruit age).

	Feed	Non-feed
H_2O (%)	9.6 ± 0.23	9.5 ± 0.07
Ash (%)	3.5 ± 0.16	3.6 ± 0.21
Protein (%)	27.6 ± 1.21	27.6 ± 0.84
Lipid (%)	12.8 ± 1.13	11.7 ± 1.01
NDF (%)	29.2 ± 1.79	31.2 ± 1.50
NFE (%)	17.4 ± 2.73	16.4 ± 2.12

Abbreviated variables: H_2O: water content, NDF: neutral detergent fibre content, NFE: soluble carbohydrates in the form of nitrogen free extract.

5.3.3 Morphological and nutritional comparisons of fruit age classes

There were clear differences in appearance between seeds extracted from young green fruits compared to those from mature and old fruits. Seeds from young fruits were wrinkled and thin and had light brown colour (Figure 5.2).

By contrast seeds from mature fruits had a smooth outer surface and were firm and thick, giving the impression of being 'filled' (Figure 5.3). Their colour was a very dark brown.

Seeds from old fruits in general looked very similar to those of mature fruits. However, two samples, one from a feed tree and one from a non-feed tree, contained seed that looked like it had started to decay and was very dry and crumbly (Figure 5.4).

Figure 5.2 – Marri seeds from young fruits (*n* = 1 tree, 10 fruits per tree)

Figure 5.3 – Marri seeds from mature fruits (n = 1 tree, 10 fruits per tree)

Figure 5.4 – Marri seeds from very old fruits (n = 1 tree, 10 fruits per tree)

Young fruits differed significantly from the two older age classes in several of the morphological and nutritional variables tested, but there was no difference between mature and old fruits.

All fruit age classes were similar in size and weight (Table 5.5). Young fruits had significantly higher moisture content, as shown by a lower fruit dry to wet weight ratio. Individual seeds from young fruits were 40% lighter than those from mature and old fruits. However, the total seed mass per fruit did not differ significantly between age classes. This may be due to the fact that young fruits tended to have a slightly higher number of seeds, although this was not significant.

Table 5.5 – Morphological characteristics of fruits and seeds of three age classes young, mature and old. Values given as the mean ± standard error, n = 30, 10 trees per age class, average of 8 fruits per tree. For each variable different letters indicate significant difference at p < 0.05 (two-way ANOVA with Tukey post hoc test. No interactions were found between tree feeding status and fruit age).

	Young	Mature	Old
Fruit height (mm)	39.9 ± 1.39	39.7 ± 1.20	38.6 ± 1.11
Fruit width (mm)	33.1 ± 1.10	32.5 ± 0.88	32.2 ± 0.89
Fruit wet weight (g)	24.5 ± 2.47	23.0 ± 1.88	22.5 ± 1.73
Fruit dry weight (g)	11.1 ± 1.19	11.8 ± 0.87	12.3 ± 1.09
Fruit dry weight to wet weight ratio	0.45 ± 0.013 [a]	0.52 ± 0.010 [b]	0.55 ± 0.008 [b]
Total seed weight (g)	0.30 ± 0.035	0.37 ± 0.026	0.36 ± 0.046
Individual seed weight (g)	0.08 ± 0.006 [a]	0.12 ± 0.005 [b]	0.13 ± 0.010 [b]
Number of seeds per fruit	3.8 ± 0.41	3.1 ± 0.29	3.0 ± 0.39
Total seed weight to dry fruit weight ratio	0.03 ± 0.003	0.03 ± 0.003	0.03 ± 0.003

The seeds from young fruits had roughly half the lipid content found in mature and old fruits (Table 5.6). They also had lower fibre content (NDF). Finally, young fruits contained more than double the amount of soluble carbohydrates (NFE) compared to the seeds from older fruits. The variables water content of seeds (H2O) and soluble carbohydrates (NFE) were log transformed and sine transformed, respectively.

Table 5.6 – Nutrient composition of seeds collected from marri fruits of three age classes young, mature and old. Values represent percentage of the total seed sample made up by each compound and are given as mean ± standard error, *n* = 30 trees, 10 seed samples per group. For each variable different letters indicate significant difference at $p < 0.05$ (two-way ANOVA with Tukey post hoc test. No interactions were found between tree feeding status and fruit age).

	Young	Mature	Old
H2O (%)	9.6 ± 0.16	9.5 ± 0.07	9.6 ± 0.32
Ash (%)	3.8 ± 0.21	3.4 ± 0.26	3.4 ± 0.20
Protein (%)	27.6 ± 1.78	27.6 ± 0.80	27.5 ± 1.12
Lipid (%)	7.8 ± 1.18 [a]	14.5 ± 0.55 [b]	14.4 ± 0.73 [b]
NDF (%)	23.3 ± 1.33 [a]	32.6 ± 0.96 [b]	34.7 ± 1.47 [b]
NFE (%)	27.8 ± 2.51 [a]	12.5 ± 0.84 [b]	10.4 ± 1.00 [b]

Abbreviated variables: H2O: water content, NDF: neutral detergent fibre content, NFE: soluble carbohydrates in the form of nitrogen free extract.

5.4 Discussion

5.4.1 Feed and non-feed trees

There appeared to be little difference between feed and non-feed trees in most of the variables measured. The nutrient composition of seeds from both groups was similar, while differences in fruit and seed morphology were contrary to expectations, with non-feed trees having heavier fruits and greater individual seed weights although a greater individual seed weight did not coincide with greater total seed mass per fruit. The fact that fruits from non-feed trees were heavier, while the total seed reward within did not differ from those of feed trees, could indicate a possible effect of handling time if heavier fruits take longer to open. This needs to be investigated in future studies.

The results from this study do not support earlier findings that fruits from feed trees yield more energy per fruit (Cooper *et al.* 2003). Since the morphological characteristics of fruits and seeds found in this study were very similar to those reported in the earlier study, the reason for the difference is not immediately apparent. Perhaps the small sample sizes in both studies, i.e. 30 (this study) and 31 trees (Cooper *et al.* 2003) allowed for a greater impact of random variability. Fresh marri fruits ranged 21-51 mm in height and 20-42 mm in width (Figure 5.5) and 8-49 g in weight (Figure 5.6) and these characteristics were often very similar for fruits collected from the same tree.

In this study fruits were collected by shooting down branches from high in the canopy, while the earlier study used pole pruners which only allowed sampling from lower branches (Cooper *et al.* 2003). If fruit profitability varies within the same tree according to location in the canopy, this may explain different findings between the two studies. However, since forest red-tailed cockatoos preferably feed in the canopy (Johnstone & Kirkby 1999) this does not explain why the strongest differences were found in the study collecting fruits from the *lower* branches.

