2017

Nocturnal roost tree, roost site and landscape characteristics of Carnaby's Black-Cockatoo (Calyptorynchus latirostris) on the Swan Coastal Plain

Candice Le Roux
Edith Cowan University

Edith Cowan University

Copyright Warning

Nocturnal roost tree, roost site and landscape characteristics of Carnaby's Black-Cockatoo (*Calyptorynchus latirostris*) on the Swan Coastal Plain

This thesis is presented in partial fulfilment of the degree of

Master of Science (Biological Sciences)

Candice Le Roux[1]

Edith Cowan University

School of Science

2017

Supervisors: Prof. William D. Stock[1], Dr Dave Blake[1], Dr Robert Davis[1], and Dr Geoffrey Barrett[2]
[1]Centre for Ecosystems Research, Edith Cowan University, Joondalup, WA
[2]Regional Ecologist (Swan Region), Department of Biodiversity, Conservation and Attractions, WA

Abstract

There is limited information on communal roosting in parrot species of Western Australia and other parts of the world. Carnaby's Black-Cockatoo is an endangered species that forms large nocturnal communal roosts, and for this reason they are an ideal model species to test the characteristics or factors that are associated with roost sites. Known roost sites distributed across the Swan Coastal Plain were identified and selected through the Great Cocky Count project. A minimum of five and maximum of ten individual trees were assessed at 11 roost sites with an overall total of 95 roost trees sampled. I determined the tree species composition and vegetation structural arrangement, as well as the roost site location properties of each of the selected roosts. A total of 18 widely dispersed roost sites on the Swan Coastal Plain were chosen for spatial analysis of landscape characteristics at three scales, namely 1, 6 and 12 km radii around each roost. Landscape characteristics were derived from data layers using a geographical information system. Generalized linear modelling was used to investigate which landscape variables best explain the roost count numbers and fidelity of Carnaby's Black-Cockatoo at the three spatial scales. Landscape variables were broadly categorised into urban pressures, tree characteristics, and, food and water availability.

I found that at the roost tree scale, the cockatoos utilised a wide range of native and non-native trees, situated within a variety of land-use types. Results showed that bird's roosted in tall (average of > 25 m) tree species that have relatively thick trunks (average DBH of 1 m) and medium foliage density (average of 50 %), and that are not too densely forested amongst other trees (average tree crown connectivity was 20.58 %). Carnaby's Black-Cockatoos showed no preferences for any particular tree species or bark colour across the study sites. At the landscape scale, models (based on Akaike Information Criterion) showed that variables associated with bird abundance and roost fidelity varied with scale. The models highlighted the importance of a 1 km radius of potential roost trees (tall trees i.e. $\geq$ 8 m) across all scales, and food (*Banksia* and pine) and water sources, particularly within a 1 and 6 km radius. Study sites surrounded by more urban pressure may be driving greater numbers of Carnaby's Black-Cockatoo at such sites because the formation of larger flocks can increase resource location in fragmented landscapes. Reduced density of roads and non-native ground cover vegetation, over the greater landscape, indicated that restricting the amount of densely urbanised structures should be considered when further developing around roost sites across the Swan Coastal Plain.

The nocturnal roost study sites had greater fidelity and numbers of cockatoos with a combination of landscape variables at different scales, which are based on habitat structure, food availability and water availability. The understanding of the characteristics of communal roosts, roost site choice, and the surrounding matrix developed in this thesis provides managers with insights on how best to conserve this species.

Declaration

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

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

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

(iii) contain any defamatory material.

