# CHAPTER 1 General Introduction

## 1.1 Introduction

The process of habitat loss and habitat fragmentation is largely responsible for a decline in biodiversity around the world. The reasons for these declines are complex and vary depending on the ecology of the species involved. Compounding the loss of essential habitats are problems associated with habitat alteration and habitat degradation. Examples of these problems are: "edge effects", changes to the dynamics of an ecosystem that arise wherever a particular habitat type is interrupted by a sharp transition to land altered by anthropogenic practices; restrictions to animal movement and dispersal; and changes to the frequency and intensity of natural disturbances such as fire.

The effects of habitat fragmentation on bird communities have been widely studied (e.g. Galetti *et al.* 2003, Campi and Mac Nally 2001, Mac Nally *et al.* 2000). However, most studies have focused on documenting changes in patterns of community composition, with relatively few studies attempting to identify the particular factors that limit the population sizes of some species relative to other, more abundant species. The reasons for the increased vulnerability of some species to habitat alteration thus remain unclear.

Land clearing for agriculture is largely responsible for declines in the distribution and abundance of 30-90% of bird species in Australia (Recher 1999). The effects of habitat alteration on nesting success are well documented (e.g. Stephens *et al.* 2003, Andren 1992). Less well studied are impacts on food availability. One of the biggest challenges for conservation biologists is to understand how changes in the quantity and quality of feeding habitat influence foraging success, or rate of food intake. An important first step for these investigations is to identify the factors influencing habitat selection at appropriate spatial scales. Only then can we define habitat selection from the animal's perspective and begin to seek strategies that maximize food availability.

Food availability has been suggested by several authors as an important factor influencing the status and distribution of cockatoo species (Saunders 1980, Cooper *et al.* 2002, Pepper 1997). The importance of food availability and feeding strategy is exemplified by this group, because some cockatoo species have expanded their range and increased in numbers to the point of becoming pests in agricultural areas, while others have severely declined in numbers and range. The cockatoo species that have expanded their range and/or have increased in numbers since European settlement are invariably the generalist species that have adapted their diets to take advantage of introduced plants. Examples include the Galah *Cacatua roseicapilla* (Rowley 1983) and inland Red-tailed Black Cockatoo

*Calyptorhychus banksii samueli* (Higgins 1998). Those that have declined, such as the South Australian Glossy Black Cockatoo *C. lathami halmaturinus*, Carnaby's cockatoo *C. funereus latirostris*, south-western Red-tailed Black Cockatoo *C. b. naso* and south-eastern Red-tailed Black Cockatoo *C. b. graptogyne*, are largely restricted in diet to one or several native plant species (Attiwill 1960, Joseph 1982, Saunders 1980, Johnstone and Kirkby 1999).

Granivorous birds such as cockatoos depend on a food supply that tends to fluctuate in abundance and distribution depending on temporal factors such as phenology (timing of reproductive events (Johnstone and Kirkby 1999), and on spatial factors such as the number of fruits per plant (Clout 1989) and tree density (Summers and Proctor 1999). Many cockatoo species are able to overcome temporal fluctuations in food supply by switching from one food source to another when food shortages occur. Introduced plants seem to be particularly important in the diets of many cockatoo populations. For example, Carnaby's Cockatoo feeds primarily on the seed of various native shrubs, but will feed on *Erodium* ssp., an introduced pasture grass, when it becomes available (Saunders 1982). In contrast, highly specialised species must depend entirely on one or a few food species when food shortages occur, and are thus much more susceptible to the negative impacts of habitat loss.

Rate of seed intake becomes critically important in situations when food availability is limiting. Saunders (1980) demonstrated that a population of Carnaby's Cockatoo occurring in a highly fragmented environment had to forage over a much greater area than a population occurring in a region where less habitat had been cleared and connectivity between remnants was high. The poorer quality habitat was linked with lower nesting success and lower nestling weights, suggesting that rate of seed intake was not sufficient for breeding in these areas (Saunders 1990a). These problems were the likely cause of a subsequent decline in population numbers in fragmented areas and the disappearance of the cockatoo from much of its former range (Saunders 1990b).

## 1.2 Study species

The south-eastern Red-tailed Black Cockatoo is one of five subspecies occurring in seven or eight isolated populations across Australia (Ford 1980, Higgins 1998). As a species, the Red-tailed Black Cockatoo occurs in a variety of habitat types ranging from tropical rainforest to the arid regions of inland Australia. It is primarily granivorous, but uses a variety of other foods including: nectar, flowers, fruits and berries, insects and insect larvae (Higgins 1998). Differences in feeding ecology between populations are striking. In some areas (usually high rainfall, forested regions), the species is exclusively arboreal, and in others (usually arid regions) is almost entirely ground-feeding (Higgins

1998). These differences in feeding ecology are likely to have arisen because of differences in climate and habitat type, and are probably associated with subtle morphological differences related to wing length and bill size. The south-eastern subspecies has shorter wings and smaller bills than the other subspecies (Ford 1980), and is also distinguished by the lack of a step in the cutting edge of its maxilla (Schodde *et al.* 1993). The smaller wing size of the south-eastern subspecies may relate to its relatively small range and dense woodland habitat, which contrasts to the open, riverine habitats of the northern subspecies and the tendency of these subspecies to undertake regular seasonal movements across large distances (Higgins 1998).

The current range of the cockatoo is restricted to a small area in the lower south-east of Australia, which straddles the South Australia-Victoria border (Figure 1.1). A picture of a juvenile south-eastern Red-tailed Black Cockatoo is given in Figure 1.2.

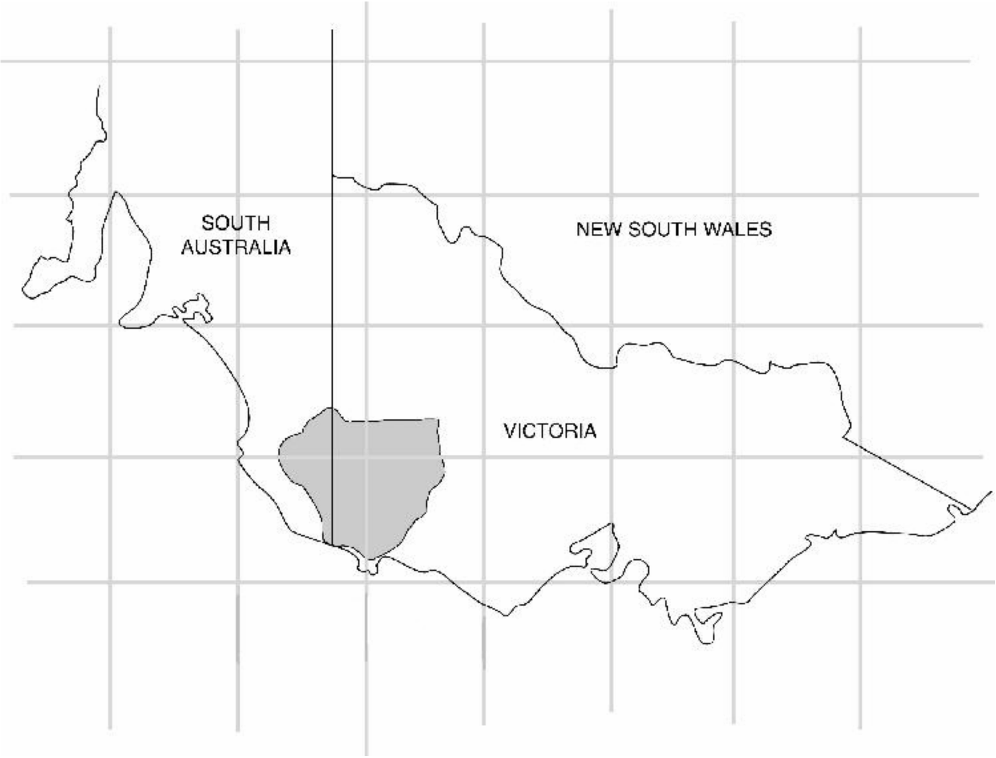


**Figure 1.1.** Overview of the range of the south-eastern Red-tailed Black Cockatoo subspecies.

**Figure 1.2.** Juvenile south-eastern Red-tailed Black Cockatoo. Photo provided by Richard Hill.

Information regarding the former range of the cockatoo is limited, but historical sightings records suggest that the subspecies occurred east of its current distribution, towards Ballarat and Melbourne (Baird 1986). Burnard and Hill (2001) speculate that the cockatoo may have occurred further west along the Naracoorte coastal plain, where stringybark was formerly abundant on sandy rises.

The south-eastern subspecies is unusual among Red-tailed Black Cockatoo populations in its degree of specialisation. It is arboreal and feeds almost entirely on seeds of the closely related stringybark eucalypts, Desert Stringybark *Eucalyptus arenacea* and Brown Stringybark, *Eucalyptus baxteri* (Attiwill 1960, Joseph 1982). The two species of stringybark are morphologically very similar and have only been distinguished on the basis of subtle differences in bud characteristics (Mills pers. comm.) and seedling morphology (Marginson and Ladiges 1988). *Eucalyptus baxteri* is strongly serotinous and retains its seed capsules in the canopy for 3-4 years, although seed availability gradually declines over time through natural decay and seed predation by insects (Andersen 1989). Very little is known about the ecology and phenology of *E. arenacea*, but it is thought that this species evolved from *E. baxteri* following the deposition of new sands when the ocean transgressed the land in the Tertiary period (Marginson and Ladiges 1988). The distributions of the two stringybark eucalypts in the range of the south-eastern Red-tailed Black Cockatoo are poorly known.

The only other food source that the cockatoos regularly use is seeds of Buloke, *Allocasuarina leuhmanii*, which occurs on prime agricultural soils and has been extensively cleared. *A. leuhmanii* seed is only available for a few months in the autumn, as the seeds are shed from the tree soon after ripening. Moreover, the species does not seem to produce a substantial crop every year, and fruiting patterns may follow a biennial or triennial pattern (Maron pers. comm.). Therefore, *A. leuhmanii* makes up a small proportion of the diet, although the importance of *A. leuhmanii* seed in the diet of the cockatoo is unclear.

The south-eastern Red-tailed Black Cockatoo is listed as endangered under the Environment Protection and Biodiversity Conservation Act 1999 (C2b), and is currently the focus of a Recovery Programme. It is considered to be endangered due to its small population size, which is reported to be at least 686 and thought to be less than 1000 (Burnard and Hill 2001), an inferred low proportion of breeding adults (Joseph *et al.* 1991) and a continued decline inferred from ongoing habitat loss due to legal and illegal clearing (Burnard and Hill 2001).

## 1.3 Potential factors limiting the south-eastern Red-tailed Black Cockatoo

### 1.3.1 Breeding success

Research on the breeding biology of the south-eastern Red-tailed Black Cockatoo was recently undertaken in order to identify possible reasons for the small population size of this subspecies (Burnard and Hill 2001). Knowledge of nesting success is limited by small sample sizes, because of the difficulties associated with finding nests. The cockatoos nest in the hollows of eucalypts, and particularly those of dead Red Gums *E. camaldulensis*, which typically occur on private land. The nests are found less often in hollows of *E. baxteri* and *E. arenacea* by researchers, although nests are more difficult to find in stringybark woodland because of greatly reduced visibility and accessibility in these areas. It is likely that fewer suitable hollows occur in stringybark woodland now than occurred prior to European settlement, because of extensive logging in the region, which has greatly reduced the extent of old growth forest (Anonymous 1999). Hollow availability is not thought to be currently limiting for the cockatoo population because large numbers of hollows are unused, though apparently suitable for nesting in terms of hollow dimensions and aspect (Hill unpubl. data, Koch pers. obs.). However, hollow availability may become limiting in the medium to long term due to the natural decay of dead, hollow bearing trees on private land (Burnard and Hill 2001).

Flock counts are used to determine the ratio of barred birds (birds with yellow markings on their feathers; females and juveniles) to unbarred birds (males), in order to estimate the percentage of juveniles recruited into the population. Burnard and Hill (2001) determined that an average of 23% of birds in flocks are juveniles or sub-adults (0-3 years old). Based on this proportion, it is likely that recruitment is sufficient to maintain the current population, because the cockatoos are long-lived (Higgins 1998) and mortality is thought to be low. However, flock composition counts assume an equal sex ratio in the population because juvenile birds are not distinguishable from females. Given that the sex ratio in the cockatoo population is unknown, the evidence with respect to breeding success is inconclusive, but suggests that the population is stable with at least some recruitment.

Nest success data, though limited to some extent by small sample sizes, suggests that the percentage of nests producing fledged young is low in some years when compared with other Black Cockatoo populations (Burnard and Hill 2001). In 1998, the estimated nest success was 30%, which is comparable to that of some other Black Cockatoo populations (Burnard and Hill 2001). In the following year, however, estimated nest success was just 13%, which is low enough to be of serious concern

(Jarmyn 2000). The eggs of Red-tailed Black Cockatoos are eaten by ravens *Corvus* sp., and the eggs and chicks are attacked and eaten by Brush-tailed Possums *Trichosuraus vulpecula*. Nest predation by possums is a major cause of nest failure for this cockatoo (Jarmyn 2000). However, nest predation is likely to be less important for this cockatoo than for the Glossy Black Cockatoo population on Kangaroo Island, where possums have increased in abundance (Garnett *et al.* 1998).

Disturbance during incubation time is also likely to be an important cause of nest failure for the south-eastern Red-tailed Black Cockatoo (Jarmyn 2000). Female absences at unusual times of day were recorded at all nests where eggs failed to hatch. Females normally leave the nest for short periods to be fed by the male each evening (Burnard and Hill 2001). Therefore, female absences during the day may indicate that the food provided by the male was inadequate, and needed to be supplemented by the female. This type of behaviour was linked to inadequate food supply for Carnaby's Cockatoo (Saunders 1980).

### 1.3.2 Loss of feeding habitat

Alteration of land use patterns associated with the settlement of south-eastern Australia by Europeans dramatically altered the landscape in this region. Extensive clearing for agricultural development greatly reduced and fragmented the amount of native vegetation, leaving "islands" of native vegetation surrounded by a "sea" of agricultural land. Land clearing was concentrated in fertile areas that were well suited to agriculture, leaving a greater proportion of native vegetation which occurred on deep sands, saline soils or limestone (Croft *et al.* 1999). Consequently, the stringybark of the region, which occurs on deep sands, was cleared less extensively than the grassy woodland communities which occur on the more fertile floodplain soils. Nevertheless, approximately 50% of stringybark has been cleared in the range of the Red-tailed Black Cockatoo since European settlement (Burnard and Hill 2001). Clearing was particularly intensive in South Australia, where approximately 87% of the total native vegetation has been removed (Croft *et al.* 1999). Because land clearing was concentrated in more fertile areas, it is likely that the remaining habitat is of lower resource value to the cockatoos than the habitat occurring prior to European settlement. Therefore, it is likely that land clearing has reduced both the quantity and quality of feeding habitat available to the south-eastern Red-tailed Black Cockatoo.

In addition to the severe loss of habitat caused by land clearing, extensive commercial logging for timber production has removed much of the old growth forest in the region (Anonymous 1999). Sawmilling commenced in the 1850s and continued until at least the 1960s, although the intensity of timber harvesting varied over this time (Anonymous 1963, Anonymous 1999). Many parts of the cockatoos' range were particularly intensively logged during the early to mid 1900s, leaving some forest stands as young as 50 years old (Anonymous 1963, Anonymous 1999). It is likely that logging has substantially reduced seed availability to the Red-tailed Black Cockatoo over the past century, due to the selective harvesting of larger, more productive trees.

### 1.3.3 Effects of fire on food availability

The woodland in southeastern Australia has a long history of deliberate burns. Prior to European settlement, deliberate "firestick" burns were performed by aboriginies for hunting, and to clear a path through dense vegetation for travel (Whelan 1995). However, the burns may have been largely restricted to grassy woodlands, and it is not known whether the burns were performed in stringybark woodland of the region (Gill 1981, Luke and McArthur 1978). From the 1900s to the 1920s, deliberate burns were performed in stringybark by farmers to reduce the risk of wildfire and to increase the palatability of plants for cattle (Luke and McArthur 1977, Cleary pers. comm.). It is thought that deliberate burns were widespread, intense and poorly controlled during this time (Christensen and Kimber 1975). A fire exclusion policy was implemented in the 1920s, but was terminated 35 years later following a number of intense wildfires.

In the mid 1950s, prescribed burns were introduced (Christensen and Kimber 1975, Luke and McArthur 1978). These burns were performed by fire management authorities, primarily to reduce the risk and extent of wildfires, and were performed under cool weather conditions that allowed for greater control and resulted in lower intensities than burns caused by wildfires. Currently, prescribed burns are performed for ecological management as well as wildfire suppression. Broad-acre (block) burning was practised throughout the region until 1989, when a moratorium on block burns was introduced in the Horsham region. The moratorium was introduced in response to concerns about food supply for the Red-tailed Black Cockatoo raised by staff from the Department of Natural Resources and Environment, Victoria. In the Horsham region, block burns were subsequently replaced by strip burns, the burning of strips along the perimeters of remnants and fire tracks. Strip burns reduce fuel loads in strategic areas to form a fire break and prevent the spread of wildfire. In most parts of the range, however, block burns are still practiced.

These burns are of particular concern in South Australia, where fire frequencies are generally prescribed at 3-8 years, with the exception of some areas set aside for less frequent or no burning (Millard 1998). Fire intervals in Victoria depend upon a system of management zones that place a varying degree of emphasis on asset protection, fuel reduction and ecological management (Coleman 1995).

Food availability after fire is an important concern for birds requiring mature vegetation for nectar or seed (Woinarski and Recher 1997), but is likely to vary depending on the responses of the food plants in question. Eucalypts are considered to be well-adapted to fire in terms of vegetative recovery (Gill 1978), but very little is known about their reproductive performance after fire. According to resource allocation theory, an increase in vegetative vigour will generally necessitate a reduction in the resources available for reproduction (Reekie and Bazzaz 1987). Therefore, the availability of seed to cockatoos following prescribed burns depends on how resources are partitioned between vegetative and reproductive functions in the years following fire.

## 1.4 Objectives of the study

The present study was initiated by the Red-tailed Black Cockatoo Recovery Team in response to an objective identified in the Recovery Plan (Action 6): to determine the effect of prescribed burns on food availability (Burnard and Hill 2001). This problem was approached first, by identifying the key components of food availability (capsule quantity, food value per capsule and tree characteristics) influencing the selection of trees and sites for foraging by the cockatoos, and second, by assessing the impact of prescribed burns on these components and levels of habitat use by the cockatoos. The issue of fire management was also considered in the broader context of food availability for the south-eastern Red-tailed Black Cockatoo population, and in relation to other factors such as phenology, periodicities between seed crops and edge effects.

Specifically, the aims of the study were to:

(1) describe the reproductive biology and distributions of *E. baxteri* and *E. arenacea* in the range of the south-eastern Red-tailed Black Cockatoo;

(2) determine the aspects of seed availability influencing the selection of trees and sites for foraging by the south-eastern Red-tailed Black Cockatoo;

(3) describe the foraging ecology of the south-eastern Red-tailed Black Cockatoo, and determine how aspects of seed availability influence foraging performance;

(4) assess the recovery of seed availability after fire and patterns of habitat use by the south-eastern Red-tailed Black Cockatoo;

(5) assess the recovery of seed availability for the south-eastern Red-tailed Black Cockatoo following burns at different intensities;

(6) assess the value of induced edges as feeding habitat for the south-eastern Red-tailed Black Cockatoo; and

(7) determine whether food supply is likely to be limiting the south-eastern Red-tailed Black Cockatoo.