The clearest difference in methodology between the two studies lies in the selection of non-feed trees. In the earlier study non-feed trees were selected randomly in the vicinity of feed trees, i.e. from the same foraging patch, while in this study non-feed trees were selected at some distance away. The reason for this was that only trees within 5 m of the road were included. Since jarrah trees outnumber marri by 4:1 the distance between suitable trees meeting the edge criterios was often 100 m or more and occasionally a few km. The consequence of this difference

in methodology might be that this study, rather than comparing between trees in the same foraging patch, compared between different foraging patches instead.
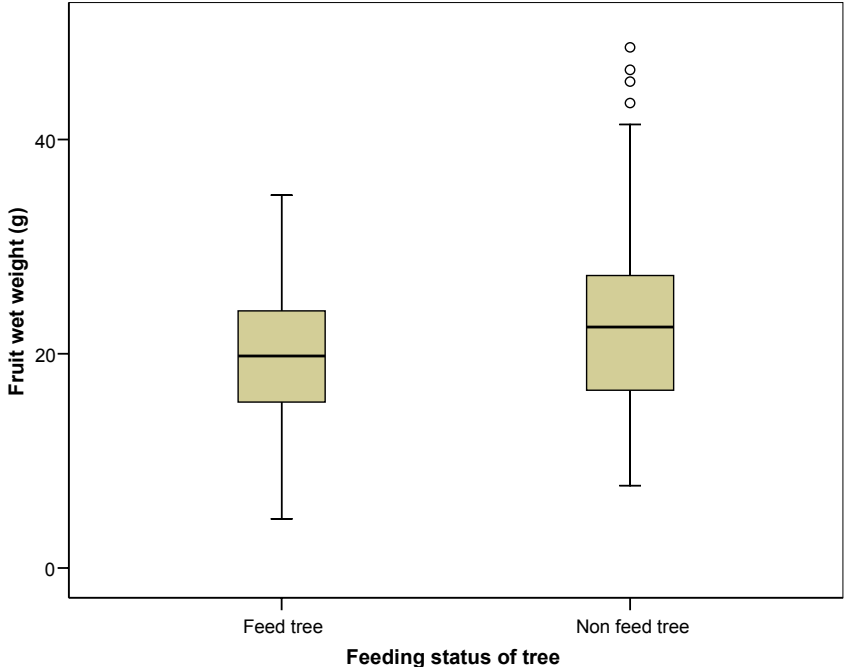
Figure 5.5 – Wet weight of freshly collected fruits from feed trees (n = 20 trees, average of 11.3 fruits per tree) and non-feed trees (n = 20, average of 11.1 fruits per tree).
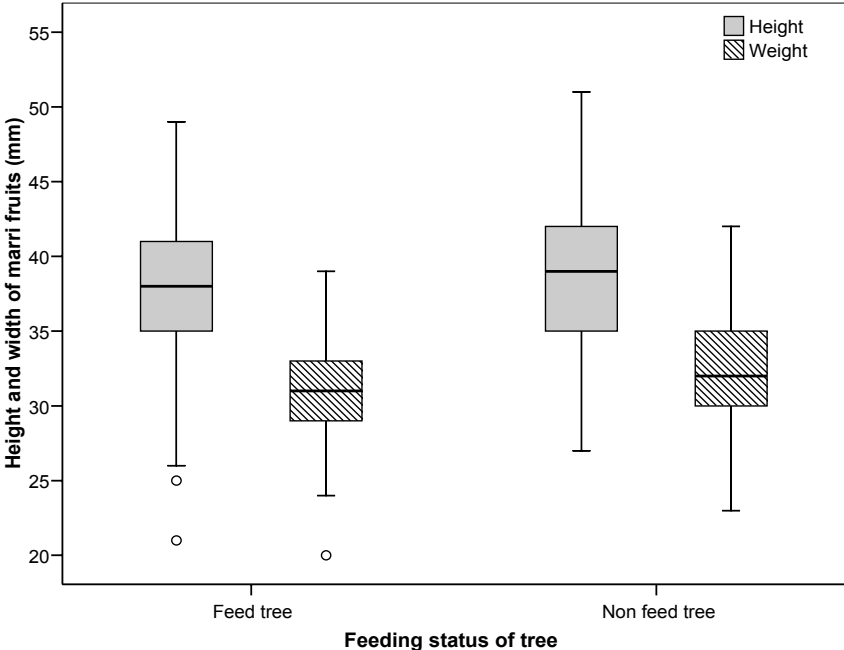
Figure 5.6 – Height and width of freshly collected fruits from feed trees (n = 20 trees, average of 11.3 fruits per tree) and non-feed trees (n = 20, average of 11.1 fruits per tree).

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Forest red-tailed cockatoos are creatures of habit, returning to the same nest and roost trees year after year (Johnstone & Cassarchis 2005, R. Johnstone *pers. comm.* March 2008). Perhaps similar habits exist with respect to foraging locations, but no published work on this topic is yet available.

The literature on other taxa of black cockatoo does provide some evidence for transmission of knowledge about feeding locations and/or the existence of foraging habits. For instance, foraging south-eastern red-tailed cockatoos follow the choices of earlier feeders. The birds may be using the presence of chewing to identify suitable feeding sites, while ignoring trees that would have been suitable feeding trees (Maron & Lill 2004). Observations on glossy cockatoos suggest that these birds might have the capacity to remember spatial pattern in great detail and transmit this information between generations (Crowley & Garnett 2001).

Hence if the forest red-tailed cockatoos follow similar traditional foraging patterns, then no true differences between trees in visited or non visited patches need to exist. However, the study design and small sample size do not allow for conclusions regarding between-patch selections in the forest red-tailed cockatoo. In future studies much larger samples are required to examine both within and between-patch differences, as well as monitoring changes in feed or non-feed status from one year to the next.

Forest red-tailed cockatoos may be selecting trees based on size. Although tree size was unrelated to any of the fruit or seed characteristics, larger trees carried significantly larger fruit crops. Glossy cockatoos (Cameron & Cunningham 2006) and south-eastern red-tailed cockatoos (Maron & Lill 2004) tend to feed in larger trees and one of the reasons suggested is that this enables family groups to feed together (Cameron & Cunningham 2006). Since forest red-tailed cockatoos also selectively feed in family groups (Johnstone & Kirkby 1999) they may indeed express a similar preference for larger trees. However, selection for tree size cannot be determined in this study because feed and non-feed trees were matched for size.

5.4.2 Fruit age classes

At the time of fruit collection, marri fruits of a variety of age classes were available to black cockatoos. Since trees from which fruits were collected for this study were not selected *a priori* for containing young green or more mature fruits, the ratio of age

classes present in the fruit samples can be considered a reliable representation of the fruit crop present in Karnet in November 2008.

There was no correlation between tree status and fruit crop age. However, since the sample sizes were very small, and most trees carried fruits of two age classes, this study cannot answer the question whether forest red-tailed cockatoos may be selecting between trees based on fruit crop age.

There was no significant difference between mature and old fruits in any of the morphological and nutritional variables examined. In addition, visual inspection of seeds from both groups suggested that they most likely represented one and the same age cohort. Hence, in the remainder of this discussion the two older age classes will be treated as one group and the term 'mature' will apply to both.

Black cockatoos consume only the endosperm of seeds, after removing the husk (seed coat) that surrounds it (Crowley & Garnett 2001, Johnstone & Kirkby 1999, Pepper *et al.* 2000). Hence comparisons should really be based on nutrient composition of the endosperm alone. Since nutrient composition was measured for seeds including the husks, these figures are not directly available. However, given that husks are particularly high in fibre (Crowley & Garnett 2001), it can be assumed that a substantial proportion of the fibre component measured in the nutrient analyses was located in husks. Hence, an estimate of the nutrient composition of endosperms may be obtained by recalculating the proportions of each nutrient after removing the fibre component. This yielded a protein, lipid and carbohydrate content of respectively 36.0, 10.2 and 36.2% for the endosperm of young seeds, respectively 41.5, 21.8 and 17.3% for the endosperm of mature seeds.