# CHAPTER 2 General Methods

## 2.1 Description of the study area and study sites

The study area and range of the south-eastern Red-tailed Black Cockatoo is shown in Figure 2.1. The study area included remnants near the Harrow, Edenhope, Dergholm and Casterton regions of south-west Victoria and near Penola in south-east South Australia. This area makes up a large proportion of the range of the south-eastern Red-tailed Black Cockatoo. The location of study sites is given in Figure 2.2.

The study sites consisted of dry sclerophyll forest of predominantly *E. baxteri*, or *E. arenacea*, in association with a diverse, heathy understorey. The stringybark of this region is restricted to well-drained, aeolian sands that occur as irregular, low dunes over fertile clay (Enright 1978). The sands are generally poor in nutrients (Venning 1978) and are unsuitable for pasture, although some areas are used for grazing and cereal crops in the Naracoorte Range (Koch pers. obs.). The understorey is typically dominated by small shrubs such as *Leptospermum* sp., *Leucopogon* sp., *Astroloma* sp., and *Hibbertia* sp. with occasional tall shrubs such as *Banksia marginata* and *Banksia ornata* (see Purdie and Slayter 1976, for a detailed description of the understorey). *Xanthorrhoea australis* and *X. caespitosa* are also prominent in some areas.

The study area has a cool, temperate climate, with rainfall tending to increase in mountainous regions such as the Grampians and with increasing proximity to the coast (Anonymous 1999). Annual rainfall in the Portland region of south-west Victoria generally exceeds 800 mm (Anonymous 1999), while average annual rainfall in the region is 600-650 mm (Croft *et al.* 1999, Anonymous 1999).

## 2.2 General approach to the study

The study was designed to assess the importance of phenology, periodicities between seed crops, time since fire, fire intensity and edge effects in relation to seed availability for the south-eastern Red-tailed Black Cockatoo. An extensive habitat survey (referred to hereafter as the broad-scale habitat survey) was used to assess the effect of time since fire on patterns of seed availability and habitat use by the cockatoos. This survey also provided the basis for investigations into the effects of edges on capsule availability, and to assess the importance of various components of resource availability as factors influencing the selection of trees and sites for foraging. The methods for this survey are described below. Additional surveys were performed to determine whether and how far edge effects extended into the interior of remnants, and to determine whether the cockatoos selected trees on the basis of capsule

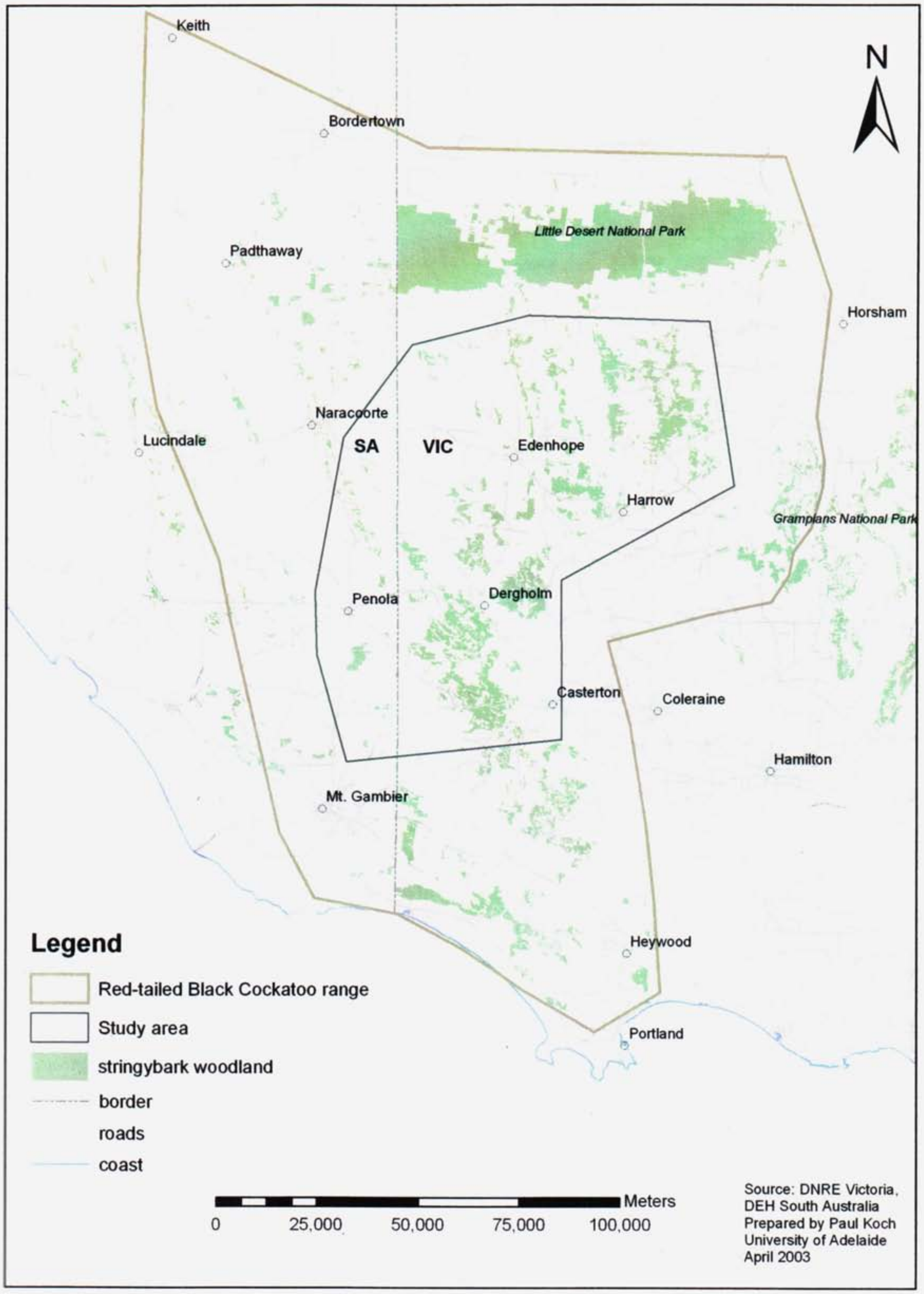
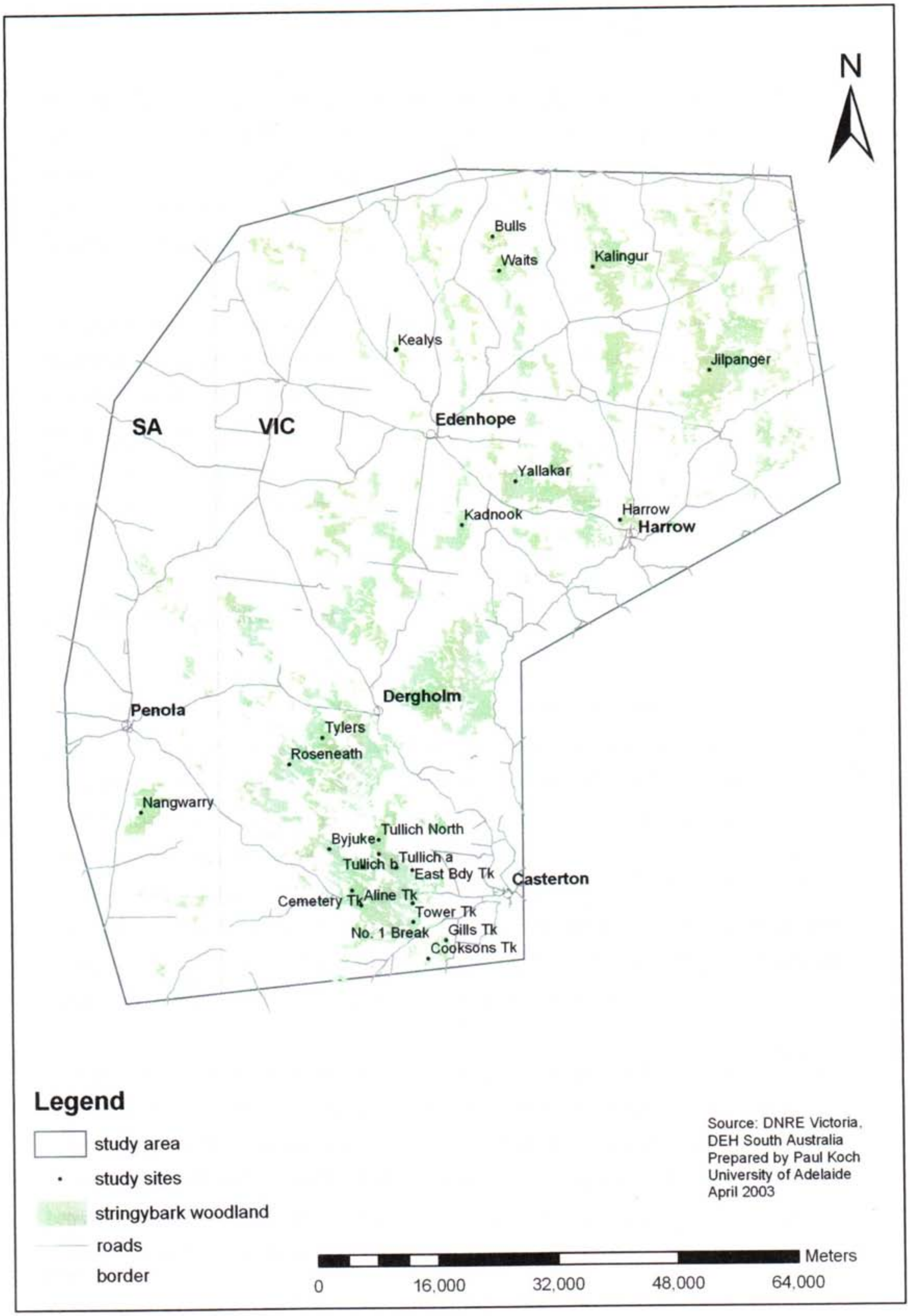


**Figure 2.1.** Overview of study area and distribution of stringybark woodland in the range of the south-eastern Red-tailed Black Cockatoo.



Source: DNRE Victoria, DEH South Australia
Prepared by Paul Koch
University of Adelaide
April 2003

**Figure 2.2.** Study area inset showing the location of study sites.

profitability (food value per capsule) characteristics. Foraging observations were used to determine whether food supply is likely to be limiting the cockatoo population, and these were made opportunistically during the study depending on where the birds were known to be feeding. Sites for phenology monitoring were set up early in the study and were monitored for the duration of the study to determine patterns of seed production for the two stringybark eucalypts.

The variables used to indicate resource availability for the cockatoos included: measurements of capsule quantity per tree and per branch (referred to in the present study as capsule availability characteristics), measurements of the amount of edible material per capsule (capsule characteristics) and measurements of tree size and health (tree characteristics). These variables were selected prior to observations of foraging cockatoos being made, based on the types of variables that influence the foraging behaviour of other Black Cockatoos (Clout 1989, Johnstone and Kirkby 1999, Pepper *et al.* 2000).

## 2.3 Broad-scale habitat survey

*Selection of sites and sampling methods*

The survey was performed during 2000, and included sites that were 3, 5, 6, 7, 9, 11 and >25 years since fire. The >25 years since fire group is referred to hereafter as “unburnt”, and the groups 3-11 years since fire referred to as “burnt”, for the purpose of comparison. All burnt sites had been burnt before the study commenced according to prescribed burn guidelines (see Coleman 1995, Millard 1998). Although the burns are prescribed as low intensity, they typically result in complete canopy scorch because of the generally low tree height in the region and the high loads of vertical, suspended fuels formed by the understorey (Koch pers. obs.). The time since fire of each site was confirmed using fire history maps, and by consultation with fire management authorities (Department of Environment and Natural Resources staff in Victoria and Forestry SA staff in South Australia).

There were three replicate sites for all time since fire groups except the 3 years since fire group, which had four replicate sites. Each burnt site was paired with an unburnt site that had not been burnt for at least 25 years. Paired sites were located not greater than three kilometres apart, to help minimise effects caused by variation in soil, topography and weather patterns. A single unburnt site was shared between multiple burnt sites where burnt sites occurred within a few kilometres of each other. A total of 30 sites were surveyed, comprising 19 burnt sites and 11 unburnt sites.

At each site, trees were selected according to a stratified random sampling design that comprised six sampling points per site, three points at the remnant “edge” and three points at the remnant “interior”. An edge was defined as any induced habitat perimeter that was bordered by an area cleared of vegetation for at least ten meters. This definition was based on the observation that many trees on the perimeter of remnants appeared to have more voluminous canopies than trees at the interior, even where edges were formed by bitumen roads, gravel roads or fire tracks. Differences in productivity between edge and interior trees are the subject of Chapter 6. Interior sampling points were located by pacing 150 m from edge sampling points into the remnant interior at a bearing perpendicular to the site perimeter. The three sampling points at each position (edge or interior) were spaced 100 m apart. The survey area per site was thus three hectares.

At each point, the eight nearest trees were selected for the survey, providing a sample of 48 trees per site and 24 trees per position. The appropriate number of trees to be sampled at each sampling point was determined using a power analysis to determine within-site variability of preliminary data. A test for differences between edge and interior showed the power of the test to be 0.97 at the 0.05 significance level, and the minimum sample size needed to detect a significant difference to be 22 trees per site.

The canopy of the trees studied is modular in architecture and is made up of clumps of foliage held on branches of approximately 10-20 mm diameter, that are easily recognised (Koch pers. obs.). Each of these branches usually held a similar quantity of foliage, and were used as the unit of measurement for estimates of habitat use and capsule availability (Figure 2.3).

**Figure 2.3.** Typical branch, the unit of measurement for the study.

*Recovery of seed availability after fire: capsule availability*

Capsule density was estimated by counting the number of capsules per branch for three branches, and calculating the average. Binoculars were used to count capsules where necessary. Crop size (size of the standing crop of capsules) was estimated by counting the number of fruiting branches per tree and multiplying by the mean capsule density per branch. Similar methods have been used by Yates *et al.* (1994) for *Eucalyptus salmonophloia* and Maron (2000) for *Allocasuarina leuhmannii* to estimate crop size and fruit density. Branches were classified as fruiting when at least one capsule was present. Although in the present study the size of the standing crop was reduced to some extent by the cockatoos themselves, the bias would tend to minimise differences in crop size and capsule density between burnt and unburnt sites, because unburnt areas were used more intensively than burnt areas (see results for Chapter 5, Part A). Efforts were made to reduce this bias by avoiding counts of branches that showed signs of being heavily pruned by cockatoos (the visible effects of pruning are described below).

Cluster size, defined as the average number of capsules per pedicel, was used as an additional indication of capsule availability. Cluster size was observed to vary substantially between trees and it was therefore included as a measure of food availability. Cluster size was visually estimated by counting the number of capsules for approximately ten clusters, and estimating the average.

*Recovery of seed availability after fire: capsule volume*

Capsule volume was measured for a subset (7 out of 19) of the pairs of burnt and unburnt sites to determine whether fire is likely to influence capsule profitability (amount of edible material per capsule) for Red-tailed Black Cockatoos. Capsule volume is considered to be a good measurement of capsule profitability because it was strongly significantly correlated with measures of the amount of edible material in capsules such as total ovule weight per capsule (seed + infertile ovular structures called chaff) and individual seed weight. At each site, 10 capsules were collected from each of 15 trees (at core sampling points) using pruning secateurs attached to a 12 m telescopic aluminium extension pole. The dimensions of capsules were determined using calipers by measuring the width of the capsule and the distance from the capsule apex to the pedicel (length). The average of these dimensions was used as the diameter. Capsule volume was determined from these measurements using the formula for the volume of a sphere, because the capsules were approximately spherical in shape.

*Patterns of habitat use by cockatoos after fire*

Patterns of habitat use by cockatoos were assessed in relation to time since fire by measuring the percentage of branches used by cockatoos per tree and the percentage of trees used per sampling point. The cockatoos typically remove approximately 25 cm of the outermost foliage from branches used for feeding, presumably to allow easier access to, and manipulation of, those portions of the branch holding the fruits. Branches used for feeding are distinguished from other branches by the presence of branch tips that terminate as a woody stump rather than as a leafy shoot (Figure 2.4). A branch was considered to be used for foraging if at least one third of the outer foliage had been removed in a manner consistent with feeding by Red-tailed Black Cockatoos. The visible effects of “pruning” last approximately as long as the inter-crop interval (2-3 years) on heavily pruned branches, although less heavily pruned branches may recover their normal appearance more quickly (Koch pers. obs.). For this reason, the number of branches used per tree is not an exact measurement and can only be used as a crude indication of habitat use intensity for individual trees. However, the number of trees pruned per site is a good indication of habitat use intensity for the site as a whole.

**Figure 2.4.** Branches pruned by cockatoos. Note that few of the branch ends terminate as leafy shoots.

*Tree characteristics*

Tree measurements included: girth (circumference), height, canopy height, canopy diameter, number of branches and number of dead branches. The distance between trees was also measured at each sampling point, by selecting the nearest tree to each sampling point, and pacing the distance from this tree to the nearest adjacent (living) tree trunk in each direction (north, south, east and west directions). The average of these distances was used as the distance between trees. Percentage dieback was calculated as the number of dead branches divided by the total number of branches (live branches + dead branches), multiplied by 100.

Girth (tree circumference) was measured at breast height using flexible measuring tape. Canopy volume was calculated from measurements of tree height, canopy height and canopy radius, using the formula for the volume of a hemisphere (volume of a sphere divided by 2). A similar method was used for measuring canopy volume by Day *et al.* (1997) for *Banksia brownii*. The shape of trees varied, but most closely resembled a hemisphere. Tree height (maximum height of live foliage) and canopy height (minimum height of live foliage) were measured using a clinometer. Canopy radius was measured by pacing the distance from the trunk to the outermost live foliage in four directions, and taking the average. These measurements are illustrated in Figure 2.5. Branch density was calculated by dividing the canopy volume by the number of branches.

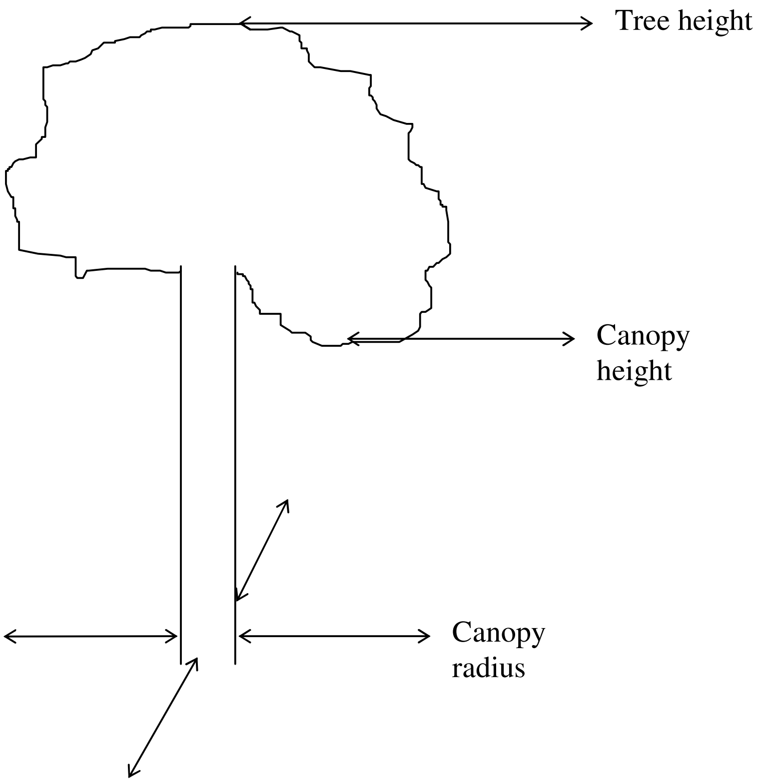


**Figure 2.5.** Diagram of the measurements used to calculate canopy volume.

# CHAPTER 3 Reproductive biology and distributions of *E. baxteri* and *E. arenacea* within the range of the south-eastern Red-tailed Black Cockatoo

## 3.1 Introduction

Aspects of reproductive biology such as phenology (within-year patterns in reproductive events) and periodicity (between-year patterns in reproductive events) are important factors influencing food availability to a wide range of birds and mammals using floral resources. For granivorous birds specialising on a small number of plant species, patterns of seed production in space and time should largely determine food availability. For example, the south-western Red-tailed Black Cockatoo feeds principally on Marri *Corymbia calophylla* and Jarrah *Eucalyptus marginata* (Johnstone and Kirkby 1999). Both trees produce a new seed crop approximately once every 4-6 years, and the cockatoos show a strong seasonal movement to Jarrah when it matures a new seed crop, suggesting that periodicity of seed production influences food availability for this cockatoo.

The south-eastern Red-tailed Black Cockatoo similarly depends almost entirely on two species for its food supply, *E. baxteri* and its close relative, *E. arenacea*. Both species of stringybark retain their capsules on the tree for 2-4 years (Andersen 1989, Koch pers. obs.), so seed is available to the cockatoos all year. However, the cockatoos seem to prefer feeding on the newly matured capsules (Attiwill 1960, Joseph 1982, Koch pers. obs.), and should forage in areas where fresh seed is available. Therefore, understanding the spatial and annual differences in seed production between the two species is central to predicting resource availability for the south-eastern Red-tailed Black Cockatoo, and the movements of the cockatoos about their range.

Prior to the present study, the distributions of the two species of stringybark within the range of the cockatoo were unknown. The two species are morphologically very similar and have only recently been distinguished on the basis of such characteristics as leaf and seedling morphology (Marginson and Ladiges 1988). However, consultation with beekeepers in the present study provided additional information that distinguishes the two species on the basis of differences in both flowering phenology and bud morphology. The flowering phenology (timing of reproductive events) of *E. baxteri* has been described previously by Andersen (1989), but the phenology of *E. arenacea* has not been described previously. The purpose of this part of the study was to: (1) confirm the differences in phenology suggested by the beekeepers; (2) compare patterns of seed production between the two species, within and between years. In addition, a new method for monitoring flowering phenology and flowering success (proportion of buds setting fruits) is presented; and (3) describe the distributions of the two species of stringybark throughout the range of the Red-tailed Black Cockatoo and relate the distribution of cockatoo sightings to these data.

## 3.2 Methods

### 3.2.1 Distinguishing between the two species of stringybark

Differences in bud morphology and in the relative position of reproductive structures were used to distinguish between the two species of stringybark. The differences in bud morphology between the two stringybark eucalypts are illustrated in Figure 3.1. Distinguishing between the two species requires practice, but the differences are consistent and reliable when viewed with “a trained eye”. Mature *E. baxteri* buds tend to be larger and are held more proximally on the branch than *E. arenacea*. The peduncles tend to be thicker, longer and older looking (more grey and warty). *E. arenacea* buds are generally light green in colour, are smaller, and are held more distally on the branch at flowering (closer to the tip of the branch). These differences probably relate to differences in the age of buds at maturity (*E. baxteri* buds are 1 year older at maturity - see results for timing of reproductive events). A tree was classified as one species or the other if it could be clearly defined according to these characteristics.

**Figure 3.1.** Comparison of mature buds between *E. baxteri* (left) and *E. arenacea* (right).

The presence of *E. baxteri* was confirmed by the presence of 1 year old buds and 2 year old buds occurring as two distinct cohorts (held separately) on a single branch. One year old buds were nearly at full size in November and were not to be confused with embryonic buds, which were smaller and emerged from the tips of the branch in November (these differences are illustrated in Figure 3.3). However, *E. arenacea* never had more than one cohort of buds present on the same branch. The presence of two conspicuous cohorts of buds on the same tree was also rare for *E. baxteri* (because the trees rarely flowered heavily in consecutive years), but often a few branches could be found with at least small quantities of both cohorts.

### 3.2.2 Method used to monitor phenology

Six study sites were selected between the months of August and October 1999 to monitor the timing of reproductive events. The study sites included remnants near Edenhope (Waits State Forest), Casterton (Tower Tk.), Dergholm (Roseneath State Forest) and Penola (Nangwarry). The location of these sites is given in Figure 2.2. The sites were selected across a large proportion of the cockatoos range to increase the chances of including both species in the survey. At the time of site selection, the species of stringybark occurring at each site was unknown. It was later determined that the sites comprised two *E. baxteri* sites (Roseneath and Nangwarry), three *E. arenacea* sites (Waits, Yallakar and Tower Tk.) and one site that occurred in a transition zone and included both species (North Tullich).

At each site, five trees were selected for phenology monitoring. All five trees at North Tullich were *E. baxteri*. The trees were selected along a transect that ran from the edge of a remnant towards its interior at a bearing perpendicular to the edge. Every 50m along the transect, the nearest tree was selected. Distances were paced and a compass used to maintain a bearing. Each tree selected was flagged with coloured flagging tape and allocated a numbered, metal tag that was nailed to each tree for subsequent identification.

Each tree was allocated three branch tags. Tagging branches helped to distinguish between different cohorts of buds, and enabled the fate of buds to be monitored more accurately. Branches were selected on the basis that they were metabolically active (active growth tips with buds emerging), within easy reach of the extension pole (less than 10 metres from the ground) and clearly visible through binoculars. Branches were tagged with metal, clip-on tags using a 12 m extension pole. The tags were made from galvanised steel brace, or builders brace. Builders brace was ideal for the tags because it had high tensile strength and was already perforated with holes at regular intervals. The brace was cut into 10 cm strips, positioning a large hole in the centre of each strip, and then shaped by hand (see

Figure 3.2), using a hammer where necessary. The hole in the centre of the strip became the attachment point for the probe of the extension pole.

To attach a tag to a branch, the probe of the extension pole was pushed through the hole at the base of each tag. Blu-tac® was used to help secure the tags onto the pole probe. The tag was then pushed over the branch with the open clasps facing toward the branch. After the tag was positioned around the branch, the extension pole was twisted to release the tag onto the branch. Each tag was tied with a piece of coloured flagging tape to distinguish between tagged branches on individual trees.

**Figure 3.2.** Tags used to identify branches of stringybarks being monitored in the study.

### 3.2.3 Timing of reproductive events

The reproductive cycle of eucalypts begins with the emergence of embryonic floral buds that are held on the plant for some time (typically 1-2 years) before the opercula are shed and flowering (anthesis) occurs (Andersen 1989, Ashton 1975). Flowering and pollination occur over a number of weeks (Ashton 1975). The ovary then develops into a woody capsule and the seeds mature, typically over a period of 9-12 months (Boland *et al.* 1980). The capsules are often retained on the plant for several years after seed maturation, and seed is shed gradually over this period through valves at the top of the capsule as it dries out (Boland *et al.* 1980). These stages are illustrated for *E. baxteri* in Figure 3.4 (see results for timing of reproductive events).

Each site was visited approximately once every three to four months over the years 2000-2002 to record information about the timing of bud initiation, flowering and caspule maturation. Sites were visited more frequently (two to three times) during times of flowering and capsule maturation to define the timing of these events more precisely. During each visit, anecdotal information was recorded about the colour, size and development of reproductive structures, for each of the branches being monitored. The timing of capsule maturation was assessed in the field by cutting the capsules open with tin snips and inspecting the seeds. Mature seeds were distinguished from immature seeds on the basis of colour, as suggested by Boland *et al.* 1980. Immature seeds were pale green with soft embryos, while mature seeds had dark brown seed coats with harder, white embryos.

### 3.2.4 Flowering success

Flowering success was defined as the percentage of mature buds producing capsules. Tagged branches were scored for the number of mature buds in early November 1999, and for the number of capsules set in May 2000, when flowering had finished. Flowering success was not measured for *E. arenacea* because these sites did not flower during this period. Counts of mature buds, flowers, immature capsules and mature capsules on each tagged branch were made using binoculars.

This method differs markedly from the cloth traps commonly used in similar studies (e.g. Setterfield and Williams 1996, Yates *et al.* 1994), which estimate capsule set from the number of opercula falling into traps. However, direct measurements of capsule set are likely to be more accurate because the cloth trap technique can only be used to measure the number of buds that flower. Tagging branches also has the advantage of being less expensive, provided that an extension pole can be acquired or purchased cheaply.

Flowering success was compared between sites using a nested ANOVA, with tree number nested in site. Flowering success data were square root transformed to improve normality for the test.

### 3.2.5 Synchrony of flowering

Synchrony of flowering was assessed as a means of predicting the synchrony of fruiting, and thus the percentage of trees that would provide seed to the Red-tailed Black Cockatoo. For the purposes of the present study, a tree was classified as synchronous if more than one third of branches had flowers produced in the same year as other trees of that species. During flowering periods (summer 2000 for *E. baxteri* and summer 2001 for *E. arenacea*) 20 trees were selected at random at each site and classified as synchronous or asynchronous. These surveys were performed once at all sites except North Tullich, since both eucalypt species occurred at this site, and trees selected at random were difficult to identify.

### 3.2.6 Flowering and fruiting intensity

On each of the 20 trees surveyed (above), the density of reproductive structures was estimated as a measure of flowering and fruiting intensity. The two cohorts measured were: (1) the most recent standing crop of capsules; and (2) mature buds, flowers or immature capsules. The canopy of the trees studied is made up of clumps of foliage held on branches of approximately 10-20 mm diameter (Koch pers. obs.). Each branch usually bears a similar quantity of foliage, and was used as the unit of measurement for the density of capsules and inflorescences per tree (a photo of a typical branch is given in Figure 2.3). Each tree was visually assessed for the density of reproductive structures per branch, and was classified according to a three point scale (low: ~0-99 capsules or inflorescences per branch; medium: ~100-299 capsules or inflorescences per branch, and high: >300 capsules or inflorescences branch). These assessments provided a crude means of comparing reproductive performance between sites and between each species of stringybark. It was assumed that the density of flowers was a reasonable indication of subsequent capsule production.

The distributions of percentage trees in each category were compared between sites and between each species of stringybark using Likelihood Ratio tests. The Likelihood Ratio test is a “goodness of fit” test that is interpreted in much the same way as Pearson’s chi-square test, but is calculated differently. The Likelihood Ratio test was used here because, unlike Pearson’s chi-square test, it does not require an expected cell count of at least five in the contingency table, and was thus more widely applicable. It has the same degrees of freedom as Pearson’s chi-square test [DF = (no. of rows-1) x (no. of columns-1)].

### 3.2.7 Distributions of the two stringybark eucalypts

All parts of the Red-tailed Black Cockatoo range were opportunistically visited over the years 2000-2002 and the stringybarks identified as being *E. arenacea* or *E. baxteri*. The only region within the known range not visited was the Grampians National Park, in which the birds are rarely sighted (Hill, unpubl. Data). Beekeepers pointed out the approximate distribution of the two species initially, and regions where the two eucalypt species overlapped (I. Mills and N. Mills pers. comm; referred to hereafter as “beekeepers”). Each area was confirmed as being one species or the other by walking through sites and inspecting buds, capsules and flowers to identify the two species. Where remnants were large or where both species were known to occur in the same region, the distribution of each species was confirmed by driving around the perimeters of remnants and stopping regularly to identify the trees. The distribution information is approximate, because not all remnants were visited for species confirmation. The locations that were visited are given in Figure 3.8 (see results).

Arcview version 8.2 was used to plot the distribution data, using a Geographic Information System (G.I.S.) of current and pre-European vegetation associations supplied by the Department of Natural Resources and Environment DNRE,(Victorian data) and the Department for Environment and Heritage DEH, (South Australian data). The distributions of the two stringybark eucalypts were mapped as an additional layer over the known distribution of stringybark woodland in each state, using data from the present study. For the Victorian vegetation data, the stringybark vegetation occurs in several "ecological vegetation classes", and these were first isolated from the other ecological vegetation classes in the current and pre-European vegetation layers, using G.I.S based methods. The ecological vegetation classes used for the stringybark woodland in Victoria included ecological vegetation class numbers: 48, 179, 645, 649, 713, 732, 786, 801 and 882. The principal ecological vegetation classes dominated by *E. baxteri* and/or *E. arenacea* were Heathy Woodland, Herb-rich Heathy Woodland and Damp Sands Herb-rich Woodland (Burnard and Hill 2001, see Anonymous 1999 for a description of ecological vegetation classes).

The percentage of each species that had been cleared in the range of the cockatoo was determined from the total area covered by each species in current and pre-European vegetation layers. The pre-European vegetation layer was not available for the Little Desert National Park, so the percentage of vegetation cleared in the park could not be determined. However, judging by the distribution of soil types suitable for the stringybark eucalypts (Tertiary and Quarternary siliceous sand deposits) it is likely that a low percentage of the park has been cleared (Koch pers. obs.). Estimates of the percentage of *E. baxteri* cleared in Victoria are likely to be conservative, because calculations were based on zero clearing of vegetation in the Little Desert National Park.

An additional layer of Red-tailed Black Cockatoo sightings was used to relate the distribution of the cockatoo in recent years to the distributions of the two species of stringybark. The cockatoo sightings layer was prepared by the DNRE, and the sightings data recorded by the Red-tailed Black Cockatoo Recovery Team.

## 3.3 Results

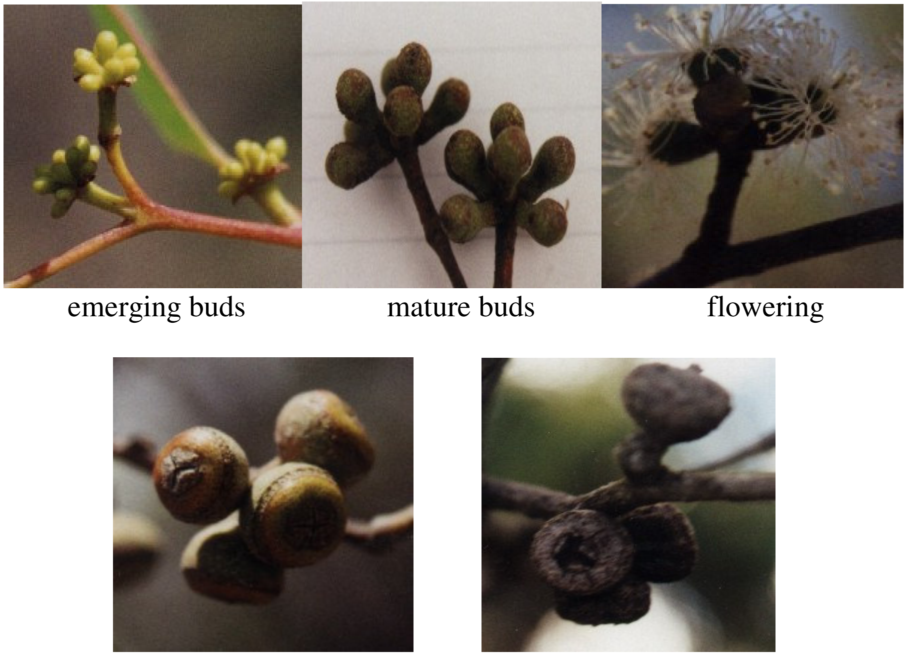
### 3.3.1 Timing of reproductive events

There were marked differences between *E. baxteri* and *E. arenacea* in the timing of reproductive events. Large, mature buds were present on most trees at *E. baxteri* sites, when the study commenced in October 1999. All three *E. baxteri* sites flowered heavily in early 2000, with flowering generally beginning in early January 2000 and finishing in early March 2000. By April all trees had finished flowering. Capsules approached full size in August 2000 and had attained maturity on most trees by October 2000. These capsules had begun to dehisce from trees by 2002. A second cohort of buds emerged on trees at *E. baxteri* sites in November 1999. These buds flowered in early 2002 and matured capsules in late 2002, although the precise timing (month) of flowering was not determined for this cohort.

By contrast, no mature buds were present at *E. arenacea* sites when the study commenced, although buds were initiated in November 1999. These buds flowered one year later in the summer of 2001, confirming the suggestion by beekeepers that this species requires only one year for bud development. Flowering began in early February 2001 and was generally completed by early April 2001. Capsules approached full size in September 2001 and had attained maturity on most trees by November 2001. A second cohort of buds emerged in November 2002. The fate of the second cohort of buds was not determined, but the buds would be expected to mature capsules in November 2004. Differences in the timing of bud and capsule development between the two species are shown in Table 3.1, and various stages of bud and capsule development are illustrated in Figure 3.3.

**Table 3.1.** Approximate timing of reproductive events recorded for two cohorts of ovules on *E. baxteri* and *E. arenacea*.

| Year | Month | ***E. baxteri*** | | ***E. arenacea*** | |
|---|---|---|---|---|---|
| | | **1st cohort** | **2nd cohort** | **1st cohort** | **2nd cohort** |
| Study commenced | Nov | Mature buds | Buds emerging | Buds emerging | |
| | Jan | ↓ | ↓ | ↓ | |
| | Mar | Flowering | | | |
| 2000 | May | | | | |
| | Jul | ↓ | | | |
| | Sep | | | | |
| | Nov | **Capsules maturing** | | | |
| | Jan | | | | |
| | Mar | ↓ | ↓ | Flowering | |
| 2001 | May | | | | |
| | Jul | | | ↓ | |
| | Sep | | | | Buds emerging |
| | Nov | Capsules aging | Mature buds | **Capsules maturing** | ↓ |
| | | | ↓ | | |
| | Jan | | | | |
| | Mar | ↓ | Flowering | | |
| 2002 | May | | | | |
| | Jul | | ↓ | | |
| | Sep | | | | |
| Study terminated | Nov | Capsules beginning to dehisce | **Capsules maturing** | | Mature buds |


emerging buds mature buds flowering

1 year old fruits 3 year old fruits

**Figure 3.3.** *E. baxteri* buds and capsules at various stages of development.

No differences between the two species in the appearance of the capsules were observed, except in relation to their age when the study commenced in October 1999. *Eucalyptus arenacea* trees generally showed an abundance of capsules which were greenish-brown at the beginning of the study. In contrast, capsules on *E. baxteri* trees were grey and woody looking, and were held more proximally on the branch (farther from the tip of the branch). Consultation with beekeepers confirmed that *E. arenacea* fruited heavily in 1998, while *E. baxteri* had not fruited heavily since 1996. *Eucalyptus arenacea* thus fruited in 1998 and 2001, and inspection of buds indicated that next fruit set would be in 2004. *Eucalyptus baxteri* fruited in 1996, 2000 and 2002. Therefore, *E. arenacea* fruited consistently on a three year cycle while *E. baxteri* fruited on a two to four year cycle.

### 3.3.2 Flowering success

Flowering success data (the percentage of mature flower buds setting capsules) were only available for the two *E. baxteri* sites (Nangwarry and Roseneath), and the site made up of both species of stringybark (Tullich). Flowering success was highly variable among trees, ranging from 0.4% to 100%. Among sites, flowering success was comparatively higher at Tullich (43%) than at Nangwarry (23%) and Roseneath (21%; Figure 3.4).