For granivorous birds, protein is often considered to be the most limiting factor for breeding success (Brodman *et al.* 1997) and is also important during moult (Earle & Clarke 1991). Some species respond to minute differences in protein content (Bosque & Calchib 2003). However, the protein concentration in the endosperms of mature marri seeds is very high (41.5%), well exceeding the estimated 16% that birds need to maintain their nutrient and energy balance (Diaz 1996). When birds feed on a food species that is generally high in protein (Valera *et al.* 2005), such as marri, small within-species variations in protein content probably do not really matter and birds are expected to select for other factors instead (Diaz 1996). This may explain why preference for particular trees by forest red-tailed cockatoos was not related to protein content of seeds.

Lipids may be just as important as proteins. For a variety of bird species lipid content is the most important factor in food selection (Stiles 1993). Deposition of sufficient lipid reserves is especially important in the breeding season (Ankney & Afton 1988) and with the onset of autumn to survive the cold winter months, (Bairlein 2002, Lepczyk *et al.* 2000) although the latter is probably most important for birds of Europe and North America.

The lipid content of marri seeds (21.8%) was much lower than the 38% reported for the seeds of eastern Australian sheoak (*Allocasuarina* spp.) (Crowley & Garnett 2001). In south-west Western Australia the native Fraser's sheoak (*A. fraseriana*) is an important food item for forest red-tailed cockatoos (Johnstone & Kirkby 1999). Seeds of Fraser's sheoak become available from late spring through to autumn (Western Australian Herbarium 2007, Marchant *et al.* 1987), which coincides with the time of egg laying and chick rearing in forest red-tailed cockatoos (Johnstone & Storr 1998). This suggests that for breeding birds the availability of sheoak as well as marri seeds may be key factors in successfully raising a chick. Incidentally, sheoak kernels are also high in protein, having an average protein content of 43.8% (Crowley & Garnett 2001).

Young marri seeds contained only half as much lipid as mature seeds, i.e. 10.2 instead of 21.8%. This indicates that the young green fruits collected in the study were indeed still in development. The fact that lipid rather than protein content was lower in younger seeds suggests a different pattern of seed loading for marri than for *Banksia* spp. (Stock *et al.* 1991). Young seeds also had significantly lower fibre content, which could mean that the husks had not fully formed. The light brown colour of young seeds, compared to almost black in mature seeds, also appeared to reflect a thinner and still developing seed coat (Figures 5.2 and 5.3).

In this study, marri seeds were analysed for nutrient composition but not for calorific value. However, following the rule of thumb that lipids yield approximately twice the energy as carbohydrates or proteins (Paine 1971), estimated at 38.9 kJ/g for lipids compared to 17.2 kJ/g for protein and carbohydrates (Karlson 1972 cited in Schaeffer *et al.* 2003a), some comparisons are possible. Translated into calorific values, the estimated nutrient composition of endosperms suggest an energy content of 20.4 kJ/g for young seeds and 27.0 kJ/g for mature seeds. These values are very similar to the energy content of 22.9 kJ/g measured on husked marri seed using a bomb calorimeter (Cooper *et al.* 2002). Hence, forest red-tailed cockatoos feeding on mature seeds would gain approximately 25% more energy than if they were feeding on young seeds.

An important *caveat* with these figures is that the absolute calorific value of a food item, often measured with a bomb calorimeter (e.g. Cooper *et al.* 2002) cannot be directly translated into energy gain to a bird. How much energy a forest red-tailed cockatoo obtains from consuming protein, lipid or carbohydrate depends on the bird's biological capacity to metabolise each of these compounds (Paine 1971). This information is currently unavailable for cockatoos (K. Dods *pers. comm.* January 2008).

Finally, the figures presented refer to the collective groups of each compound, without consideration of the specific types of proteins, lipids and carbohydrates involved. Different proteins have a different amino acid composition and some bird species actively select for proteins containing certain essential amino acids (Schaefer *et al.* 2003a). Hence, it is recommended that future studies focus not only on crude nutrient composition but also take into account the specific types of nutrients involved. Marri seeds should be husked prior to chemical analyses to obtain a more reliable estimate of nutrient composition. Given the importance of knowing exactly how much energy a bird is able to extract from its food, relative to absolute calorific value, conversion formulas specific to black cockatoos are greatly needed.

Despite the focus of many studies on the chemical characteristics of food items, an extensive literature review on the topic suggests that birds generally tend to select food items that require the least handling time, while energy and nutrient content are of secondary importance (Diaz 1996).

The profitability of a food item is a function of energy gain as well as handling time (Benkman 1987, Shuman *et al.* 1990) and birds are expected to make weighed decisions based on both factors. For instance, crossbills (*Loxia* sp.) selectively feed on smaller pine cones that are easier to open, despite the fact that smaller cones contain fewer and smaller seeds than larger ones (Summers & Proctor 1999). Similarly, glossy cockatoos select younger sheoak cones over older cones, as young cones appeared to be softer and easier to open (Clout 1989, Crowley & Garnett 2001).

Handling time may indeed be an important factor in food selection of forest red-tailed cockatoos. Marri fruits are hard to open and it takes considerable skill to do so rapidly (Johnstone & Kirkby 1999). Young marri fruits had a higher water content, which probably explains why they appeared softer and easier to open than hardened mature fruits. Opening fruits of different age classes with secateurs

confirmed this impression. Hence, it is likely that forest red-tailed cockatoos required less handling time to extract the seeds from young, compared to mature fruits. The fact that fruit crop age did not appear to affect tree selection suggests that reduced handling time for young fruits may compensate for their lower energy content, yielding similar profitability for young and mature fruits in terms of energy gain per unit time. This, however, has not been studied.

One study reports that an adult bird took 38 seconds to extract the seeds from a green marri fruit (Johnstone & Kirkby 1999). However, the exact age class of the fruit is not mentioned, nor is handling time compared between crops of different ages. Further studies are needed to compare the profitability of marri fruits at various stages of maturity. These studies should include detailed field observations on wild birds to measure handing times for different crop ages, as well as feeding experiments using captive birds and pre-opened marri fruits, and analyses of the nutrient composition of endosperms over a much wider range of age classes than reported in this study.

5.4.3 What is it then that cockatoos want?

The findings of this study do not offer an explanation as to why forest red-tailed cockatoos fed in the trees they fed in. Both morphological and nutritional data suggest that feed and non-feed trees did not differ from each other in any of the variables deemed to be important in food selection.

Perhaps tradition plays an important role, given the high fidelity of this taxon to other elements of its home range such as nest and roost trees (Johnstone & Cassarchis 2005, R. Johnstone *pers. comm.* March 2008). Forest red-tailed cockatoos have a detailed memory of their territory and young birds learn from their parents which trees to feed on (Johnstone & Kirkby 1999). This may represent the passing on of feeding habits from one generation to the next, as has been demonstrated in many vertebrate species (Galef & Giraldeau 2001, Galef & Laland 2005, Slagsvold & Wiebe 2007). Traditional foraging habits need only be abandoned when a tree fails to meet nutritional requirements (Crowley & Garnett 2001).