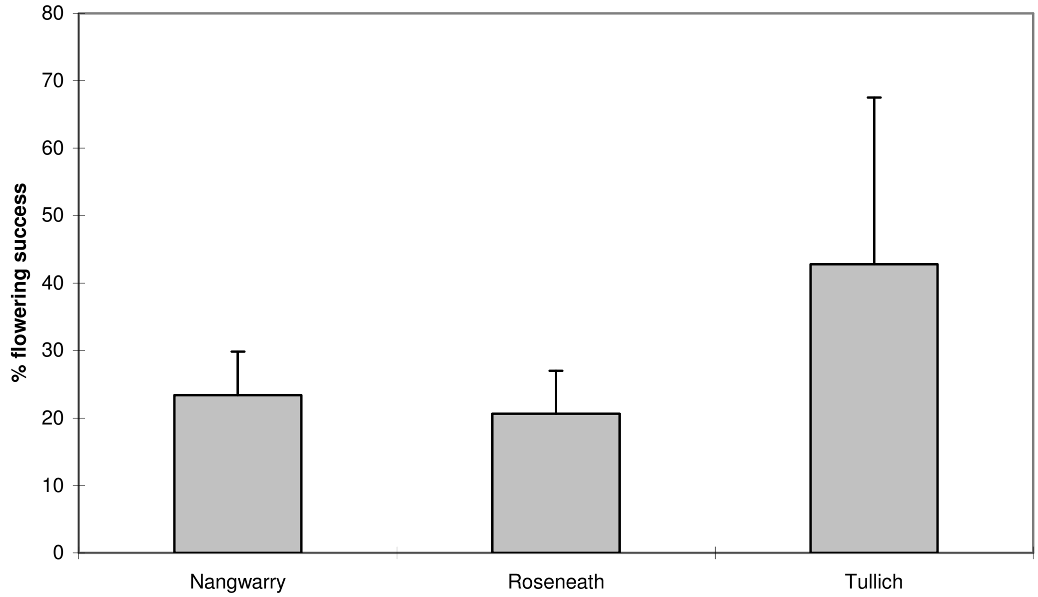


**Figure 3.4.** Mean (±SE) flowering success (percentage of mature buds setting capsules) at each site (n = 5 trees per site).

Comparison of flowering success (square root transformed) between sites using a nested ANOVA with tree nested within site showed no significant differences between sites ($F_{2,30} = 0.29$, $P = 0.75$). Branches of trees were used as replicates for the analysis (n = 5 trees x 3 sites x 3 branches = 45). However, there were significant differences between individual trees ($F_{12,30} = 3.08$, $P = 0.006$). The number of mature buds was significantly correlated with the number of capsules subsequently set ($r_s = 0.29$, n = 45, $P = 0.049$).

### 3.3.3 Synchrony of flowering

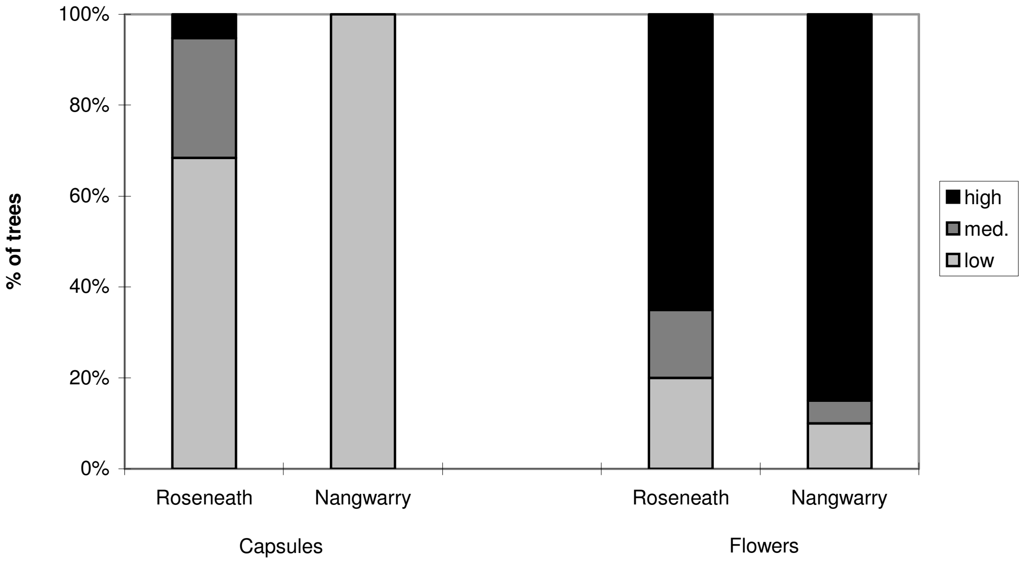
Trees were highly synchronous (flowered in the same year) within sites. Of *E. baxteri* sites, 100% of the 20 trees surveyed were synchronous at Nangwarry and 85% of trees (17 trees) were synchronous at Roseneath in the 2000 season. Trees at the three *E. arenacea* sites were all 100% synchronous in the 2001 flowering season. Trees at the Tullich site were not surveyed since they were made up of both *E. arenacea* and *E. baxteri*, and were not easily distinguishable.

### 3.3.4 Flowering and fruiting intensity

Flowering and fruiting intensity showed a similar pattern within species, but a markedly different pattern between species for the 2000 flowering season. The percentage of trees producing a high (>300 capsules or inflorescences), medium (100-299 capsules or inflorescences) and low density (0-99 capsules or inflorescences) of capsules and flowers at each site is given in Figure 3.5. Among *E. baxteri* sites, 65% of trees had a low density of capsules at Roseneath and 100% of trees had a low density of capsules at Nangwarry (capsules were matured in 1996 for this species). Both *E. baxteri* sites produced large amounts of flowers in the year 2000, with 65% of trees producing high amounts of flowers at Roseneath and 85% of trees producing high amounts of flowers at Nangwarry.

*Eucalyptus arenacea* sites produced few or no flowers in the year 2000 but had a generally high density of capsules (matured in 1998). A small percentage of trees produced a low density of capsules, with one site (Yallakar) had no trees with a low density of capsules matured in 1998.

**(a) *E. baxteri***



**(b) *E. arenacea***

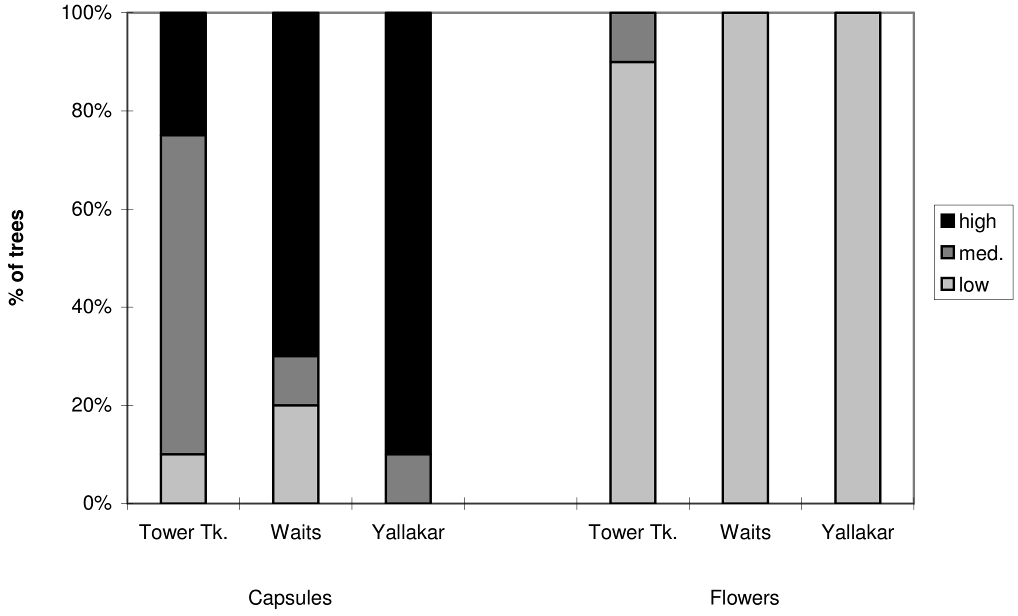


**Figure 3.5.** Percentage of trees in low (<100 capsules/inflorescences), medium (100-299 capsules/inflorescences) and high (300+ capsules/inflorescences) categories at: (a) *E. baxteri* sites; and (b) *E. arenacea* sites (n = 20 trees per site); for the 2000 flowering season. The two cohorts measured were: (a) mature capsules; and (b) flowers (mature buds, flowers or immature capsules).

There were significant differences between *E. baxteri* sites in the percentage of trees with low, medium and high capsule densities (Likelihood Ratio tests: n = 20, $\chi^2$ = 11.2, d.f. = 2, *P* = 0.004), but not in the percentage of trees with low, medium and high flower densities ($\chi^2$ = 2.26, *P* = 0.32). Similarly for *E. arenacea*, there were significant differences between sites for the density of capsules ($\chi^2$ = 26.93, d.f. = 4, *P* <0.0001), but not for the density of flowers ($\chi^2$ = 4.53, *P* = 0.1).

Averaged across sites for each species (Figure 3.6), the vast majority (83%) of *E. baxteri* trees produced low densities of capsules, while a large percentage of trees (75%) produced high quantities of flowers in the year 2000. In contrast, the majority of *E. arenacea* trees (62%) produced high densities of capsules, but most trees (97%) produced low densities of flowers during the year 2000.

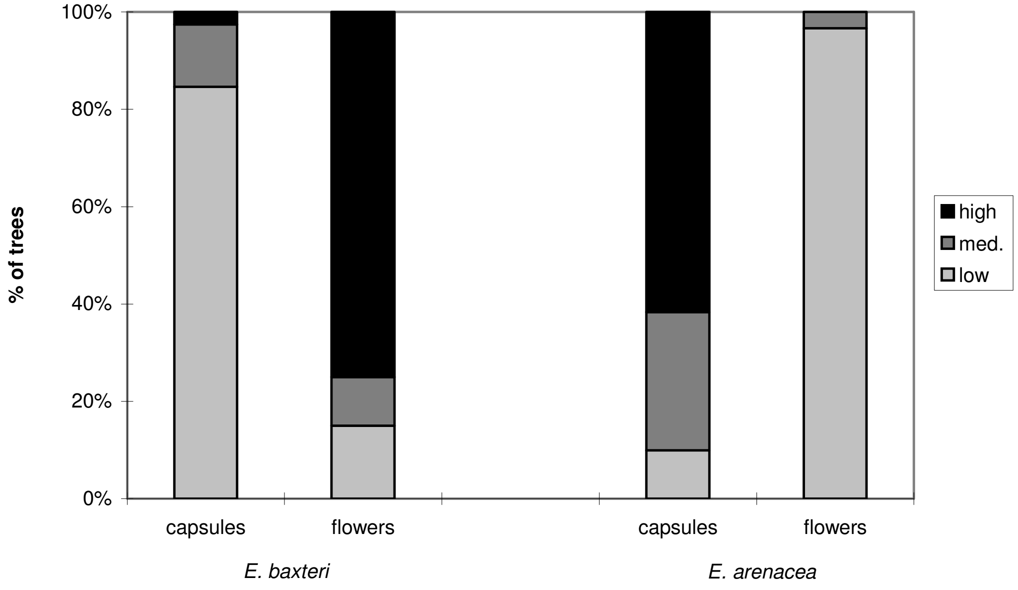


**Figure 3.6.** Percentage of trees in low (<100 capsules/inflorescences), medium (100-299 capsules/inflorescences) and high (300+ capsules/inflorescences) categories for each eucalypt species in the 2000 flowering season (n = 40 trees for *E. baxteri*; n = 60 trees for *E. arenacea*). The two cohorts measured were: (a) mature capsules; and (b) flowers (mature buds, flowers or immature fruits).

Significant differences between sites for the density of capsules categories precluded statistical comparisons between species for this variable, but differences between *E. baxteri* and *E. arenacea* in the percentage of trees with low, medium and high capsule densities were highly significant ($\chi^2 = 87.14$, d.f. = 2, $P < 0.0001$).

### 3.3.5 Distributions of the two stringybark eucalypts

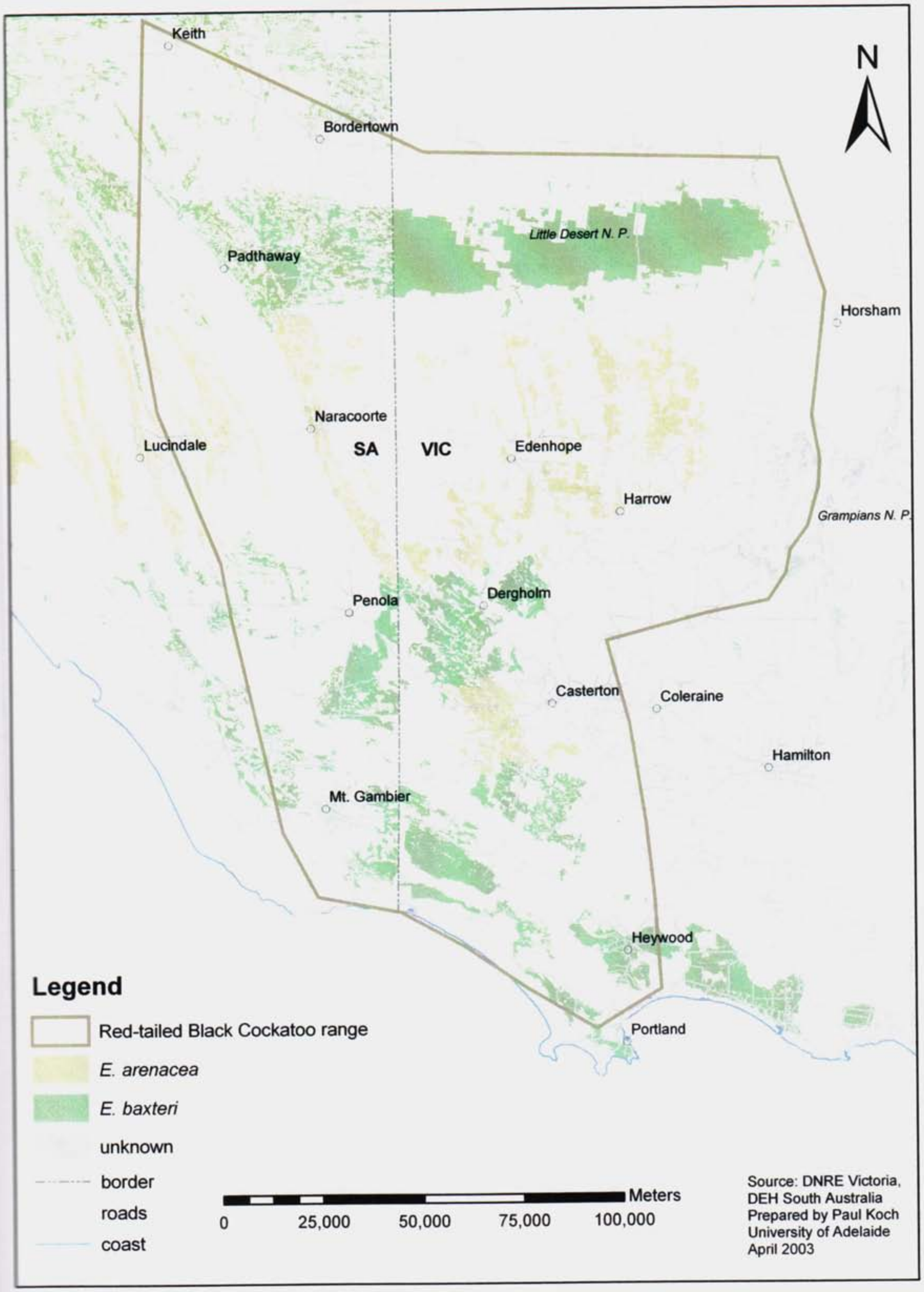
The pre-European and current distributions of the two species within the range of the south-eastern Red-tailed Black Cockatoo are given in Figures 3.7 and 3.8. *E. arenacea* occurs in the Casterton and Edenhope regions of Victoria and in the Naracoorte and Lucindale regions of South Australia. *E. baxteri* occurs in the Dergholm, Heywood and Dartmoor regions and in the Little Desert National Park within Victoria, and in the Padthaway, Mt Gambier and Penola regions of South Australia.

Comparison of Figures 3.7 and 3.8 shows the extent of clearing in the range of the Red-tailed Black Cockatoo. The areas worst affected by land clearing are the Padthaway, Naracoorte, Lucindale and Heywood regions. A large proportion of habitat remains in some regions of Victoria.

Prior to European settlement, *E. baxteri* comprised 72% of the habitat in the range of the Red-tailed Black Cockatoo, while *E. arenacea* comprised only 28% (excluding the “unknown” regions of Grampians National Park and the area north of Bordertown in South Australia). Remarkably, the same percentage of each species of stringybark remains currently. The percentage of each species cleared in each state was comparable within states, but a much higher percentage of both species has been cleared in South Australia than Victoria (Table 3.3).

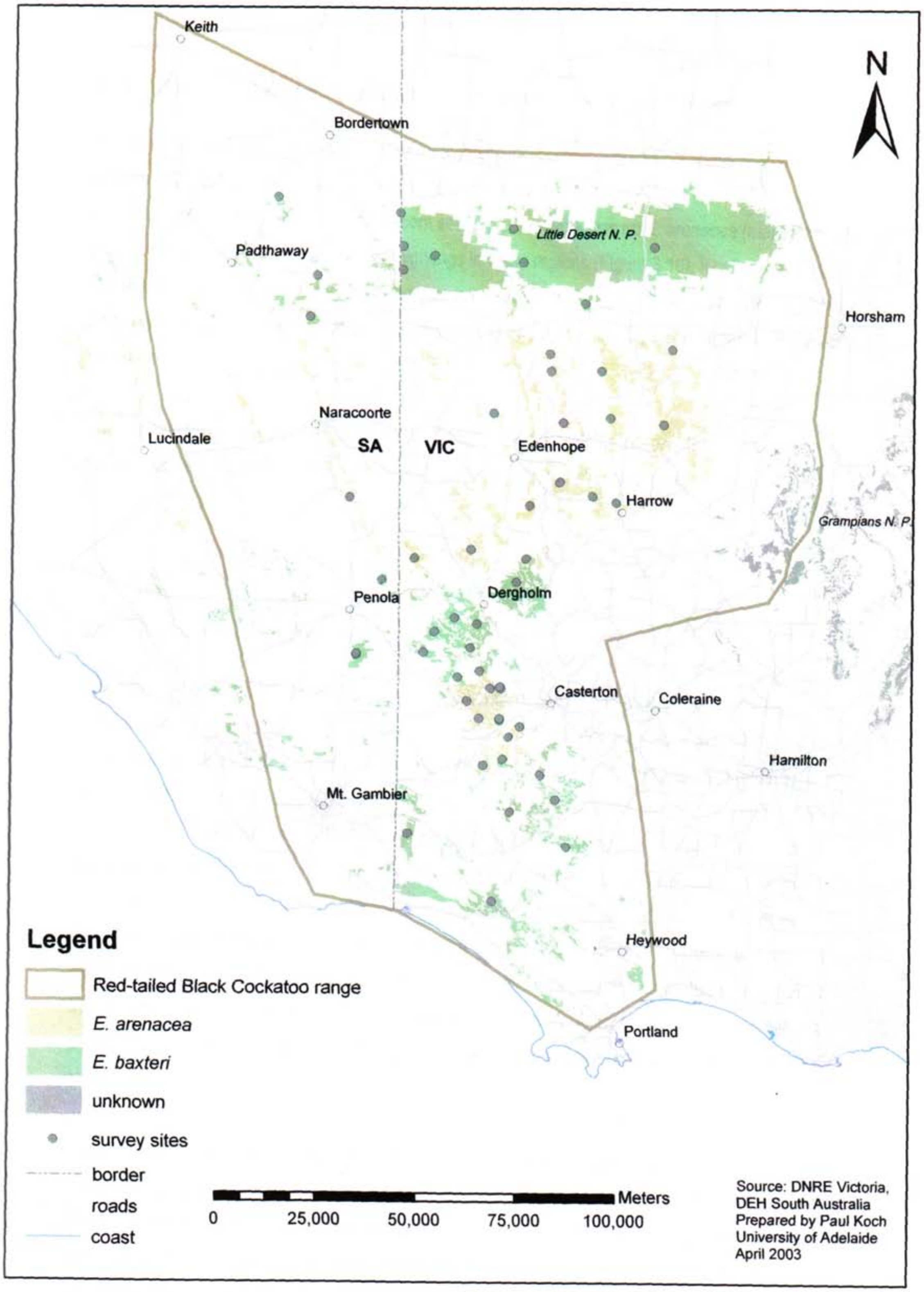
**Table 3.3.** Percentage of stringybark habitat cleared for each state and each species of stringybark within the range of the south-eastern Red-tailed Black Cockatoo. The values were determined using distribution data from this study and using current and pre-European vegetation mapping data supplied by the DNRE (Vic) and DEH (SA).

| | Percentage of stringybark habitat cleared | | |
|---|---|---|---|
| | *E. arenacea* | *E. baxteri* | Total habitat |
| South Australia | 81 | 86 | 84 |
| Victoria | 22 | 30 | 29 |
| Total habitat | 49 | 51 | 50 |



Source: DNRE Victoria,
DEH South Australia
Prepared by Paul Koch
University of Adelaide
April 2003

**Figure 3.7.** Estimated pre-European distributions of *E. arenacea* and *E. baxteri* in the range of the south-eastern Red-tailed Black Cockatoo.



Source: DNRE Victoria, DEH South Australia
Prepared by Paul Koch
University of Adelaide
April 2003

**Figure 3.8.** Estimated current distributions of *E. arenacea* and *E. baxteri* in the range of the south-eastern Red-tailed Black Cockatoo, and locations where the stringybarks were identified (survey sites).

### 3.3.6 Red-tailed Black Cockatoo sightings in relation to species distributions

A concentration of Red-tailed Black Cockatoo sightings occurred in the Casterton and Edenhope regions of Victoria (where *E. arenacea* occurs) in the years of 1999 and 2000 (Figure 3.9). This coincided with the time when the most recent seed crop available was on *E. arenacea* (matured in late 1998). In the year 2001, there were few sightings in these regions (Figure 3.10), most notably in the Casterton region where sightings were common in the previous 2 years. The apparent movement of birds away from the Casterton region coincided with the maturation of a new seed crop on *E. baxteri* elsewhere.

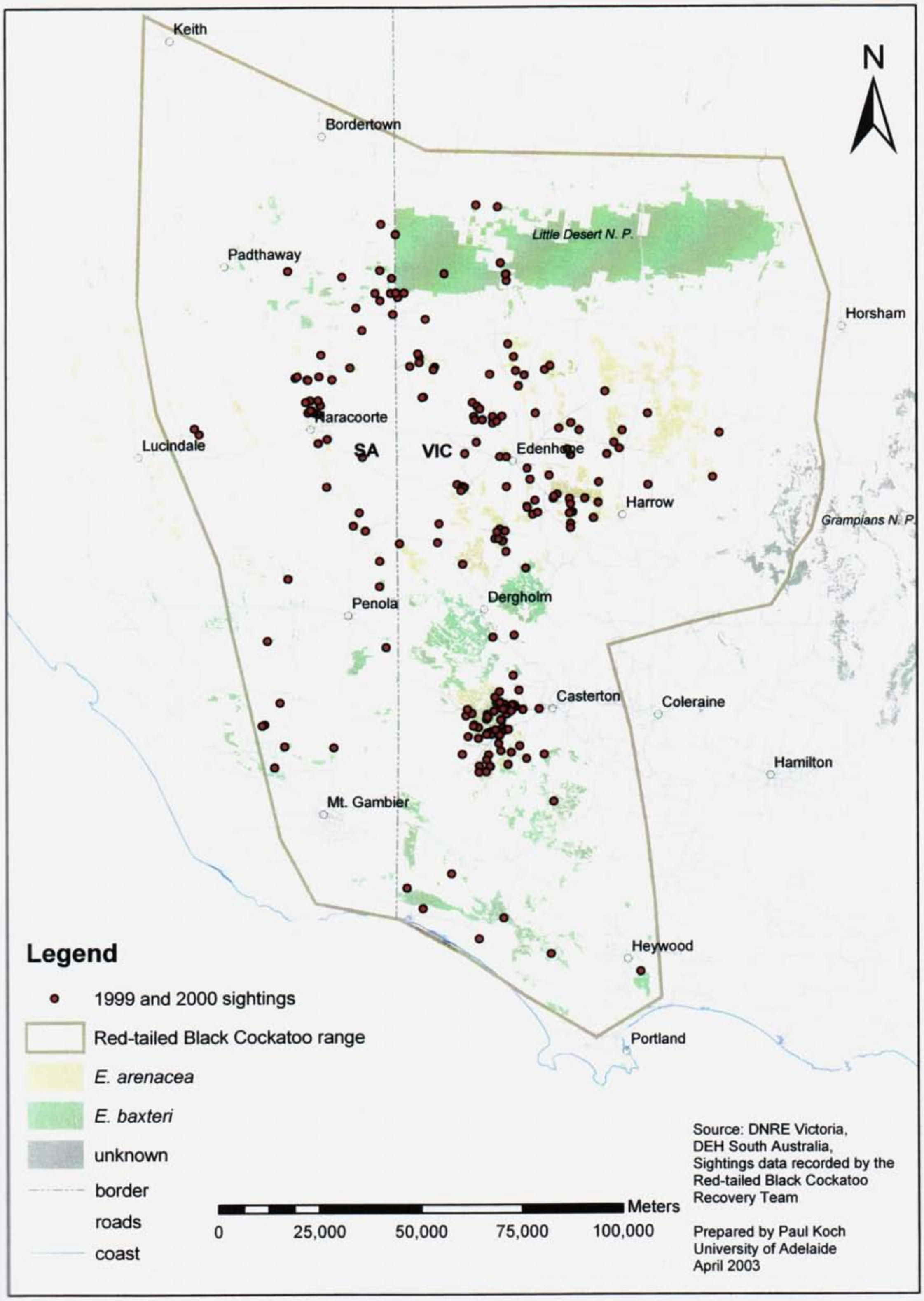
There were few sightings of Red-tailed Black Cockatoos in the Little Desert and Grampians National Parks, despite the large size of these areas in relation to other habitat remnants.

## 3.4 Discussion

### 3.4.1 Patterns of seed production

The study demonstrated that there are some fundamental differences between the two stringybark species with respect to phenology. *Eucalyptus arenacea* fruited in the years 1998 and 2001, while *E. baxteri* fruited in the years 1996, 2000 and 2002. When both species are considered together in terms of seed availability for the Red-tailed Black Cockatoo, the interval between consecutive seed crops varied between one and two years. Although longer term studies are needed to determine whether these patterns are consistent over time, the results suggest that the two eucalypt species tend to alternate between years of seed production and that, in some years, the seed crop is not renewed. Furthermore, the fruiting of *E. baxteri* appeared to be irregular, fruiting on a 2-4 year cycle. Andersen (1989) similarly found that the pattern of fruiting in *E. baxteri* was irregular, with an absence of fruiting in the first year of study followed by two consecutive years of fruiting. At times when E. baxteri has not produced a crop for more than three years, the overall interval between seed crops available to the Red-tailed Black Cockatoo would be prolonged.

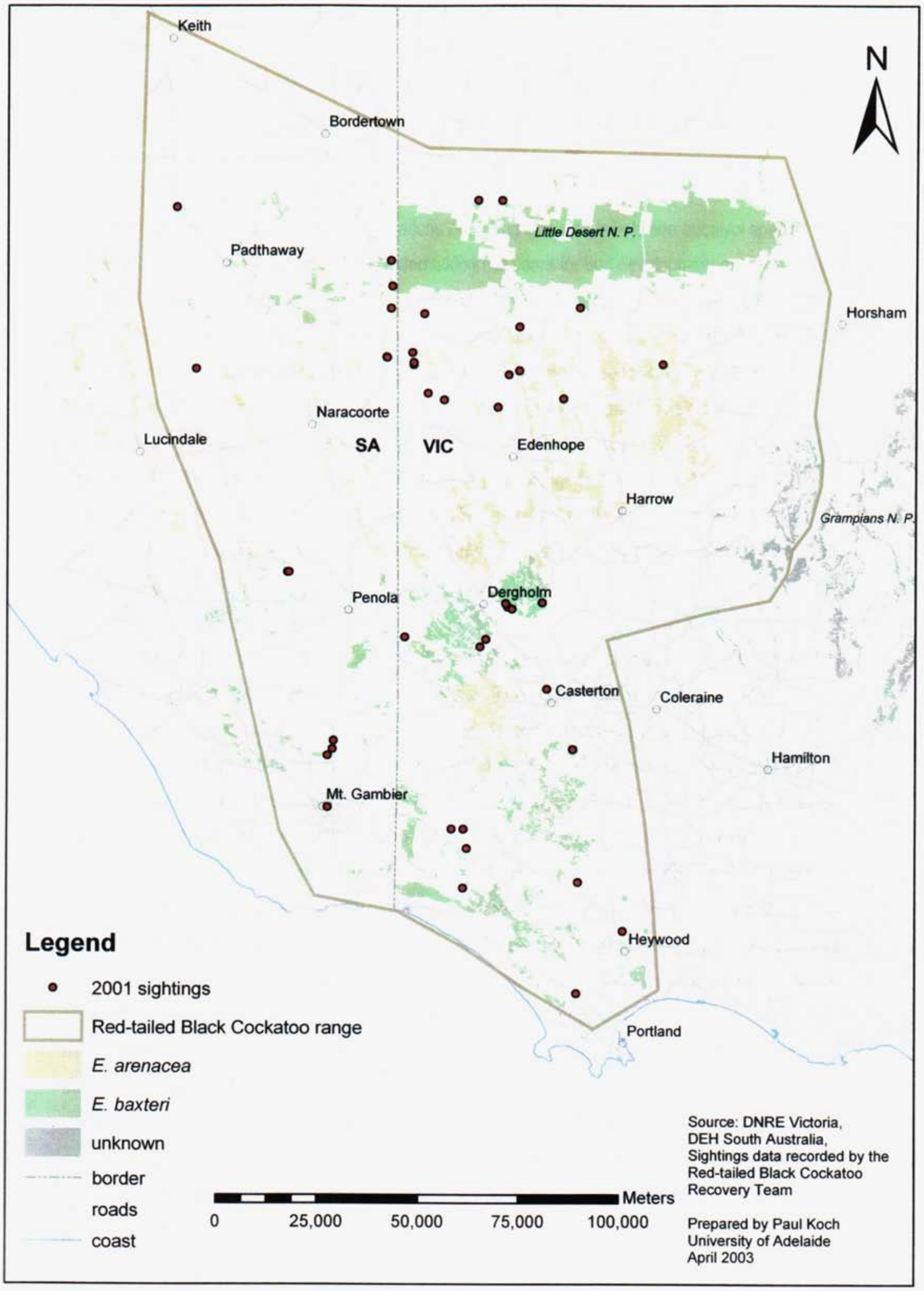
Phenological studies of other eucalypts indicate that periodicities between seed crops of greater than one year may be typical of the genus (eg. Ashton 1975, Yates *et al.* 1994, Setterfield and Williams 1996, Wellington and Noble 1985, Johnstone and Kirkby 1999). Such periodicities in seed production are both environmentally and internally regulated (Harper and White 1974). Periodicity enables plants to take advantage of environmental conditions that favour the production of large seed crops, such as



Source: DNRE Victoria,
DEH South Australia,
Sightings data recorded by the
Red-tailed Black Cockatoo
Recovery Team

Prepared by Paul Koch
University of Adelaide
April 2003

**Figure 3.9.** Sightings of the south-eastern Red-tailed Black Cockatoo recorded during 1999 and 2000.



Source: DNRE Victoria,
DEH South Australia,
Sightings data recorded by the
Red-tailed Black Cockatoo
Recovery Team

Prepared by Paul Koch
University of Adelaide
April 2003

**Figure 3.10.** Sightings of the south-eastern Red-tailed Black Cockatoo recorded during 2001.

favourable rainfall and temperature (Boland *et al.* 1980). However, these periods of reproductive activity are necessarily followed by a period of vegetative recovery that varies with the vigour of individuals (Harper and White 1974, Reekie and Bazzaz 1987).

The study also confirmed beekeeper observations regarding differences between eucalypt species in the duration of bud development, with *E. baxteri* taking two years for bud development compared to one year for *E. arenacea*. Losses of buds due to insect predation make up a high percentage of the total ovules initiated in *E. baxteri* (Andersen 1989). Therefore, the reduced period of bud development for *E. arenacea* may represent an adaptive strategy that evolved as a response to reduce bud losses caused by insect predators. Differences in the duration of bud development might also help prevent interbreeding if they tend to cause the two species to flower in different years, since such mechanisms are important for cohabiting species of *Eucalyptus* in dry sclerophyll forest (Gill 1981). Such a mechanism could be regulated by rainfall if favourable rainfall causes the two species to initiate buds in the same year. In the present study, both species initiated buds in the year 2000, and consequently the two species flowered in alternate years.

Flowering success, defined as the percentage of mature buds maturing capsules, ranged between 21% and 43% of buds initiated, when averaged for each site. These values were comparable with the flowering success reported for *E. baxteri* (26% and 33% for two sequential years, Andersen 1989). Variable flowering success has been reported for other members of the genus, such as: *E. miniata* and *E. tetrodonta* (14% and 30%, respectively, Setterfield and Williams 1996), *E. salmonophloia* (flowering success varied between 1% and 60%, Yates *et al.* 1994) and *E. regnans* (flowering success varied between 3% and 40%, depending on the site and year of study, Ashton 1975). Also similar was the high variability in flowering success between individual trees, which ranged between 0.4% and 100% of buds initiated in the present study. The extreme variability between trees in flowering success suggests that differences in the maternal (internally regulated) investment of resources associated with the vigour of individual trees were more important than pollination limitation for flowering success in the present study. Although trees can vary substantially in the attractiveness of floral displays, the timing and duration of flowering and other factors influencing pollination (Campbell and Halama 1993, Rathcke and Lacey 1985, Richardson and Stephenson 1991, Wyatt 1982), it is unlikely that these differences could account for the wide variation in flowering success between trees. Therefore, resource limitation associated with tree vigour may be more important as a factor influencing flowering success than pollination limitation for *E. baxteri*.

Despite the large differences between trees in flowering success, however, both species were highly synchronous within sites with regard to flowering; that is, a high proportion of trees flowered in the same year. This finding suggests that the onset of fruiting is also highly synchronous within sites. Furthermore, there was a relatively high level of consistency in the intensity of flowering and fruiting within and between sites, with approximately 70% of trees at the two *E. baxteri* sites producing high amounts of flowers, and a similarly large percentage of trees producing medium-high amounts of capsules at the *E. arenacea* sites for the 2000 season. Therefore, although the individual vigour of trees varied, the trees were generally well synchronised with respect to periodicity within species. This would benefit foraging cockatoos by minimising the time required to search among trees for capsules at a suitable stage of development.

### 3.4.2 Red-tailed Black Cockatoo sightings in relation to patterns of seed production

There were large areas of stringybark within the range of the Red-tailed Black Cockatoo in which the cockatoos were rarely sighted, most notably the higher rainfall areas of Lower Glenelg National Park and Grampians National Park. Sightings data is biased to some extent because the community awareness campaigns that promote the reporting of Red-tailed Black Cockatoo sightings tend to focus on the Casterton and Edenhope districts, where key nesting and feeding areas occur. However, the sightings data is well-supported by annual count data, which covers most areas within the range of the cockatoo (Hill unpubl. data).

A more likely explanation for the lack of sightings within the Lower Glenelg and Grampians National Parks is that there are few areas within the Parks that are dominated purely by *E. baxteri* or *E. arenacea*, since *E. baxteri* tends to codominate with *E. obliqua* in these damp forest regions (Anonymous 1999, Koch pers. obs.). Another large area of stringybark where the cockatoos are rarely sighted is Little Desert National Park, which makes up 33% of the *E. baxteri* woodland occurring in Victoria. In some parts of the park, the trees are more mallee-like in form, but there are also large areas that are typical of stringybark habitat in the region. It is therefore likely that the cockatoos use most areas within the park (Koch pers. obs.). The lack of sightings within the park is probably a consequence of its poor accessibility to observers, because there are few access points into the park apart from fire trails in difficult terrain. The value of the park for the south-eastern Red-tailed Black Cockatoo could be ascertained by documenting the percentage of trees showing recent feeding signs at various locations in the park.

Comparison of the former and current range of stringybark habitat within south-eastern Australia suggests that a range contraction has probably occurred and that large areas of potential habitat remain that are not regularly visited by the cockatoos. In particular, the Naracoorte Ranges (the area east of Lucindale and north-west of Padthaway) are areas that were probably used extensively by the cockatoos prior to European settlement (Hill pers. comm.). In pre-European times, there were "corridors" of virtually continuous stringybark habitat that extended along the sandy ridges running parallel to the coastline which make up the Naracoorte Ranges. It is likely that in these highly fragmented areas, the cockatoos would need to forage over a much larger area than they would in other parts of the range, and the costs of foraging in such areas may be greater than the energetic rewards. The disappearance of Carnaby's Cockatoo from certain parts of its former range was linked to severe habitat fragmentation and the problems associated with food harvesting in fragmented areas (Saunders 1990a).

We would expect the cockatoos to show a definite movement towards the species which had matured seed most recently, because the cockatoos seem to prefer feeding on the newly matured capsules (Attiwill 1960, Joseph 1982). In support of this hypothesis, the sightings data suggested that the cockatoos moved out of most *E. arenacea* regions in 2001, following the maturation of a new seed crop on *E. baxteri* in November 2000. Furthermore, all the cockatoos found during the annual counts of 2001 and 2002, which are performed to estimate population size each year, were located in regions dominated by *E. baxteri* (Hill pers. comm.). The cockatoos had not been sighted in some *E. baxteri* areas since 1996, when the species last produced a seed crop (D. Cooper pers. comm., R. Hill pers. comm.). These results and observations suggest that the cockatoos feed almost entirely on one species of stringybark or the other, depending on which species has fruited the most recently. The presence of both species of stringybark is likely to be an important habitat requirement for this cockatoo, because if only one species were present, resource renewal would occur much less frequently.

The majority of stringybark habitat was *E. baxteri* (72%), both for current and pre-European data, and approximately half of each species has been cleared in the range of the Red-tailed Black Cockatoo. Remarkably, clearing has not changed the ratio of *E. baxteri* to *E. arenacea* for either South Australia or Victoria, within the current range of the cockatoo. However, the former range of the Red-tailed Black Cockatoo may have included a higher percentage of *E. arenacea*. If the two species of stringybark are similar in terms of their resource value for the Red-tailed Black Cockatoo, then the ideal ratio of *E. baxteri* to *E. arenacea* would be 50:50, because this would ensure an even supply of food in years when the two species do not produce seed in the same year. Given that *E. arenacea* makes up only 28% of stringybark habitat in the current range of the cockatoo, this species is more likely to be a limiting resource for the Red-tailed Black Cockatoo than *E. baxteri*. Therefore, it is essential to determine whether food supplies are limiting the population, particularly in years when the cockatoos depend on *E. arenacea* for their food supply.