One aspect that was not explored in this study is the possible impact of chemical defences, often referred to as secondary metabolic compounds (see Diaz 1996 for a comprehensive review), on the palatability of marri seeds. Secondary compounds can be either directly toxic such as alkaloids, terpenoids, peptides and

some flavonoids (Becerra *et al.* 2001, Simonsen *et al.* 2005, Treutter 2006, Veldman *et al.* 2007), or suppress nutrient and energy assimilation such as phenols and tannins (Koenig & Heck 1988, Fleck & Tomback 1996, Numata *et al.* 1999, Müller *et al.* 2006, Xiao *et al.* 2006), which may lead to depressed growth rates of chicks (Helsper *et al.* 1996, Perrins 1976).

A study on food selection by a South-American bird community found that fruit removal was mediated by the stimulating effects of nutrients and the deterring effects of chemical defences, mainly phenols and tannins (Schaefer *et al.* 2003b). A similar interaction between tannins and protein content was found for Western scrub-jays (*Aphelocoma californica*) (Fleck & Tomback 1996).

Cockatiels (*Nymphicus hollandicus*), which like the forest red-tailed cockatoo feed nearly exclusively on seeds, show avoidance responses to very dilute levels of alkaloids and tannins (Matson *et al.* 2004). This suggests that detection of even low level concentrations of secondary compounds may be adaptive to Australian granivorous birds.

If feed tree selection by forest red-tailed cockatoos is partially driven by variance in secondary compounds in the seeds, then studies that examine energy or nutrient content alone will yield inconclusive or misleading results. Furthermore, since dispersal of unripe seeds is unfavourable to a plant (Schaefer & Schmidt 2002), it is likely that the concentrations of secondary compounds will change as seeds mature. This needs to be taken into account in any study relating fruit maturity to profitability as a food source for black cockatoos.

Given the generally high energy value and protein content of marri seeds, as well as the fact that fruits are available throughout the year, it appears that the forest red-tailed cockatoo enjoys a stable and reliable food source that should easily meet its daily nutritional requirements (Cooper *et al.* 2002). However, this conclusion does not match with evidence suggesting that only 10% of the population breeds in any one year (Johnstone & Kirkby 1999).

Since the number of nest hollows is believed to be sufficient at present (Abbott 1998, but see Recher 2004), other factors may be responsible for the lower than expected breeding activity. A possibility is that female forest red-tailed cockatoos are unable to acquire the essential nutrients to reach breeding condition and produce eggs. Egg production by female birds requires sufficient quantities of both protein and lipid in roughly equal ratio (Ankney & Afton 1988). In bird eggs the yolk forms the greatest energy investment to the female (Pearson 1999) and is the main source

of energy and nutrients for the developing embryo (Royle *et al.* 1999). Yolk is especially rich in lipids, which make up about 30% of fresh yolk weight (including on average 50% water, Sotherland & Rahn 1987) (Couch & Saloma 1973, El Bagir *et al.* 2006) or 60% of yolk solids (Christians & Williams 2001, Lill & Fell 1990). These figures are remarkably stable across bird taxa (Couch & Saloma 1973, Lill & Fell 1990, Sotherland & Rahn 1987).

While marri seeds are high in protein, their lipid content is much lower, suggesting that female forest red-tailed cockatoos may need an additional source of lipid to reach breeding condition. Fraser's sheoak (*Allocasuarina fraseriana*) produces seeds that are very high in lipid and these become available at specifically the start of the breeding season. This suggests a possible complementary role of sheoak in the diet of the forest red-tailed cockatoo which may be of key importance for the onset and success of breeding.

Fraser's sheoak is susceptible to phytophthora (*Phytophthora cinnamomi*) dieback (Lewis & Colquhoun 2000), a destructive plant disease present in a significant portion of the forest red-tailed cockatoo's range (Garkaklis *et al.* 2004), while marri is not. Hence, it is possible that phytophthora dieback has reduced the availability of sheoak seeds to the forest red-tailed cockatoo by killing and weakening the trees, which may adversely affect the birds' ability to breed. The effects of phytophthora dieback on the forest red-tailed cockatoo are poorly known and mechanisms like the one suggested above need to be investigated urgently.

The jarrah forest is a complex and very biodiverse ecosystem and focusing on a single plant species may not be sufficient to identify all of the key elements operating on the forest red-tailed cockatoo. The nutrient content of other important food species such as jarrah (*Eucalyptus marginata*) and Fraser's sheoak needs to be studied further. Furthermore, the nutritional requirements of cockatoos as well as the availability of food items are likely to change from one season to the next (Earle & Clarke 1991).

Hence, detailed studies on food selection as well as food availability need to take place over the course of one or possibly many years. These results should be combined with year-round studies on the nutritional requirements of captive birds, most especially during breeding and moult, in order to identify potential deficiencies of key nutrients at particular times of the year.

Successful management of a species involves at the very least the protection of key resources such as nesting and foraging habitat. This study has provided a

valuable contribution to the knowledge on the ecology of the endangered forest red-tailed cockatoo by quantifying the nutritional characteristics of marri, its main food species. The relatively low lipid content, compared to protein content, of marri seeds suggests that the birds require a balanced diet that includes the seeds of many other native species. Hence, Alcoa's current revegetation protocol of seeding a mix of native species appears to be appropriate. Fraser's sheoak, potentially a very important element in the diet of the forest red-tailed cockatoo, grows in discrete stands in the jarrah forest. Within the jarrah forest as a whole, these sheoak stands are relatively rare and may be hard to re-create using the standard revegetation methods. This suggests that, where possible, sheoak stands should be set aside when bauxite mines are developed and revegetation should include planting patches of exclusively Fraser's sheoak in order to more accurately approach the structure of native jarrah forest.

Chapter 6 – Synthesis

6.1 Introduction

Humans have had a considerable impact on most ecosystems of the world, with clearing or fragmentation of native vegetation as one of the most obvious processes. Modification of natural landscapes is a major threat to many species (Huxel & Hastings 1999), especially those with a restricted distribution, specific habitat requirements or a specialised diet (Saunders 1986). Proper management plans for such species require detailed knowledge on which aspects of the landscape are most important. However, most mobile animals inhabit a variety of habitats, which makes it difficult to study how landscape change impacts on the species (Pulliam *et al.* 1992) and which habitat types are most important for conservation. The ability of a species to utilise modified land use types can have a significant impact on their long-term persistence (Fahrig 2001).

The south-west of Western Australia has undergone recent and rapid changes due to large-scale land development over the past century (Saunders 1985, 1986). Consequently, the three native taxa of black cockatoo, the forest red-tailed cockatoo (*Calyptorhynchus banksii naso*), Baudin's cockatoo (*C. baudinii*) and Carnaby's cockatoo (*C. latirostris*), have all experienced a reduction in range and numbers (Johnstone & Storr 1998, Higgins 1999). All three taxa depend strongly on native vegetation but are also able to utilise some of the modified land use types. Because black cockatoos are have a foraging range of several kilometres, studies on the impact of habitat modification require a study area of comparable magnitude.

6.2 Landscape characteristics and occurrence of black cockatoos

This study examined the distribution, abundance and habitat use of black cockatoos in the south-west of Western Australia, with an emphasis on comparing between landscapes (i.e. study areas) with different types of human modification. Given the ecology of the study taxa and the limited time available, the study focused on distribution patterns related to foraging (Chapter 1).

Three study areas, each 400 km^2 in size, were selected on the basis of each containing a different combination of the most abundant land use types present in the northern jarrah forest region (Chapter 2). Pickering Brook contained a number of

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orchards and also several small town sites. The Wungong study area consisted of a mosaic of mature forest and revegetation of various ages, the oldest of which contained exotic eastern-state eucalypt species while the younger revegetation was a balanced mix of native species aimed to closely resemble the original forest. The Karnet area contained large amounts of mature native forest, but also some pasture and a small amount of revegetation.

In the vicinity of the survey transects the differences between the study areas were large, with Pickering Brook and Wungong containing a high proportion of the modified land use types they were selected for with respect to the purpose of this study (Chapter 3). However, at increasing spatial scales the study areas became more similar and at the 400 km^2 scale which constituted the entire study area, all three had a proportions of roughly 80% native forest and 20% modified land. Nonetheless the study areas continued to differ with respect to the nature of the modified areas: At the study area scale, orchards and revegetation were most prevalent in Pickering Brook and Wungong, respectively, while the modified part of Karnet contained more than twice as much pasture as the other areas.

The forest red-tailed cockatoo was present in high and stable numbers throughout the year, and the local population of this taxon in each of the three study areas appeared to be quite similar (Chapter 3). These findings agree with the literature which states that the taxon is relatively sedentary and remains in its breeding areas year-round (Johnstone & Storr 1998, Higgins 1999).

Baudin's cockatoo was only present in high numbers between April and August, with a peak in June. The species does not breed in the study areas and its sudden peak abundance in June agrees with published records of post-breeding migration in search of food (Saunders 1974b, Johnstone & Storr 1998, Higgins 1999). The majority of records for Baudin's cockatoo were in the Pickering Brook area, which has extensive apple orchards, a known food species for this cockatoo in the non breeding season (Chapman 2007a).

Carnaby's cockatoo was recorded in all study areas throughout the year in relatively low numbers. This pattern of year round presence does not match earlier literature which reported that the species undergoes post- and pre-breeding migration (Saunders 1974a, Johnstone & Storr 1998, Higgins 1999). Instead, its year round presence agrees with recent observations that the species is shifting its distribution south-westwards (Johnstone & Storr 1998), and suggests that some of

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the birds may have been residents to the study areas and bred nearby (cf. Johnstone & Cassarchis 2003, 2004, 2005).

6.3 Significance of the various land use types for black cockatoos

The relationship between the distribution patterns of black cockatoos and the various land use types in the study areas was investigated by constructing generalised linear models (GLM), based on bird observations and land use data within 100 m from the transect roads (Chapter 3). Models were selected based on the Akaike Information Criterion (AIC). No models were constructed for Carnaby's cockatoo due to paucity of data for this species.

GLM for the forest red-tailed cockatoo suggest that this taxon perceived the three study areas as roughly similar on the regional scale, but selected against young post-1988 revegetation at the finer scale within the Wungong study area. Models for Baudin's cockatoo suggest a habitat selection pattern that was the reverse of the forest red-tailed cockatoo. On the regional scale the birds selected in favour of Pickering Brook, which contained orchards, but within the Pickering Brook study area, the models suggest that the distribution of Baudin's cockatoo was unrelated to the distribution of the land use types examined in this study. The difference between the taxa in how they selected between and within the study areas have been due to the different habitat requirements each taxon placed on the study areas and possibly also to differences in the amount and detail of spatial knowledge they were able to obtain of the study region and the individual study areas within (Chapter 3, Section 3.4.5).

Model predictions for the for the forest red-tailed cockatoo and Baudin's cockatoo (Chapter 3), were compared with observations of feeding behaviour (Chapter 4) to gain insight into the factors driving the observed correlations between cockatoo distribution and land use patterns. For the forest red-tailed cockatoo, additional data on selection of feeding trees (Chapter 5) enabled a more detailed explanation of distribution patterns for this taxon. Since no models were constructed for Carnaby's cockatoo, conclusions for this species were based on basic abundance data (Chapter 3) and feeding observations (Chapter 4) only. The results are discussed in the light of management implications and recommendations for future study.

6.3.1 Native forest – Forest red-tailed cockatoo and Baudin's cockatoo

Native forest was the dominant land use type in all study areas, both in the vicinity of the transect roads and at the larger study area scale. Because native forest was superabundant in all three study areas, and the purpose of the study was to investigate the significance of the various modified land use types for black cockatoos, the forest variable was not included in the modelling process.

The land use type "forest" included a wide range of forest ages and structures, with variable history in terms of fire and sawlog harvesting, as well as differences in elevation, hydrology and soil type. The large scale of the study areas did not allow including forest subtypes into the spatial models. However, one aspect of possible heterogeneity within the forest land use type was investigated in this study (Chapter 5) by comparing the fruit crop quality between trees fed on or ignored by forest red-tailed cockatoos. However, no clear differences in morphological or chemical characteristics between the fruits of feed and non-feed trees were found.

Jarrah and marri are the dominant tree species in the jarrah forest. The two species featured in 90% of all feeding events recorded for the forest red-tailed cockatoo, while marri featured in 92% of all feeding events for Baudin's cockatoo (Chapter 4). This finding underlines the importance of jarrah and marri in terms of food quantity. However, other plant species may be important in terms of food quality. This study found that marri seeds are relatively low in lipids compared to their high protein content (Chapter 5). Egg production requires sufficient intake of both lipid and protein, and this suggests that other native plant species such may be important to black cockatoos in terms of food quality. The seeds of sheoak species tend to be high in lipid and this suggest that the seeds of the native Fraser's sheoak could be an important element in the diet of forest red-tailed cockatoos in the breeding season.

Whether or not species can persist in areas with modified land use types depends on their ability to utilise the novel land use types (generalist species) or to traverse unsuitable land use types while moving between native patches (Fahrig 2001). These same characteristics, however, may make it difficult to produce good distribution models. A study on the performance of models for a large number of bird species showed that model accuracy is reduced for species with a large range or which are able to utilise a broad range of habitat types (McPherson & Jetz 2007). Given that large ranges generally include a wider variety of land use types (Pulliam *et al.* 1992), the effects of mobility and versatility cannot easily be distinguished.

However, in order to develop sound management plans, it is important to know whether species are utilising a wide variety of land use types within their range or utilise only one or two while only traversing the others.

Models for the superb parrot (*Polytelis swainsonii*) indicate that this species views the modified landscape it lives in as a continuum of usable habitat (Manning *et al.* 2006). In contrast, glossy cockatoos (*Calyptorhynchus lathami*) are reported to fly large distances between critical resources such as feeding and nesting sites, while ignoring the surrounding habitat (Cameron & Cunningham 2006). In the light of progressive landscape modification, it seems likely that more generalist species would be able to persist longer, i.e. at higher degrees of modification, than mobile species as the latter are greatly dependent on the distance between and connectivity of critical resources. The importance of connectivity has been demonstrated clearly for a population of Carnaby's cockatoo breeding in the wheatbelt. As their habitat became more and more reduced and fragmented, the population eventually was unable to "connect the pieces" and disappeared (Saunders 1977b, 1980, 1990).