A new seed crop should be depleted to a lesser extent than an older seed crop by cockatoos, natural decay and insect parasites. Correspondingly, the density of capsules per tree for *E. baxteri* sites surveyed in 2000 was generally low (<100 capsules, matured in 1996), while the density of capsules at *E. arenacea* sites was generally high (>300 capsules, matured in 1998). The *E. baxteri* crop was four years old at the time of study compared with two years for *E. arenacea*. If capsule density improves foraging efficiency, then we would expect the cockatoos to select trees with higher capsule densities, and feeding profitability to be greater in areas with a fresh seed supply. These ideas are tested in the next chapter.

# CHAPTER 4 Foraging ecology of the south-eastern Red-tailed Black Cockatoo

## 4.1 Introduction

Food availability has been suggested as an important factor influencing the status and distribution of several taxa in the genus *Calyptorhynchus*, including Carnaby's Cockatoo (Saunders 1980), the Glossy Black Cockatoo (Pepper 1997) and the south-western Red-tailed Black Cockatoo (Cooper *et al.* 2002, Johnstone and Kirkby 1999). Both the Glossy Black Cockatoo and south-western Red-tailed Black Cockatoo are similar in ecology to the south-eastern Red-tailed Black Cockatoo in that they specialise on one or a few native food plants, the former feeding almost entirely on *Allocasuarina* sp. and the latter on Jarrah and Marri. Of these, the Glossy Black Cockatoo has received the most attention with regard to foraging ecology. The Glossy Black Cockatoo selects trees primarily on the basis of "cone profitability", characteristics of cones which are thought to increase its rate of seed intake (Clout 1989, Crowley and Garnett 2001, Pepper *et al.* 2000). Less attention has been given to aspects of fruit quantity such as crop size (number of fruits per tree) in relation to the feeding profitability of trees, even though this factor was found to influence the selection of trees for foraging in studies of both the Glossy Black Cockatoo (New South Wales population; Clout 1989) and south-western Red-tailed Black Cockatoo (Johnstone and Kirkby 1999).

In the present study, two approaches were used to identify the characteristics of stringybarks which determine food availability for the south-eastern Red-tailed Black Cockatoo. First, habitat surveys were used to compare trees selected for foraging with non-selected trees in a range of resource characteristics; and second, foraging observations were used to confirm that the cockatoos forage more efficiently when feeding in trees with increased resource availability. The importance of various characteristics of capsule availability, capsule profitability and tree size and structure are discussed in relation to the food requirements of this cockatoo.

## 4.2 Methods

### 4.2.1 Factors influencing the selection of foraging locations

The broad-scale habitat survey provided the basis for comparisons of trees used for feeding with other trees in terms of various measured habitat components. The details of these measurements, survey methods and study sites are given in section 2.2. The status of each tree in the present study (feed or other) was determined from the presence/absence of branches that showed signs of pruning characteristic of Red-tailed Black Cockatoos. Other trees included those trees that showed no visible signs of pruning but were fruiting (had at least 1 capsule present).

*Capsule availability, capsule volume and tree characteristics*

Capsule availability and tree measurements for feed trees and other trees were performed as part of the broad-scale habitat survey. The study included only those sites that were long unburnt, and included only trees sampled at the habitat interior (three sampling points per site, eight trees per sampling point), in order to reduce variability caused by fire (the subject of Chapter 5) and edge effects (the subject of Chapter 6). The seven sites used for the study were: Tullich, Tower Tk., Jilpanger, Yallakar, Kadnook and Cemetery Tk. The location of these sites is given in Figure 2.2. Measurements of capsule availability were: capsule density (number of capsules per branch), crop size (number of capsules per tree) and cluster size (number of capsules per pedicel). Capsule volume was used as a measure of capsule profitability (amount of edible material per capsule), since it was significantly correlated with the quantity of edible material in capsules (eg. total weight of seed and chaff per capsule). Other measurements were: girth, height, canopy volume, branch density and percentage dieback (defined in section 2.2).

The capsule availability data were biased to some extent because trees were sampled after the cockatoos had used them, and this would reduce crop size and capsule density scores. The depletion of resources on feed trees would tend to minimise differences between feed trees and other trees, so the observed differences between feed trees and other trees are likely to be conservative.

Two way ANOVAs were used to test for differences between feed trees and other trees, between sites (listed above) and to test for a significant interaction between status and site, for each of the resource availability measurements. The test is useful in that the effect of feed status can be tested in relation to the effect of site, which is an important source of variability (Chapter 5). However, the test requires a balanced design for maximum power (Zar 1984). Sample sizes were unequal for the capsule availability data and tree measurements because unequal numbers of feed trees and other trees occurred at sites in the broad-scale habitat survey. Equal sample sizes for each “cell” were achieved by finding the minimum number of replicate trees, and then randomly deleting the appropriate number of trees where necessary, as suggested by Zar (1984) and Underwood (1981). Two sites (Tullich and Tower Tk.) were combined for the analysis due to the small number of “other” trees occurring at these sites, and because the two sites occur within close proximity (approximately 1 km) of each other. All variables were normally distributed for most sites following log transformation. The ANOVA test is considered to be sufficiently robust to overcome small departures from normality (Underwood 1981).

In addition, non-metric Multi-Dimensional Scaling (MDS) was used to ordinate the data in Primer version 5.2.0, using replicate sampling points for each site as samples, and using site as a factor in the analysis. The ordination was based on the following variables: percentage of trees used for foraging, capsule density, capsule volume, canopy volume and girth. These values were averaged for all trees sampled at each sampling point. Each variable was selected to represent a different aspect of resource availability (capsule availability, capsule profitability and tree characteristics). There was a high level of inter-correlation among variables, so the other variables (crop size, cluster size, percentage dieback etc.) were not included in the analysis to prevent excess “noise” in the data. Capsule volume was used as the primary measure of capsule profitability, since it was the only measure of capsule profitability to be measured for the sites used in the broad-scale habitat survey. It is considered to be a good measure of capsule profitability, since it was highly significantly correlated with total ovule weight per capsule and individual seed weight (see results for capsule characteristics). Normalised Euclidean distance was used as the measure of similarity in the analysis.

### *Intensity of habitat use*

The percentage of trees used for foraging by cockatoos per sampling point was used as a measure of the intensity with which patches of trees were exploited. Spearman’s Rank Correlations were used to correlate each characteristic of resource availability with the percentage of trees used per sampling point.

### *Capsule characteristics*

Capsule characteristics were compared between feed trees and other trees at a single site (Tylers; not part of the broad-scale habitat survey) in March 2000. The survey differed from the broad-scale habitat survey in that feed trees were identified on the basis of recent feeding signs left by the cockatoos, rather than from the visible effects of pruning. The cockatoos prune the outer foliage-bearing branches during feeding, presumably to allow easier access to the portions of the branch bearing the seed capsules (Joseph 1982, Koch pers. obs.). Feed trees are distinguished by the presence of large quantities of leaf litter that accumulates beneath them (Figure 4.1). Other feeding signs include small capsule-bearing "twigs" which are held in the left foot while processing individual capsules, and the discarded capsule casings or husks (Figure 4.2). Recent feeding signs left by the cockatoos are greener and more conspicuous than old feeding signs. The feeding signs are similar to those left by the Gang-gang Cockatoo *Callocephalon fimbriatum* when feeding on stringybark eucalypts. However, this cockatoo tends to occur close to riverine areas such as the Glenelg river in Victoria, and does not normally occur in the region north of Casterton where this part of the study was performed (Higgins 1998).

**Figure 4.1.** Recent leaf litter scattered under a tree used for foraging by the south-eastern Red-tailed Black Cockatoo.

**Figure 4.2.** Discarded outer casings of capsules, and capsule-bearing twigs used for feeding by the south-eastern Red-tailed Black Cockatoo (scale 3:2).

Ten feed trees and ten other trees were selected at the site, in an area where the cockatoos had recently been observed feeding (an area of approximately two hectares). “Other” trees were trees within the feeding area that showed no recent feeding signs and no visible effects of pruning. The location of each tree was recorded using a Geographic Positioning System, and each tree was flagged with coloured flagging tape. A numbered, metal tag was nailed to each tree for subsequent identification. A sample of ten capsules was collected from each tree using pruning secateurs attached to a six metre aluminium extension pole.

Each capsule was placed in a labelled, sealed envelope, and dried in an oven at 100°C for two hours, to enable the valves to open. The samples were stored in a desiccator for overnight storage between weighing sessions. Fine forceps were used where necessary to remove the seeds and chaff (infertile ovules). In cases where the capsules had been heavily parasitised by insects (described by Andersen 1989), the contents of capsules could not be removed and the sample was discarded. The seed and chaff were counted and weighed separately for each capsule, using an electronic balance, to the nearest milligram. The capsules were also weighed after the contents had been removed. The dimensions of capsules were determined using calipers by measuring the width of the capsule (at its widest point) and the distance from the capsule apex to the pedicel (length). The average of these dimensions was used as the diameter. Capsule volume was determined from the diameter using the formula for the volume of a sphere (the capsules were approximately spherical in shape).

In addition, the following other characteristics were recorded or calculated: number of seed per capsule, total seed weight per capsule, individual seed weight (seed number divided by total seed weight per capsule), number of chaff per capsule, total chaff weight per capsule, individual chaff size (number of chaff divided by total chaff weight per capsule), total ovule weight per capsule (seed weight + chaff weight), seed : chaff weight ratio, seed : capsule weight ratio and chaff : capsule weight ratio. Chaff characteristics have not been considered previously in studies of Black Cockatoo foraging behaviour, but they are likely to influence the profitability of eucalypt fruits because chaff makes up a large proportion of the edible material (Boland *et al.* 1980). It is not known whether the cockatoos eat the chaff, because some of the edible material (both seed and chaff) is discarded during feeding (Koch pers. obs.).

Capsule characteristics (measured for one site only) were usually normally distributed, although some variables were log transformed (total ovule weight per capsule, seed : capsule weight ratio, individual chaff weight, chaff : capsule weight) to improve normality. All capsule characteristics were compared between feed trees and other trees using t tests.

### 4.2.2 Foraging observations

*Location of cockatoos*

Observations of foraging cockatoos were made during February 2001, February 2002 and July 2002. The observations were carried out at various locations in the Casterton region, south-west Victoria. The areas used by the cockatoos during the study were all long unburnt, and were all composed of *E. baxteri*.

The location of cockatoos depended on recent sightings by a volunteer observer, who would search for the birds in the Casterton region and record their location at least once a week. Usually, a single flock of cockatoos would spend several weeks in a particular area or remnant of vegetation. The precise location of the birds was determined on any given day by driving along fire access trails and pausing regularly to listen for the birds. Recent feeding signs left by the birds on the edges of tracks helped pinpoint their location. Once the birds were within listening range, the observer would walk slowly and quietly through the scrub towards a position that offered good visibility (within a distance of approximately 50m).

*Percentage of the day spent foraging*

Scan sampling was performed to determine the percentage of birds actively foraging, while perched in trees. The scans were performed irregularly throughout the day, whenever a suitable observation position could be attained. During observation sessions, the scans were performed at 5 minute intervals. Observations of a particular flock were usually performed over one week, or until the birds left the area. A full day of observations (just after sunrise to just before sunset) was made whenever possible. However, in many cases an observation day would be terminated prematurely when the birds left the area. In such cases, efforts were made to collect data over all hours of the day over two or more consecutive days.

For each scan, the following were recorded: number of birds clearly visible, number of birds foraging, number of birds resting and number of birds engaged in other activities. Bird visibility was a potential source of bias in the data, since foraging birds were much easier to see than resting birds (Wagner 1981). This bias was countered by recording only the activity of those birds that were clearly visible through binoculars. A bird was considered to be feeding if it was handling capsules, manipulating branches bearing capsules or if it was moving along the branch in search of capsules (these behavioural patterns are described below). A bird was assumed to be resting if it was not engaged in any feeding activity and was not engaged in any other activity, such as preening or allopreening. Individual birds of this species are not distinguishable, except in relation to their sex and position in the tree when foraging. Therefore, a number of different flocks were included in the observations to increase the independence of observations.

The percentage of birds observed to be foraging was averaged for all scans and multiplied by the number of hours of daylight that birds were recorded in feeding areas to determine the number of hours spent foraging by cockatoos each day. It was assumed that the cockatoos fed at a constant rate while foraging, between seasons. The percentage of birds observed to be foraging was compared for data collected in February (summer) 2000, February (summer) 2001 and July (winter) 2001, to determine whether the percentage of time spent feeding each day by cockatoos varied seasonally. The percentage of birds foraging was non-normally distributed, and transformation did not improve normality. Therefore, a (nonparametric) Kruskal Wallis test was used to compare the percentage of birds foraging in each scan between observation months (February 2001, February 2002 and July 2002). There were a small number of observation days for each observation month (2 days, 3 days and 2 days for each observation month, respectively). For this reason, the percentage of birds foraging was also compared between observation days for each observation month to determine whether differences between months were consistent. Wilcoxon Rank Sum tests or Kruskal Wallis tests were used to test for differences between observation days, depending on which month was being considered. Wilcoxon Rank Sum tests are used to test for differences between two groups, while Kruskal Wallis tests are used to test for differences among three or more groups (Zar 1984).

### *Percentage of foraging time spent flying within and between trees*

The number of flights made within and between trees and the distances travelled per flight were recorded during 5 minute observation sessions, to estimate the percentage of foraging time spent in flight. In these observation sessions, the observer would pick a location where a small flock of birds (around 20 birds) were clearly visible with the naked eye or through binoculars. The number of birds that were clearly visible was recorded for each observation session. As each flight was made, the observer would estimate the distance flown, and record whether the flight was made between branches of a single tree (within tree) or between trees. The distances travelled were averaged for each observation session as the distance flown per minute, and then averaged for each bird by dividing this value by the number of birds visible in the observation session. The speed of flights was also estimated by counting the number of seconds required to fly a distance of 10 m (estimated). The flight speed, the flight distance and the number of flights made per minute were used to calculate the percentage of foraging time spent by birds in flight.

### *Foraging efficiency in relation to capsule availability*

Observations of cockatoos engaged in feeding behaviour were performed to determine foraging efficiency in relation to capsule density and cluster size. The two measures of foraging efficiency used were: (a) the percentage of foraging time spent handling capsules; and (b) the number of capsules processed per minute. The duration of observation sessions was 5 minutes. The total number of capsules processed during each observation session was counted using a hand counter while observing the birds through a 20x spotting scope, to determine the number of capsules processed per minute.

The percentage of foraging time spent handling capsules by cockatoos was determined using time budgets, by recording the time devoted to each aspect of feeding behaviour. The duration of each activity was recorded by speaking softly into a dictophone, whenever the bird changed its behaviour. The percentage of foraging time allocated to each activity was subsequently determined by timing each activity with a stopwatch as it was played back.

The types of feeding behaviour recorded were: looking around, moving along branch, manipulating branches, handling and other. However, these categories were grouped for analysis into: (a) handling behaviour (the handling of individual capsules); and (b) searching behaviour (looking around, moving along branch or manipulating branches); so that they could be compared with other studies. Handling behaviour was highly stereotyped and involved the actual husking (or processing) of capsules and the extraction of the edible material (seed and/or chaff) contained within. Handling behaviour was recorded whenever a cockatoo came into contact with an individual capsule. Manipulating behaviour usually involved the cockatoo nipping a small branch off the main branch, removing the leafy shoot and then positioning the twig bearing capsules in one foot. At other times, manipulating behaviour involved the cockatoo removing a single capsule from the branch with its beak and positioning it in the left foot ready for processing. A cockatoo was said to be looking around if it was obviously leaning in the direction of capsules held on the branch. A cockatoo was said to be moving along the branch if it was side-stepping along the branch to access another area of the branch. All other types of behaviour such as preening, courting and resting were termed “other”.

For each observation session, capsule density was estimated as the number of capsules per branch for the branch being used for foraging. A photo of cockatoos perched on a typical branch is given in Figure 4.3. A typical branch is described in Section 2.2. It was often difficult to make accurate counts of capsules on the branch, so capsule density was estimated simply as high (100 capsules or greater) or low (much less than 100 capsules). Cluster size (the number of capsules per pedicel) was counted for all clusters on each twig that was handled by the cockatoo, while observing the cockatoo through a spotting scope. The term “twig” refers to the portion of the branch bearing capsules that was severed from the main branch by the cockatoo. Cluster size was determined for each observation session as the average of these counts.

**Figure 4.3.** Pair of Red-tailed Black Cockatoos (female on left and male on right) perched on a typical branch used for feeding. Photo taken by Dr. David Paton.

An observation session was terminated when the bird left a branch, moved out of sight or paused for greater than 30 seconds. Observations were made throughout the day, whenever a bird could be clearly sighted. The identity of each bird was recorded in relation to its sex and position in the tree while feeding. Replicate observations of a cockatoo whose identity was known were averaged to increase the independence of each observation.

The percentage of time spent handling, the percentage of time spent searching and the number of capsules processed per minute were all non-normally distributed and transformation did not greatly improve normality. Non-parametric Wilcoxon Rank Sum tests were therefore used to test for differences between high and low capsule density groups in the percentage of time spent handling, the percentage of time spent searching and the number of capsules processed per minute. The test was also used to test for differences between sexes in each measure of foraging efficiency. Spearman's Rank Correlations were used to test for significant correlations between each measure of foraging efficiency and cluster size.

## 4.3 Results

### 4.3.1 Factors influencing the selection of foraging locations

*Capsule availability, capsule volume and tree measurements*

Measurements of capsule availability (capsule density, crop size, cluster size) and capsule volume are compared between feed trees and other trees for each site in Table 4.1. All measures of capsule availability were generally greater for feed trees than other trees. Capsule density and crop size varied greatly between sites, but were higher for feed trees than other trees at all sites. Mean capsule density at each site ranged between 37 and 224 capsules per branch for feed trees and between 18 and 71 capsules per branch for other trees. Mean crop size ranged between 2027 and 14691 capsules per tree for feed trees and between 24 and 2042 capsules per tree for other trees. Averaged overall sites, feed trees were nearly eight times greater in crop size and four times greater in capsule density than other trees. Crop size also varied greatly between trees (within sites).

Differences between feed trees and other trees in cluster size were less pronounced, but cluster size was higher for feed trees than other trees at all sites. The cluster size of all feed trees combined (3 capsules per pedicel) was substantially higher than for all other trees combined (1.8). Capsule volume was also higher for all feed trees combined (3204 $mm^3$) than for all other trees combined (2622 $mm^3$). However, capsule volume was not consistently higher for feed trees at all sites, being comparable between feed trees and other trees at Jilpanger and lower for feed trees than other trees at Tower Tk. and Tullich. The highest capsule volume (5075 $mm^3$) was recorded for other trees at Tower Tk..