The three taxa of black cockatoo under study have a daily foraging range large enough to encompass all available land use types. With the exception perhaps of Carnaby's cockatoo feeding on pine, all three taxa are also highly dependent on native vegetation. Hence, the three taxa of black cockatoo can be considered mobile rather than generalist. Hence, all can be expected to be very sensitive to landscape modification beyond a certain threshold level. However, it is hard to determine how high this threshold is as this depends on the ability of birds to survive in the modified areas (Fahrig 2001).

More detailed studies are needed to establish fine-grained distribution patterns of black cockatoos in order to discover whether and how they might utilise the various modified land use types. In addition, comparative studies conducted in landscapes with different proportions of modification would help identify the persistence threshold for each taxon of black cockatoo. Whether the taxa under study utilised or simply traversed the modified land use types does not affect the conclusions that both were capable of persisting in landscapes (defined in this study as the 400 km^2 study areas) with 20% modification.

This study has demonstrated that at the study area scale a native forest cover of 80% was sufficient to support large populations of especially forest red-tailed and Baudin's cockatoos. However, the threshold value below which a decline in numbers

can be expected is unknown. Black cockatoos are highly dependent on native forest and woodlands for food, nest trees and roost trees. Hence, a reduction in jarrah forest cover in any of the study areas will likely have negative effects on the taxa, given that they have disappeared from parts of their former range where forests and woodlands were cleared extensively (Saunders *et al.* 1985, Higgins 1999, Garnett & Crowley 2000). Future studies to determine the minimum (threshold) amount of native vegetation that can support and maintain a healthy population of black cockatoos are urgently needed.

6.3.2 Orchards – Baudin's cockatoo

Orchards occurred primarily in the Pickering Brook study area (Chapter 3). Small patches were found in Wungong, but orchards were virtually absent from Karnet even at the study area scale. Orchards mainly influenced the distribution patterns of Baudin's cockatoo. The forest red-tailed cockatoo neither utilised nor avoided this land use type and although no models could be constructed for Carnaby's cockatoo, this species was never observed utilising the apple orchards for food.

Models for Baudin's cockatoo indicate that at the regional scale this species was attracted to areas containing orchards, but that within the orchard-rich study area distribution appeared unrelated to the patterns of land use types. The regional-scale model appears to be in conflict with the fact that Baudin's cockatoos were never observed feeding on apples. Instead, feeding observations suggest that marri seeds were by far the most important food source for this species.

Baudin's cockatoo has been reported damaging apples and pears in commercial orchards in Western Australia since the early 1990's (Long 1985, Chapman 2007a). Given their high abundance along the transects in Pickering Brook, an area where orchards made up 16 % of the total land use within 500 m on either side of the transects (Chapter 3), the fact that no feeding in apple trees was recorded throughout the study is surprising.

It is very unlikely that the lack of feeding observations truly reflects that Baudin's cockatoo was not feeding on apples during the 2007 study. Instead, the surveys were probably held a time of day when the birds were not feeding in orchards.

The transect surveys were timed to avoid the dawn and dusk periods, when birds are travelling between their roost trees and feeding sites. This was done to ensure that the distribution data collected was strictly related to foraging behaviour, rather than travelling. However, it appeared that with this survey protocol the critical time when Baudin's cockatoo fed in orchards was systematically missed.

Anecdotal evidence and personal observations outside the study areas indicate that the time of day when the birds tended to visit orchards was the early morning. Vigilance by orchardists who were chasing the birds out of their orchards may have been the reason for this. Being intelligent and adaptable birds, Baudin's cockatoo probably learned to feed in the orchards before the orchardists were in the field. During the rest of the day they fed on marri in the nearby jarrah forest, sometimes even sitting in trees adjacent to orchards, but they only flew down to feed on the fruit trees when the sun began to set and most orchardists had retired home.

Personal observations on Baudin's cockatoos leaving their roost trees in the early morning showed that the birds began to fly at the first rays of sunlight. Presuming that they were hungry after a long night, they probably flew straight to their preferred feeding grounds, which in Pickering Brook were likely the orchards. These observations suggests that future transect surveys for Baudin's cockatoo should start earlier and finish later in order to incorporate the critical orchard feeding time for this species. Furthermore, it is possible that the data used to develop regression models, may have been suboptimal with respect to detecting the full effect of orchards on the distribution and abundance of Baudin's cockatoos.

Despite these limitations, the models still indicated a strong positive effect of orchards at regional scale. There are two ways of looking at this. First, presuming that the data in this study was indeed collected during suboptimal times of the day, the fact that such strong patterns still emerged suggests that the "true" effect of orchards on Baudin's cockatoos was many times stronger. GLM models developed in future studies, using data collected both earlier and later in the day could show whether this is indeed the case.

Second, given that feeding in orchards only occurred during a relatively small percentage of the daylight hours, with the birds feeding on marri for the rest of the time, apples may not be of critical importance in the diet of Baudin's cockatoo. This can be investigated in future studies by studying the time-budget of a group of Baudin's cockatoos feeding throughout the day, combined with data on the amount of apple seeds and/or juice consumed by the birds and knowledge of the energetic

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content of these food items. Comparing the energy content of apple seeds and juice with the energy content of marri seeds (Chapter 5) would show to what extent Baudin's cockatoo depends on apples to meet its daily energy requirements. This knowledge is of great importance with respect to conservation of this endangered species.

Shooting by orchardists has been the main cause of death to Baudin's cockatoo in the past (Crowley & Garnett 2000), and it is believed that illegal shooting is still the principal threat to the species (CALM 2006). Given the species' slow rate of reproduction (Johnstone & Storr 1998), even low levels of shooting might drive the species to extinction (Chapman 2007b). Exclusion netting has proven to be the most effective approach to protecting orchards (Bomford & Sinclair 2002). Since this method provides a physical barrier between the birds and the fruits, any other means of control including shooting would no longer be necessary.

However, if apples are of great importance to the survival of Baudin's cockatoo in the non-breeding season, then exclusion netting may actually do damage to the population. If this is the case, a better solution might be to focus scaring and netting on parts of the orchards with the most commercially valuable crop, while allowing the birds access to a sacrificial or "decoy" crop (Bomford & Sinclair 2002) of low commercial value.

6.3.3 Pasture – All three taxa

Areas classified as pasture were mainly paddocks but also some open areas in the forest (Chapter 3). In the vicinity of the study transects, pasture was most common in Pickering, while at the study area scale it was the dominant modified land use type in Karnet.

Paddocks contain grasses and herbs, some of them native some introduced like the cape weed (*Arctotheca calendula*), which were used infrequently as a food source by Carnaby's cockatoo (Chapter 4). Models for the forest red-tailed cockatoo, showed a positive response to pasture; this is best explained by the birds feeding on native eucalypt trees on the edge of paddocks, which may yield a better fruit crop (Koch 2005). It appears that on its own, the pasture land use type is much too open and contains too little native plant species to offer a suitable foraging habitat for black cockatoos. Observations of birds traversing areas with paddocks at dusk showed that they followed the narrow corridor of trees and large shrubs lining

the edges, in which they often briefly alighted. This observation underlines the importance of maintaining and creating a suitable landscape structure, which includes corridors of native vegetation, allowing the birds to traverse less preferred land use types (Saunders 1990, see also Section 6.3.4).

6.3.4 Pine – Carnaby's cockatoo

All three study areas contained several pine blocks of various sizes (Chapter 2). Pine was most abundant in the Wungong study area, followed by Pickering Brook, and occupied a minute part of the Karnet study area (Chapter 3).

Models for the forest red-tailed cockatoo and Baudin's cockatoo indicate that the distribution patterns of these taxa were not related to pine blocks. Nonetheless, Baudin's cockatoo was recorded feeding in pine often in mixed flocks with Carnaby's cockatoo. Foraging flocks in pine tended to be large, with up to 60 Carnaby's cockatoos and 100 Baudin's cockatoos recorded in a single flock. The stem density of pine plantations and the fact that pine cones occur high in the canopy suggests that these numbers may be an underestimation of the actual size of the feeding flocks present. The protracted period over which pine seeds were available, with feeding recorded from February through to August, indicates that pine seeds form a stable and reliable food source throughout the year.

Commercial pine plantations are known from the literature to form an important part of the diet of Carnaby's cockatoo for at least part of the year (Saunders 1974a, 1980). However, the full value of pine trees for Carnaby's cockatoo is yet unknown. At present no study has quantified even the most elementary aspects of the relationship between pine plantations and Carnaby's cockatoo, such as which percentage of the population makes use of pine plantations (see Saunders et al. 1985), or how many birds a pine block of a certain size can sustain. Knowledge on these issues is urgently needed, especially in the light of existing plans to gradually remove most of the pines and replace them with native vegetation in the proposed Gnangara Park (CALM 1999).

Considering the serious conservation status of Carnaby's cockatoo (Garnett & Crowley 2000), management plans should follow the precautionary principle (Goodall 1999) and suspend clearing of pine plantations until a suitable alternative food source is available. The results of this study suggest that at present Carnaby's cockatoo may be best served by preserving the existing pine plantations and

revegetating with native proteaceous species in the vicinity. The latter form the traditional food of Carnaby's cockatoo and are known to mature quickly, producing seeds within five years (H. Finn *pers. comm*. May 2008). The spatial configuration of revegetation and pine blocks is probably as important as their total area (*cf.* Huxel & Hastings 1999) since birds need corridors of native vegetation to move from one patch to the next in order to exploit all available food sources within a landscape effectively (Recher 1985, Saunders 1990).

6.3.5 Revegetation – Forest red-tailed cockatoo

Revegetation was only present near the transect areas in the Wungong area. This study area appeared to be primarily used by the forest red-tailed cockatoo, although it was not certain whether the taxon was actually feeding in the revegetated areas.

Baudin's and Carnaby's cockatoo were recorded very infrequently in the Wungong area and did not appear to be using the revegetation. In fact, whenever these two species were recorded in Wungong they were either associated with small blocks of mature pine or near a small stream deep inside a part of mature native forest in Wungong where they gathered to drink (Chapter 4).

Models for the forest red-tailed cockatoo showed a strong negative response to the younger revegetation, established between 1988 and 2001. In the Wungong study area this land use type made up roughly 20% of the area within 500 m on either side of the transect roads, which was the maximum distance at which cockatoos could be detected (see Chapter 3). Young revegetation was structurally quite different from mature native forest, resembling shrubland rather than forest. Avoidance of this land use type may have been due to increased exposure to avian predators, as well as the fact that forest red-tailed cockatoos are reluctant to feed too close to the ground.

In addition to the younger post-1988 revegetation, another 16% of total land use within the area 500 m on either side of the transects consisted of older revegetation, planted between 1966 and 1988. At the time of the study the oldest trees in this land use type were 40 years old and produced good flower and seed crops. Records from other areas have shown that forest red-tailed cockatoos feed on some of the introduced tree species, especially spotted gum (*Corymbia maculata*) and lemon-scented gum (*C. maculate citriodora*), both of which are present in the pre-1988 revegetation. Although no feeding on these species was not

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observed in this study it is likely that forest red-tailed cockatoos are able to feed in the older revegetation.

Models suggest that forest red-tailed cockatoos did not avoid the older revegetation (Chapter 3). One possible explanation for this may be the structural similarity between this older revegetation type and the surrounding native forest. However, because the birds were never directly observed in pre-1988 revegetation, the data does not provide a conclusive answer on whether forest red-tailed cockatoos utilised, rather than simply traversed the older revegetation. In order to answer this question, more detailed studies on the feeding behaviour of forest red-tailed cockatoos are needed, including targeted searches for feeding signs inside the revegetated areas rather than just on the roads.

Feeding events by forest red-tailed cockatoos in Wungong were all on mature native vegetation (Chapter 4). The birds appeared to utilise the patches of remnant native forest among the revegetation, but did not use the revegetation itself. Hence, feeding observations agreed with the models indicating avoidance of young revegetation by forest red-tailed cockatoos. Because patches of mature native forest and revegetation formed a complex mosaic, the models may in fact have underestimated the degree to which forest red-tailed cockatoos avoided young revegetation since the birds readily fed in mature jarrah and marri trees on the edge of young revegetation. This was illustrated clearly in December, when a pair of forest red-tailed cockatoos fed in a single mature marri tree in the middle of a large patch of very young revegetation.

The fact that the revegetated patches formed a mosaic with native forest probably enabled the forest red-tailed cockatoo to persist in the Wungong area while it was being mined, and is likely to facilitate recolonisation of the revegetated patches in the future. How old the revegetation needs to be before black cockatoos will begin to utilise it as a food source is not known. Although marri trees in Wungong were producing fruit only five years after they were planted, the known avoidance of forest red-tailed cockatoo to feed too close to the ground will probably render these young trees unsuitable as a food source for at least another two decades. However, it is likely that in time, as the trees mature, the young revegetation will indeed be utilised by black cockatoos.

However, to successfully persist in an area the forest red-tailed cockatoo also needs sufficient nest trees. Recent studies (Abbott 2001) suggest that the availability of nest trees is not a limiting factor at present. Given the records of

courtship behaviour of forest red-tailed cockatoos, behaviour only exhibited close to a nest hollow, the Wungong area appeared to fulfil the breeding requirements for this taxon at the time of this study. However, natural senescence of trees may prove to become an issue in the future. Trees suitable for nesting are on average 300 years old, which suggests that it will be another 260 years before the first trees in the revegetated areas begin to provide the birds with nest hollows.

The current mosaic pattern of mining and revegetation, conveniently driven by the patchy distribution of bauxite, appears to be quite suitable to maintain a healthy population of forest red-tailed cockatoos at present. Over time, however, it may become important which percentage of the original forest was replaced by revegetation as this will affect the number of suitable nest trees that become available while existing nest trees collapse. Not all of the trees that reach the required age will eventually form hollows large enough for black cockatoos, and not all large hollows are suitable nest sites. Hence, care must be paid to preserving areas which contain a mix of trees of different ages and not simply preserve the oldest ones.

Nutrient analyses of marri seeds (Chapter 5) suggest that forest red-tailed cockatoos may require a second food source to supply them with sufficient lipids needed for egg production. Since seeds of sheoak (*Allocasuarina* spp.) are very high in lipid (Crowley & Garnett 2001), the importance of the native Fraser's sheoak for the forest red-tailed cockatoo, especially in the breeding season, may be much greater than hitherto believed. Hence, future revegetation efforts may need to focus on preferentially planting Fraser's sheoak to offer black cockatoos a sufficiently balanced diet to reach breeding condition.