**Table 4.1.** Comparison of capsule density (capsules per branch), crop size (capsules per tree), cluster size (capsules per pedicel) and capsule volume between feed trees and other trees at each site, using data from the broad-scale habitat survey (excluding burnt sites and trees sampled at the edge position). Capsule density, crop size and cluster size were measured for 24 trees per site. Capsule volume was measured for six of the seven sites and approximately 15 trees per site. The number of feed trees and other trees is given for each site (n), with separate sample sizes given for capsule volume.

| Feed status | Site | n | Capsule density | Crop size | Cluster size | n | Capsule volume (mm$^3$) |
|---|---|---|---|---|---|---|---|
| Feed | Cemetery Tk. | 9 | 37 ± 15 | 2856 ± 2170 | 1.8 ± 0.2 | 6 | 2929 ± 292 |
| Other | | 15 | 18 ± 6 | 310 ± 131 | 1.3 ± 0.2 | 8 | 2278 ± 105 |
| Feed | Jilpanger | 18 | 149 ± 23 | 4262 ± 1200 | 2.9 ± 0.2 | 11 | 1878 ± 9 |
| Other | | 6 | 45 ± 19 | 2042 ± 1389 | 1.9 ± 0.2 | 2 | 1878 ± 9 |
| Feed | Kadnook | 14 | 62 ± 8 | 2027 ± 518 | 2.7 ± 0.2 | 9 | 3079 ± 335 |
| Other | | 10 | 32 ± 7 | 209 ± 76 | 2.4 ± 0.2 | 6 | 2504 ± 184 |
| Feed | Kealys | 12 | 213 ± 25 | 14691 ± 4683 | 4.4 ± 0.3 | - | - |
| Other | | 12 | 36 ± 12 | 1837 ± 832 | 1.8 ± 0.4 | - | - |
| Feed | Tower Tk. | 21 | 224 ± 30 | 12206 ± 4650 | 3.2 ± 0.1 | 13 | 3657 ± 318 |
| Other | | 3 | 71 ± 64 | 159 ± 121 | 1.8 ± 0.9 | 1 | 5075 |
| Feed | Tullich | 22 | 92 ± 15 | 2343 ± 706 | 3.3 ± 0.2 | 14 | 3698 ± 194 |
| Other | | 2 | 12 ± 12 | 24 ± 24 | 1.8 ± 1.8 | 1 | 4637 |
| Feed | Yallakar | 12 | 116 ± 14 | 6016 ± 1336 | 2.9 ± 0.2 | 6 | 2805 ± 197 |
| Other | | 12 | 50 ± 13 | 608 ± 213 | 2.1 ± 0.3 | 8 | 2681 ± 197 |
| **Feed** | **Combined** | **108** | **135 ± 10** | **6362 ± 1164** | **3 ± 0.1** | **59** | **3204 ± 125** |
| **Other** | | **60** | **35 ± 5** | **814 ± 233** | **1.8 ± 0.1** | **26** | **2622 ± 157** |

Feed trees were also comparatively greater in girth, canopy volume and percentage dieback than other trees and were comparatively lower than other trees in height and branch density (Table 4.2). Tree characteristics were generally comparable between sites both for feed trees and other trees, with the exception of canopy volume and branch density, which varied substantially between sites for both feed trees and other trees.

**Table 4.2.** Comparison of tree characteristics between feed trees and other trees at each site, using data from the broad-scale habitat survey (excluding burnt sites). There were 24 trees sampled per site. The number of feed trees and other trees is given for each site (n).

| Feed status | Site | n | Girth (cm) | Height (m) | Canopy volume ($m^3$) | % dieback | Branch density |
|---|---|---|---|---|---|---|---|
| Feed | Cemetery Tk. | 9 | 131 ± 18 | 10.2 ± 0.9 | 104 ± 27 | 30 ± 3 | 1.8 ± 0.4 |
| Other | | 15 | 81 ± 12 | 8 ± 0.6 | 48 ± 21 | 31 ± 3 | 3.2 ± 0.6 |
| Feed | Jilpanger | 18 | 126 ± 15 | 7.7 ± 0.4 | 39 ± 7 | 35 ± 2 | 3.1 ± 0.8 |
| Other | | 6 | 90 ± 19 | 7.7 ± 1 | 55 ± 26 | 35 ± 5 | 4.3 ± 2.4 |
| Feed | Kadnook | 14 | 102 ± 12 | 9.4 ± 0.4 | 56 ± 13 | 30 ± 3 | 1.8 ± 0.2 |
| Other | | 10 | 58 ± 5 | 6.9 ± 0.3 | 13 ± 3 | 38 ± 3 | 2.3 ± 0.3 |
| Feed | Kealys | 12 | 111 ± 8 | 12.3 ± 0.6 | 95 ± 24 | 35 ± 3 | 1.5 ± 0.2 |
| Other | | 12 | 99 ± 17 | 9.3 ± 0.7 | 55 ± 21 | 27 ± 3 | 2.1 ± 0.3 |
| Feed | Tower Tk. | 21 | 94 ± 10 | 9.1 ± 0.4 | 54 ± 8 | 37 ± 2 | 1.7 ± 0.3 |
| Other | | 3 | 36 ± 4 | 8.9 ± 0.5 | 20 ± 7 | 32 ± 2 | 0.9 ± 0.4 |
| Feed | Tullich | 22 | 91 ± 9 | 6.8 ± 0.3 | 27 ± 6 | 42 ± 2 | 3.4 ± 0.7 |
| Other | | 2 | 50 ± 10 | 5.2 ± 0.6 | 7 ± 5 | 26 ± 6 | 6.5 ± 1.2 |
| Feed | Yallakar | 12 | 133 ± 16 | 10.9 ± 0.8 | 124 ± 35 | 35 ± 3 | 1.8 ± 0.3 |
| Other | | 12 | 122 ± 29 | 9.6 ± 0.7 | 74 ± 21 | 30 ± 3 | 2.1 ± 0.7 |
| **Feed** | **Combined** | **108** | **110 ± 5** | **9.2 ± 0.2** | **65 ± 7** | **36 ± 1** | **2.4 ± 0.2** |
| **Other** | | **60** | **83 ± 7** | **8.2 ± 0.3** | **43 ± 8** | **31 ± 2** | **2.9 ± 0.3** |

The two sites Tullich and Tower Tk. were combined for the analysis, due to the small sample sizes of non-feed trees at these sites, and because the two sites occur within close proximity (approximately 1 km) of each other. Sample sizes were reduced for the analysis due to the deletion of samples to obtain equal sample sizes. Differences between feed trees and other trees were significant for capsule density (two way ANOVAs: $F_{1,48} = 23.25$, $P < 0.0001$, n = 5 feed trees and 5 other trees per site), crop size ($F_{1,48} = 35.31$, $P < 0.0001$), cluster size ($F_{1,48} = 8.41$, $P = 0.0056$), girth ($F_{1,48} = 11.85$, $P = 0.0012$), canopy volume ($F_{1,48} = 5.19$, $P = 0.027$) and percentage dieback ($F_{1,48} = 8.26$, $P = 0.006$). There were no significant differences between feed trees and other trees for height ($F_{1,48} = 1.7$, $P = 0.2$) or branch density ($F_{1,48} = 1.72$, $P = 0.2$). Differences between feed trees and other trees in capsule volume were also not significant ($F_{1,10} = 0.13$, $P = 0.73$, n = 2 feed trees and 2 other trees per site, using 5 sites), although note the small sample size and power for this test (Power = 0.07).

Differences between sites were significant for capsule density (two way ANOVAs: $F_{5,48}$ = 6.55, $P$ = 0.0001), crop size ($F_{5,48}$ = 4.74, $P$ = 0.0013), cluster size ($F_{5,48}$ = 5.72, $P$ = 0.0003), girth ($F_{1,48}$ = 2.42, $P$ = 0.049) and height ($F_{1,48}$ = 2.96, $P$ = 0.021), but not for capsule volume, canopy volume, percentage dieback or branch density. The interaction between feed status and site was not significant for any variable, indicating that the influence of each resource availability characteristic on tree selection was not dependent on which site was being considered.

There was a high level of inter-correlation among the characteristics that were significantly different between feed trees and other trees. Girth and canopy volume were strongly positively correlated with crop size, capsule density and cluster size (e.g. with crop size; Spearman's Rank Correlations: $r_s$ = 0.33, $P$ <0.0001, n = 177 for girth; $r_s$ = 0.35, $P$ <0.0001 for canopy volume). However, percentage dieback was not significantly correlated with either capsule density ($r_s$ = 0.04, $P$ = 0.49, n = 177), crop size ($r_s$ = 0.04, $P$ = 0.5), cluster size ($r_s$ = 0.04, $P$ = 0.54) or capsule volume ($r_s$ = 0.04, $P$ = 0.74). Capsule volume was not significantly correlated with either capsule density ($r_s$ = -0.06, $P$ = 0.78, n = 177), crop size ($r_s$ = 0.08, $P$ = 0.7) or cluster size ($r_s$ = -0.14, $P$ = 0.49).

Ordination using MDS showed good clustering (a high level of similarity) within sites, with the exception of Yallakar and Cemetery Tk., which were not well clustered (Figure 4.4). The variables used for the ordination included: percentage of trees used per sampling point, capsule density, capsule volume, canopy volume and girth. A one way ANOSIM showed significant differences between sites ($R$ = 0.31, $P$ = 0.01), indicating that differences within sites were not as great as differences between sites, based on the variables listed above.

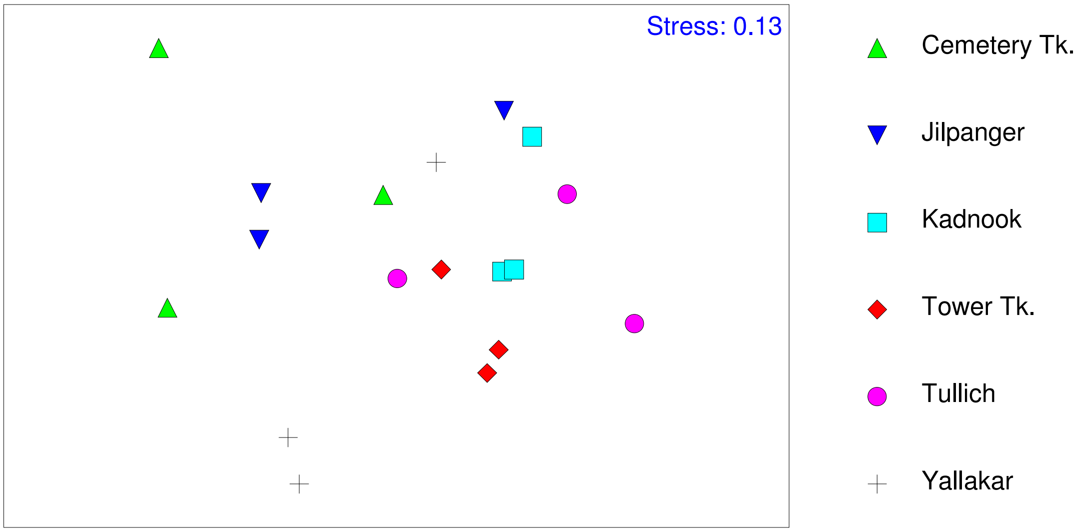


**Figure 4.4.** MDS ordination showing the distribution of sites, with replicate sampling points as samples. The variables used for the ordination included: percentage of trees used per sampling point, capsule density, capsule volume, canopy volume and girth. The analysis included only those sites for which capsule volume data were available (n = 6 sites x 3 sampling points = 18 samples).

### *Capsule characteristics*

Feed trees were comparatively higher than other trees in total seed weight per capsule, individual seed weight, total chaff weight per capsule, total ovule weight per capsule, seed : capsule weight ratio, chaff : capsule weight ratio and capsule volume (Table 4.3). Feed trees were comparatively lower than other trees in seed : chaff weight ratio, number of seeds per capsule and number of chaff per capsule. Chaff made up approximately half of the total edible material in the capsules, with a ratio of approximately 1:1 for both feed trees and other trees.

**Table 4.3.** Comparison of various capsule characteristics (mean ± SE) between feed trees and other trees, based on measurements of 10 capsules per tree. Capsule samples were taken from a single site (Tylers) during March 2001 (n = 10 trees).

| Variable | Feed trees | Other trees |
|---|---|---|
| total seed weight per capsule (mg) | 22 ± 2 | 20 ± 2 |
| number of seeds per capsule | 12.4 ± 1.3 | 14.3 ± 1.4 |
| individual seed weight (mg) | 1.9 ± 0.1 | 1.4 ± 0.1 |
| total chaff weight per capsule (mg) | 26 ± 3.2 | 18 ± 1 |
| individual chaff weight (mg) | 1 ± 0.08 | 0.9 ± 0.04 |
| number of chaff per capsule | 20.9 ± 0.6 | 25.1 ± 1.5 |
| total ovule weight per capsule (mg) | 49 ± 4 | 38 ± 2.4 |
| total seed weight : total chaff weight | 0.99 ± 0.15 | 1.12 ± 0.11 |
| total seed weight : capsule weight | 0.06 ± 0.005 | 0.05 ± 0.004 |
| total chaff weight: capsule weight | 0.063 ± 0.007 | 0.047 ± 0.003 |
| capsule weight (mg) | 410 ± 2 | 390 ± 2 |
| capsule volume ($mm^3$) | 4099 ± 222.9 | 3707 ± 190.1 |

Feed trees had significantly greater individual seed weights ($t = 2.86$, $P = 0.01$, $\alpha = 0.05$, d.f. = 18) and total ovule weight per capsule ($t = 2.2$, $P = 0.041$), and significantly lower in number of chaff per capsule ($t = 2.55$, $P = 0.02$). There were no significant differences for the other characteristics. However, there was a high level of inter-correlation between capsule characteristics. For example, individual seed weight and total ovule weight per capsule were significantly correlated with capsule volume (Spearman's Rank Correlations: n = 58, $r_s = 0.53$, $P < 0.0001$; $r_s = 0.82$, $P < 0.0001$; respectively).

### *Intensity of habitat use*

Results of correlations between each characteristic of resource availability and the percentage of trees used per sampling point are given in Table 4.4. All three measurements of capsule availability (crop size, capsule density and cluster size) were significantly positively correlated with the percentage of trees used for foraging, with crop size and capsule density showing the strongest correlations. In contrast, capsule volume was not significantly correlated with the percentage of trees used for foraging.

**Table 4.4.** Results of Spearman's Rank Correlations relating various resource availability characteristics (averaged for each sampling point) to the percentage of trees used for foraging per sampling point (n = 21 sampling points, n = 18 sampling points for capsule volume).

| Variable | $r_s$ | *P* |
|---|---|---|
| Capsule density | 0.52 | 0.015 |
| Crop size | 0.51 | 0.017 |
| Cluster size | 0.44 | 0.046 |
| Capsule volume | 0.32 | 0.19 |
| Girth | 0.09 | 0.7 |
| Height | -0.29 | 0.2 |
| Canopy volume | -0.0092 | 0.97 |
| Percentage dieback | 0.4 | 0.069 |
| Distance between trees (m) | 0.5 | 0.022 |

Distance between trees was the only tree characteristic to be significantly (positively) correlated with the percentage of trees used for foraging, indicating that a higher percentage of trees was used at sampling points with lower tree density. Again, there was a high level of inter-correlation between variables, and distance between trees was significantly positively correlated with capsule density (Spearman's Rank Correlations: $r_s = 0.56$, $P = 0.0076$; n = 58), crop size ($r_s = 0.69$, $P = 0.0006$), cluster size ($r_s = 0.48$, $P = 0.029$), girth ($r_s = 0.38$, $P = 0.012$) and canopy volume ($r_s = 0.36$, $P < 0.0001$).

### 4.3.2 Foraging observations

*Percentage of the day spent foraging*

While perched in feed trees, the cockatoos spent, on average, 76% of their time foraging, 15% of their time resting and 8% of their time engaged in other activities such as preening, courting and allopreening. The cockatoos foraged over a period of approximately 13 hours in summer (February) and 9 hours in winter (July). When the effect of day length was considered (day length multiplied by the percentage of time spent foraging), the cockatoos spent more hours foraging per day in February 2001 (9.5 hours) than in February 2002 (7 hours) or July 2002 (8 hours). There was generally low variability in the percentage of birds observed to be foraging within the months of February 2001, February 2002 and July 2002. The total number of hours spent foraging and number of scans (n) is given for each observation date in Table 4.5. There was generally a high level of consistency between observation days (within months) in the percentage of birds observed to be foraging.

**Table 4.5.** Mean (± SE) percentage of cockatoos observed to be feeding and total foraging time for each observation date (in the months of February 2001, February 2002, July 2002). The number of scans (n), approximate number of hours over which birds were observed to be foraging (day length) and approximate foraging time (% of birds feeding x day length), are given for each observation date.

| Observation date | Mean (± SE) % of birds feeding | No. of scans | Day length (hours) | Approx. foraging time (hours) |
|---|---|---|---|---|
| day 1 | 50 ± 8 | 16 | 13 | 6.5 |
| day 2 | 52 ± 17 | 2 | 13 | 7 |
| **February 2001** | **52 ± 7** | **18** | **13** | **7** |
| day 1 | 55 ± 13 | 4 | 13 | 7 |
| day 2 | 77 ± 7 | 17 | 13 | 10 |
| day 3 | 82.7 ± 13 | 10 | 13 | 11 |
| **February 2002** | **73 ± 6** | **31** | **13** | **9.5** |
| day 1 | 82 ± 7 | 24 | 9 | 7.5 |
| day 2 | 94 ± 4 | 22 | 9 | 8.5 |
| **July 2002** | **88 ± 4** | **46** | **9** | **8** |
| **Grand mean** | **76 ± 3** | **95** | **11.1** | **8.4** |

The percentage of time spent foraging in February 2001 (52%) was substantially lower than for February 2002 (73%) and July 2002 (88%). The differences between these months in the percentage of cockatoos observed to be foraging were significant (Kruskal-Wallis test: $\chi^2$ = 23.16, d.f. = 2, $P$ <0.0001). There were no significant differences between observation days in the percentage of birds observed to be foraging for either the month of February 2001 ($Z_{16, 2}$ = 0.07, $P$ = 0.94), February 2002 ( $\chi^2$ = 3.34, d.f. = 2, $P$ = 0.19, n = 4, 17 and 10 scans), or July 2002 ($Z_{24, 22}$ = 1.38, $P$ = 0.17).

*Percentage of foraging time spent flying within and between trees*

While foraging, the cockatoos made an average of 3.2 flights per bird per hour within trees (between branches) and 2.9 flights per bird per hour between trees (n = 34 scans). The average distance flown within trees was 2.6 m within trees and 9.5 m between trees. An average of 5.5 flights per hour were made by each cockatoo, at an average distance of 6.1m, when combined within and between trees. The cockatoos thus flew 5.5 x 6.1 = 33.55 m per hour, on average. The speed of flying cockatoos was estimated to be 2 metres per second. Therefore, the average time spent flying within and between trees by cockatoos was 33.55 / 2 = 16.8 seconds per hour. There are 3600 seconds in an hour, so the cockatoos spent (16.8 / 3600) x 100 = 0.5% of their foraging time in flight.

*General observations on foraging behaviour*

General observations on foraging behaviour were made over approximately 20 days (includes all observation dates). The cockatoos seemed to show selectivity at several spatial scales. Some trees were clearly sampled and then abandoned in favour of another tree. Usually, a number of cockatoos cohabited a particular tree, and it was not unusual to find 20 or more birds in a single tree. In one case, 40 birds were observed feeding in a moderately sized tree. After some time, birds would gradually (one by one) leave the tree and find another tree for foraging. Numbers of birds would then gradually increase on an unexploited tree as the used tree became depleted. In some cases, small groups of birds fed in neighbouring trees but more often, neighbouring trees were apparently ignored in favour of a tree some distance away. Often the cockatoos appeared to compete for a particular branch. In these cases, one bird would be displaced by another (flying) individual, followed by loud squawking. The cockatoos often used a high proportion of the branches on a particular tree, but usually left a large number of capsules intact.

Occasionally (usually several times a day) the entire flock would take off and fly a distance of up to several kilometres. These flights occurred suddenly and without notice, and were often made in response to a raptor flying past. At other times, the flock appeared to take off in order to search for a new feeding area. At these times, an increased frequency and loudness of calls would precede a departure from the area, and the flock would often circle several times before settling in a new area. Sometimes the flock would return to the same area after scanning surrounding areas. A flock would usually return to a particular area over several consecutive days. On several occasions during very hot weather (approximately 38° C), the birds foraged in the cool of the morning and then went to roost in a nearby stand of red gums until the late afternoon.

### *Foraging efficiency in relation to capsule availability*

Both capsule density and cluster size influenced foraging efficiency. The percentage of foraging time spent on each type of foraging behaviour for low and high capsule density branches is given in Table 4.6. The percentage of foraging time spent on all types of searching behaviour (moving along branch, manipulating branches and looking around) was substantially higher for low capsule density branches than for high capsule density branches. Differences were most pronounced for the percentage of foraging time spent moving along branches (side-stepping to access other areas of the branch).