6.4 Caveats and recommendations for future study

The study took place over a single year in 2007, and such a limited time span can unlikely reveal the full picture on how the three taxa of black cockatoo utilise each of the three study areas. Nonetheless, some interesting patterns were identified, while at the same underlining the fact that to properly study species as large and wide ranging as black cockatoos, very large study areas are needed.

The jarrah forest is a biodiverse habitat, which displays heterogeneity at a range of spatial scales. For instance, fire history and sawlog harvesting create mosaics of different forest structure at the study landscape scale; hydrology and soil

characteristics drive smaller-scale mosaics in terms of understorey vegetation and availability of drinking water, while the ongoing infestation of phytophthora dieback affects the jarrah forest at the regional scale by altering vegetation composition (Garkaklis et al. 2004). The large scale of the study areas did not enable adding more detailed aspects of forest heterogeneity into the study design, in order to investigate their effects on the distribution patterns of black cockatoos. Future studies on either a smaller study area scale, or with a greater number of researchers on the ground, or with a longer time period available to collect data, may be able to illuminate the impacts of forest heterogeneity on cockatoo distribution.

The impacts of forest heterogeneity may also be more subtle, affecting not distribution patterns per se, but reproductive success. This study has demonstrated that landscapes with 80% native forest are able to support large populations of black cockatoos. However, current presence of large flocks in the study areas does not immediately imply long-term persistence, since black cockatoos are long-lived. Nearly all of the areas classified as native forest have been modified or impacted by humans to some extent, either through fire or sawlog harvesting, introduction of phytophthora dieback, introduction of feral bees or through general disturbance due to constant human presence. Since black cockatoos can live for over forty years (captive records: Brouwer *et al*. 2000) and have a slow reproductive rate (Johnstone & Storr 1999), reductions in reproductive success due to modification of landscapes will not immediately become apparent in a decline in the number of birds.

In order to establish with certainty that black cockatoos can persist in the study areas, we would need to know that reproductive success is adequate to replace adult mortality. To investigate this, long-term studies are needed to monitor reproductive success over many years. Researchers from the Western Australian Museum have been documenting and monitoring nest trees of black cockatoos since 1995 (Johnstone & Kirkby 1999, Johnstone & Cassarchis 2003, 2004, 2005) and research is ongoing. Since finding and monitoring nest trees is very time consuming, study efforts that support or compliment the work already undertaken by the Western Australian museum would be of great value to the conservation of black cockatoos.

The study areas are not static over time. Ongoing development and revegetation will alter the location and extent of the different land use types, while processes such as the spread of *P. cinnamoni* dieback and feral honeybees, forest fires and climate change are likely to bring about progressive changes within the jarrah forest over the coming decades. At a smaller time scale, year to year

differences in asynchronous mast flowering and fruiting marri trees throughout the region may lead to different distribution patterns of forest red-tailed cockatoos in future years. Great abundance of marri fruits may also reduce the dependence of Baudin's cockatoos on orchards and studying the species in a mast year may yield very different patterns, compared to those recorded in this study. Changes in the study landscapes and accompanying changes in distribution patterns of black cockatoos require ongoing studies, and this study has laid a solid basis to do so. This study has demonstrated a successful and time-efficient method to study large-scale habitat use black cockatoos, and provides as baseline dataset against which future changes in distribution patterns can be monitored.

It is recommended to conduct future studies on the same transect roads and perhaps on the same feeding trees to compare the results with the present study. Such repeat studies will undoubtedly reveal changes in usage of the younger revegetation by forest red-tailed cockatoos and perhaps the other two taxa as well. At the same time the impact of future changes in the Karnet area, which is currently being prepared for mining, can be compared with the current distribution patterns of forest red-tailed cockatoos.

6.5 Conclusions

Conservation planning for animal species inhabiting modified landscapes requires understanding of where animals occur and how they utilise both natural and modified habitats.

Black cockatoos have disappeared from areas where all native vegetation has been cleared. This study has demonstrated that landscapes, defined as 400 km^2 study areas, containing 80% of native jarrah forest can still support large flocks of forest red-tailed cockatoos and Baudin's cockatoo, as well as smaller numbers of Carnaby's cockatoo. Feeding observations demonstrated the importance of the jarrah forest vegetation as a food source for especially the forest red-tailed cockatoo and Baudin's cockatoo, with especially marri seeds constituting the main part of the their diet. At present, it is unknown what minimum ("threshold") percentage of native forest cover is required to sustain healthy populations of especially forest red-tailed and Baudin's cockatoos. Given the serious conservation status of both taxa, it is important that management plans focus on preservation of the existing northern and southern jarrah forest and where possible revegetate previously cleared areas.

The Pickering Brook, Wungong and Karnet study areas all contained 20% modified land, but differed in the type of modification. This study investigated the relationship between the distribution patterns of modified land use types and those of black cockatoos by constructing Generalised Linear Models based on bird counts and land use data along 90.5 km of road transects. The Akaike Information Criterion (AIC) was used to select a set of the most parsimonious candidate models. Models were constructed at two scales: Regional models incorporated the datasets of all three study areas, while study area models used the datasets of single study areas.

Models for the forest red-tailed cockatoo indicated that the taxon avoided young post-1988 revegetation at both the regional scale and within the Wungong study area. This response most likely reflects known adversity of this taxon to feeding close to the ground and indicates that at the time of the study, the trees in the young revegetation were still too small to offer the birds a feeding habitat. Hence, the findings of this study do not suggest that modification of Alcoa's current revegetation practices is necessary with respect to planting jarrah and marri trees. However, preferential planting of patches of Fraser's sheoak in among the uniform "jarrah-marri mix" may form an important addition.

Models for Baudin's cockatoo indicate that this taxon selected in favour of orchards at the regional scale. These findings suggest that post-breeding movement patterns of Baudin's cockatoo were affected by the distribution of orchards, to which they are known to flock in great numbers. Since feeding in orchards exposes the birds to the risk of being shot illegally by orchardists, this is a serious issue. Baudin's cockatoo has a naturally low reproductive rate and recent figures indicate that the current annual loss of adult birds due to shooting is unsustainable and, will lead to extinction of the taxon in the next few decades (Chapman 2007b). An extensive management program for Baudin's cockatoo in the orchard regions of Western Australia is urgently needed, and should focus on preventing mortality due to shooting is urgently needed.

No models were constructed for Carnaby's cockatoo due to a limited number of observations for this species. Feeding observations showed that plantations of introduced pine were the most frequently utilised feeding habitat. This suggests that management plans for Carnaby's cockatoo in the northern jarrah forest region should focus on preserving existing pine plantations while revegetation with native species is under way. The greatest gain in conservation of this taxon, however, probably lies in protection and large-scale revegetation of their traditional breeding habitat in the Avon Wheatbelt. However, this is outside the scope of this study.

In conservation efforts, identification of critical habitats is an important first step. This study has highlighted the importance of studying habitat selection and constructing management plans at an appropriate scale, relative to the range of the target species. Wide ranging species like black cockatoos require regional scale protection of important broad vegetation types such as the northern jarrah forest, combined with landscape scale protection and restoration – for instance during post-mining revegetation – of specific feeding habitat and food species, such as pine for Carnaby's cockatoo and possibly Fraser's sheoak for the forest red-tailed cockatoo.

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