**Table 4.6.** Mean (±SE) percentage of foraging time spent on searching (moving along branch, manipulating branches and looking around), handling and other behaviours for low capsule density branches (n = 62 observations) and high capsule density branches (n = 25 observations).

| % of time spent on behaviour | Capsule density | |
|---|---|---|
| | Low (<100 capsules) | High (≥100 capsules) |
| moving along branch | 6.4 ± 1 | 1.5 ± 0.6 |
| manipulating branches | 5.3 ± 0.4 | 2.9 ± 0.4 |
| looking around | 8.3 ± 0.8 | 4.3 ± 0.8 |
| **all search behaviours combined** | **20 ± 1.6** | **8.7 ± 1.4** |
| **handling capsules** | **80 ± 1.6** | **91.3 ± 1.6** |
| other activities | 0.8 ± 0.5 | 0.2 ± 0.2 |

More than twice as much time was spent on all searching behaviours combined (moving along branch, manipulating branches and looking around) in areas of low capsule density than in areas of high capsule density. The percentage of time spent handling capsules was 11.3% greater in high capsule density areas than in low capsule density areas. Feeding in low capsule density areas also reduced the number of capsules processed by 17%, from 6.2 ± 0.3 capsules per minute to 5.3 ± 0.3 capsules per minute.

Differences in foraging parameters between capsule density categories were significant for the percentage of foraging time spent searching (Wilcoxon Rank Sum tests: ($Z = 4.71$, $P = 0.0007$), the percentage of foraging time spent handling ($Z = 4.71$, $P < 0.0001$) and the number of capsules processed per minute ($Z = 2.64$, $P = 0.0083$).

The percentage of foraging time spent handling capsules was significantly positively correlated with cluster size ($r_S = 0.46$, $P < 0.0001$, n = 87 observations; Figure 4.5), while the percentage of foraging time spent searching was significantly negatively correlated with cluster size ($r_S = -0.48$, $P < 0.0001$).

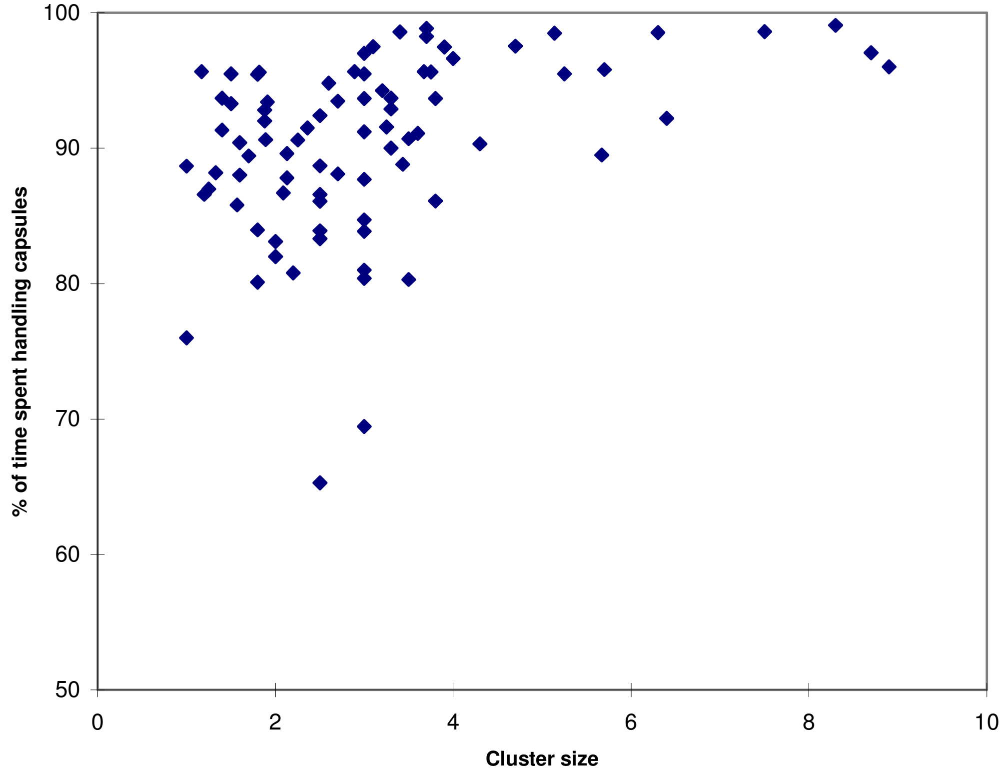


**Figure 4.5.** Correlation between the percentage of foraging time spent handling capsules and cluster size (mean number of capsules per pedicel on severed branches used for feeding; no. of observations, n = 87).

All types of searching behaviour were significantly negatively correlated with cluster size, including: the percentage of time spent looking around ($r_s$ = - 0.32, $P$ <0.0032), manipulating branches ($r_s$ = - 0.48, $P$ <0.0001) and moving along branches ($r_s$ = - 0.32, $P$ <0.0033). The number of capsules processed per minute was not significantly correlated with cluster size ($r_s$ = 0.12, $P$ = 0.28).

### *Foraging efficiency in relation to sex*

Foraging efficiency was comparable between sexes for both foraging parameters. The percentage of time spent handling capsules was 89% for females and 91% for males. The mean (±SE) number of capsules processed per minute was 5.3 ± 0.3 for females and 5.7 ± 0.2 for males. There were no significant differences between sexes in either the number of capsules processed per minute (Wilcoxon Rank Sum test: $Z$ = 0.95, $P$ = 0.34, n = 34 observations for females and 53 observations for males) or the percentage of time spent handling capsules ($Z$ = 0.89, $P$ = 0.37). The mean number of capsules processed per minute for both sexes combined was 5.6.

### *Calculation of total seed intake per day*

There are 8.4 hours of total foraging time in a day, averaged over all seasons. This time includes flying time within and between trees, which makes up 0.5% = 0.042 hours of the total foraging time, leaving 8.36 hours of actual feeding time. The cockatoos spend 92% of their actual feeding time handling capsules, which gives 7.69 hours (461.4 minutes) of time per day spent handling capsules. While handling capsules, the cockatoos process 6.2 capsules per minute when feeding on high density branches and capsules contain 22 mg of seed, on average. Therefore, the maximum daily seed intake of cockatoos is 461.4 x 6.2 x 22 = 62935 mg or 62.9 g of seed.

## 4.4 Discussion

### 4.4.1 Factors influencing the selection of foraging locations

Previous studies of tree selection by Black Cockatoos have concentrated on aspects of fruit profitability as being the most important variables influencing the selection of trees for foraging (Clout 1989, Pepper 1997, Cooper *et al.* 2002, Crowley and Garnett 2001, Pepper 2000). In the present study, however, it appeared that aspects of capsule availability were more important than aspects of capsule profitability as factors influencing the selection of foraging sites. Feed trees were significantly higher than other trees in both capsule availability characteristics (capsule density, crop size and cluster size) and capsule characteristics (individual seed weight and total ovule weight per capsule). However, the largest differences between feed trees and other trees occurred in capsule density and crop size, and these variables were also highly significantly correlated with the percentage of trees used for foraging per sampling point. In contrast, capsule volume was not significantly different between feed trees and other trees for either the broad-scale habitat survey data or data from the survey of capsule characteristics, and was not significantly correlated with the percentage of trees used per sampling point.

Moreover, feed trees were generally either lower or comparable to other trees in the broad-scale habitat survey. Capsule volume is considered to be a good measure of capsule profitability, since it was significantly correlated with total seed weight per capsule, individual seed weight and total ovule weight per capsule. It was not possible to accurately define which characteristics the cockatoos may select for, because there was a high level of inter-correlation among variables. However, it was possible to distinguish between capsule availability and capsule profitability as factors influencing the selection of foraging locations, because capsule volume was not significantly correlated with either capsule density, crop size or cluster size. These results suggest that the south-eastern Red-tailed Black Cockatoo selects trees primarily on the basis of capsule availability. Nevertheless, the profitability of capsules would be likely to have an effect on rate of seed intake, and the cockatoos may be able to increase their foraging efficiency by spending more time feeding in trees that have large capsules with more edible material per capsule. In the present study, it appeared that trees with large individual seed weight and a high total ovule weight per capsule were selected more often than other capsule characteristics. Larger *E. arenacea* seeds have a higher energetic content (Maron 2000). Presumably, the cockatoos are continually assessing their rate of seed intake in relation to the availability and density of resources in the environment, and make decisions based on these assessments. If this is the case, the cockatoos may select trees primarily on the basis of capsule availability characteristics such as crop size, but may spend more time foraging in trees with more profitable capsules.

In the present study, there was particularly large variation between trees in aspects of capsule availability such as crop size and capsule density and low variability in aspects of capsule profitability. In these situations, it may be more profitable for cockatoos to select trees primarily on the basis of capsule availability characteristics. By selecting areas of high capsule availability, the cockatoos may increase their rate of intake more than by sampling large numbers of trees in order to find those trees with the highest capsule profitability. Trees and areas with higher capsule availability characteristics could be found easily on the basis of visual cues, and would not need to be sampled to assess profitability. Furthermore, cockatoos selecting trees or patches of trees with high capsule availability characteristics would need to spend less time searching among trees, because each tree would support more foraging activity. This would reduce the energetic costs associated with foraging considerably. The south-western Red-tailed Black Cockatoo similarly uses tree species that vary greatly in crop size (Johnstone and Kirkby 1999), and capsule availability may be the most important factor determining the selection of foraging sites for this cockatoo as well.

Maron (2000) found that the density of fruits per branch was an important factor influencing the selection of foraging locations by the south-eastern Red-tailed Black Cockatoo when feeding in Buloke *Allocasuarina leuhmanii*. In contrast to the present study, however, the ratio of seed to fruit mass was found to be more important than fruit density per branch. In Maron's study, there were larger differences between feed trees and other trees in aspects of fruit profitability than in fruit density per branch. This suggests that the south-eastern Red-tailed Black Cockatoo uses different selection criteria depending on whether it is feeding in Buloke or stringybark. Therefore, the particular characteristics of the food plants are likely to determine whether the cockatoos select trees primarily on the basis of fruit availability or on the basis of fruit profitability, and this may also help to explain the apparent differences in selection criteria used by different Black Cockatoo populations.

Feed trees were also distinguished from other trees on the basis of tree characteristics such as girth, canopy volume and percentage dieback. However, girth and canopy volume were strongly correlated with crop size, capsule density and cluster size. Therefore, the selection of trees with larger girth and canopy volume probably represents selectivity for capsule availability characteristics. In contrast, the selection of trees with greater percentage dieback could not be explained in terms of either capsule availability or capsule profitability, since percentage dieback was not significantly correlated with any aspect of capsule availability or capsule volume. This result suggests that habitat features other than food availability can influence the selection of trees for foraging. Such characteristics have not previously been considered in foraging studies of Black Cockatoos. Trees with greater dieback may provide enhanced visibility of surrounding areas for foraging birds and may also provide more perches for non-foraging "sentinel" birds (birds watching for predators). The cockatoos are particularly wary of predators and commonly flush suddenly from trees when raptors fly past (Koch pers. obs., Hill, pers. comm.).

The MDS further indicated that the birds may show selectivity at the landscape scale, or may use some areas more intensively than others. Sites were significantly different on the basis of the percentage of trees used for feeding, capsule density, capsule volume, canopy volume and girth, but there was a high level of similarity within sites (between sampling points). This suggests that some sites are of greater resource value than others, and that these sites are also used more intensively than others. Correlations of each variable with the percentage of trees used per sampling point again showed aspects of capsule availability to be the most important factors. A higher percentage of trees was used in areas that were high in crop size and capsule density. Distance between trees was also positively correlated with the percentage of trees used for foraging, indicating that a greater percentage of trees were used where the density of trees was lower. Again, this correlation may simply reflect an increase in capsule availability, rather than selection for lower tree densities *per se*, because distance between trees was significantly positively correlated with capsule density, crop size and cluster size. However, the significant correlation of capsule availability with distance between trees suggests that "patches" of favourable trees do exist. Presumably, tree density could be assessed relatively easily by cockatoos flying overhead, and it may therefore be a valuable cue pinpointing areas of high capsule availability. Such cues may play an important role in reducing search times and increasing foraging efficiency.

### 4.4.2 Foraging behaviour

Pepper *et al.* (2000) demonstrated that Glossy Black Cockatoos feeding on trees with a higher ratio of seed to cone mass significantly increased their rate of seed intake. The present study demonstrated that aspects of fruit quantity such as capsule density and cluster size can also influence foraging efficiency. Cockatoos feeding on branches with low capsule density processed 17% less capsules per minute than those feeding on branches with high capsule density, and spent 6% less of their foraging time handling capsules. These effects on foraging efficiency were no doubt compounded by a two-fold increase in the percentage of foraging time spent searching when feeding on low capsule density branches. Searching behaviour was potentially energetically expensive, as the birds often struggled to reach branches bearing capsules and sometimes had to hang up-side-down.

The decline in foraging efficiency would either have a substantial impact on net seed intake over the course of a day, or would increase the amount of time per day that the cockatoos have to spend foraging to meet the increased costs associated with foraging. The maximum daily seed intake of cockatoos was calculated at 6294 g. Cockatoos feeding on low capsule density branches process 17% less capsules, and would therefore achieve a daily seed intake of 5224 g. Cockatoos feeding on exclusively low capsule density branches, say, in areas that had already been extensively exploited by cockatoos previously, would need to spend approximately 9 hours a day handling capsules (11% more handling time) and nearly 10 hours a day foraging to harvest the same quantity of seed. This estimate is conservative, because feeding in low density areas probably entails additional time and energetic costs associated with searching among trees and among branches, further increasing the energetic cost : benefit ratio. Assuming that Red-tailed Black Cockatoos strive to maximise their rate of food intake, capsule availability should be a critically important factor influencing the selection of foraging locations on a landscape scale, and we would expect the south-eastern Red-tailed Black Cockatoo to avoid areas of low capsule density.

The cockatoos spent a significantly higher percentage of their time foraging in winter than in summer. This is not surprising given that days are shorter in the winter and energy requirements are greater (Brotons *et al.* 2001). However, the number of daylight hours spent foraging per day for July 2002 (8 hours) and February 2002 (9.5 hours), were comparatively higher than for February 2001 (7 hours). The result needs to be interpreted with caution due to the small number of days over which observations were performed, but was nonetheless consistent with the expectation that the cockatoos would need to spend more time foraging per day as the seed crop ages and becomes more depleted. Furthermore, there was a high level of consistency between observation days in the percentage of the day spent foraging. Foraging observations performed in February 2001 represented a time when the seed crop was largely unexploited, since a new seed crop was produced on *E. baxteri* in November 2000 (Chapter 3). Therefore, it is likely that the increased foraging time spent in February 2002 and July 2002 was due to reduced capsule densities at this time. Capsule densities were not measured for scan sampling observations on the percentage of birds foraging. However, given that the number of hours spent foraging at this time was similar to the value predicted for cockatoos feeding entirely on low capsule density branches (above), it is likely that capsule densities were generally lower for observations performed in February 2002.

Large cluster sizes also significantly increased foraging efficiency. The percentage of foraging time spent handling capsules was positively correlated with cluster size, while the percentage of time spent searching was negatively correlated with cluster size. The cockatoos spent a lower percentage of their time searching (manipulating branches, looking around, or moving along the branch), and a higher percentage of their time handling capsules, when feeding on branches with large cluster sizes. With reduced search time and greater handling time, the cockatoos should be able to process more capsules per minute. However, the number of capsules processed per minute was not significantly correlated with cluster size. The cockatoos may drop a larger proportion of capsules when feeding on branches with larger cluster sizes, and so cannot or do not improve their foraging efficiency on a capsule per minute basis. Nevertheless, given that the cockatoos spend less time searching when feeding on branches with large cluster size, it is likely that they can increase their rate of energy intake when larger cluster sizes are present because of reduced foraging costs associated with searching behaviour.

The importance of capsule availability may help to explain why food supply appears to be a limiting factor for the south-eastern Red-tailed Black Cockatoo, despite the fact that large areas of stringybark woodland remain. If feeding profitability is determined primarily by capsule availability, then large areas of woodland may quickly become of low habitat value after the cockatoos have selectively used all the trees and branches with the high capsule density required to maximise profitability. Given that half of the stringybark within the range of the cockatoo has been cleared, food shortages would arise far more often than occurred prior to European settlement, because the cockatoos would have to spend more time feeding in areas with depleted resources.

The south-eastern Red-tailed Black Cockatoo is known to breed throughout the year, but most nesting attempts occur in spring or early summer, from September to December (Burnard and Hill 2001). It is unlikely that many of the birds observed during the study were breeding because observations were performed in the months of February and July. Therefore, the mean percentage of daily time spent foraging by the cockatoos (76%) is likely to represent non-breeding birds. By comparison, non-breeding Glossy Black Cockatoos spend approximately 60% of their time foraging (South Australian population; Chapman unpubl. data).

If the high percentage of time spent foraging by the cockatoos in the present study is representative of non-breeding birds, then it is unlikely that many cockatoos would be able to meet the food requirements of breeding. Breeding males need to harvest enough seed to provide food for their female partner and a young nestling, in addition to their own food requirements (Burnard and Hill 2001, Jarmyn 2000). Breeding males would need to forage for twice as long as non-breeding birds to meet these demands, or increase their net seed intake in some other way. Breeding male Glossy Black Cockatoos increase their net seed intake by extracting seed more efficiently than females and spend more time foraging each day (Pepper *et al.* 2000). By contrast, there were no significant differences between sexes for any measure of foraging efficiency in the present study, suggesting that breeding male Red-tailed Black Cockatoos would need to spend more time foraging each day to meet the increased costs associated with breeding. However, the cockatoos were limited by the number of daylight hours, and it is unlikely that breeding males would be able to spend enough time foraging to harvest such a quantity of seed, without suffering severe loss of body condition.

The percentage of time spent foraging by birds feeding on the newly matured seed crop in February 2001 was 52%. Male cockatoos breeding at this time may meet their food requirements by foraging for a greater percentage of time each day. As time progressed since the seed crop was produced, however, the cockatoos spent an increasing percentage of their time foraging, 73% in February 2002 and 88% in July 2002. At these times, it is unlikely that many cockatoos could have successfully raised a chick. These findings suggest that the birds would struggle to meet the demands of breeding in those years when a new seed crop is not produced.

In accordance with this expectation, studies of nest success (proportion of nests fledging young) for this cockatoo indicated that nest success was substantially lower for 1999 (Jarmyn 2000), a year when no new seed crop was produced, than in 1998 (Burnard and Hill 2001), when a new seed crop was produced on *E. arenacea* (see Chapter 2). Moreover, the primary cause of nest failure for 1999 was thought to be incubation disturbance associated with females leaving the nest at unusual times of the day (Jarmyn 2000). The likely cause of these absences was that the females needed to forage during the day in order to supplement food provided by the male. Saunders (1980) observed similar behaviour for Carnaby's Cockatoo, which was attributed to low food availability and resulted in low nesting success. The evidence from the present study suggests that few nesting attempts are successful in years when a new seed crop has not been produced. Therefore, food supplies in the range of the cockatoo may be generally limiting population growth.

This chapter identified aspects of capsule availability as key factors influencing the selection of foraging sites, and strongly suggests that food supplies are limiting the growth of the south-eastern Red-tailed Black Cockatoo population. It is therefore important to determine the effects of prescribed burns on these aspects of resource availability, and to identify possible management strategies for reducing the effects of prescribed burns. These issues are the subject of the next chapter.