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

Candice Le Roux

USE OF THESIS

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

Acknowledgements

I am very grateful for being able to take on this project, which was suggested to me by my Principal Supervisor, Professor Will Stock. He was a supportive mentor and guide throughout the many challenging aspects of the project. His feedback was helpful, insightful and to the point; and despite having his own busy schedule, he would always make time for our meetings. I learned a great deal about the Carnaby's Black-Cockatoo and Professor Stock was able to provide me with interesting insights on the species and their ecology. I would also like to express my gratitude to my co-supervisor, Dr David Blake, who patiently worked with and guided me through the GIS aspects of my project, putting a great deal of time aside for my GIS questions and queries. I also gratefully acknowledge my co-supervisor Dr Rob Davis for advising me wherever possible and for his encouragement throughout the research project. I wish to sincerely thank Dr Geoffrey Barrett from the Department of Biodiversity, Conservation and Attractions (DBCA) for the many insights he provided on the species, and for his assistance in connecting me to relevant contacts. Each supervisor was helpful in their own way, and I feel fortunate to have been able to work with and learn such a great deal from them.

I would like to extend my thanks to Yvonne Garwood, Lisa Skepper, Rob Czarnik, Clay Millar, Pierre Horwitz and Mary Boyce at ECU, for their help with various administrative aspects of my project. I was also fortunate to have received help with GIS related tasks from Ricky van Dongen, Geoffrey Banks, and Vicky Reynen, all of whom work at DBCA. My project expenses were paid for by funding from DBCA and ECU, and I am grateful to have had this financial assistance and support. Thanks to BirdLife Australia for providing data and information from the Great Cocky Counts (GCC), including roost site and count data. I was able to gain further insight into this citizen science survey by assisting Matt Byrne with the 2015 GCC volunteer coordination. The current GCC coordinator Adam Peck has also been helpful where I have needed information. I'm appreciative of the help provided by Adam, Matt and Birdlife Australia, and I hope to be involved in future GCCs. I received help from a number of GCC volunteers who very kindly provided me with exact locations of roost sites.

I would not have enjoyed the post-graduate journey as much without all my post-graduate friends, and so I would like to say a big thank you to them. I have forged wonderful friendships through doing this Masters project and I am keen to continue being involved with their research and to assist where I can. Some of these friends did GIS-related work for me; Jessica Bruce and Nakisa Shahrestani, thank you! Jonathan Boeyen was my GIS mentor on many occasions, he was exceptionally patient and helpful, and has an incredible knack for working with data and GIS in general. For the final proofread of my thesis, I am appreciative to my mom, Jenni Le Roux and friend Grant Buller. Finally, for their encouragement and patience, I would like to thank those closest to me - my parents, and partner Zachary Redmond. I am especially grateful to my Dad, Ben Le Roux and Zac for accompanying me to the various roost sites at sunset, to do my research, and also for assisting me with roost tree measurements and observations.

Table of contents

Chapter 1 - Introduction and Rationale

1.1 Communal roosting

For many animals, communal roosting is an integral life-history trait, and roost selection can play a key role in their survival because of the implications it can have on a number of other life-history traits. Communal roosting occurs in many species of birds and bats (Ward and Zahavi 1973, Marshall 1983), however it is a poorly understood behaviour, particularly in birds (Smith et al. 2008). Communal roosting can be described as the grouping of two, or more, resting individuals and occurs in insects, arachnids, mammals, and birds (Bijleveld et al. 2010). In birds, social roosting is commonly found in parrots and an indication of communal roosting can be seen when flock size increases at sunset (Warburton and Perrin 2005). When individuals roost, they are able to spend time preening and resting (Conklin and Colwell 2007). The formation of large communal roosts can be associated with pre-migratory assembly and migratory influx, however some species form large communal roosts outside of the migratory periods, such as European Starlings *Sturnus vulgaris* (Michael and Wan-tsih 1973, Caccamise et al. 1983). Caccamise et al. (1983) suggested that communal roosting might be promoted where there is a shortage of available sites, depending on the circumstances.

1.1.1 Communal roosting: an aspect of flocking behaviour

Communal roosting is a behaviour displayed by many species of animals. In birds, it is an aspect of flocking behaviour whereby they gather in groups to raise young or rest (Dall 2002). The advantage of flocking or living in groups is generally regarded as a behavioural adaptation to: 1) aid in detecting or avoiding predators; 2) compensate for variations in food availability; 3) defend resources from competing species or conspecifics; 4) locate potential mates; 5) develop richer learning environments for slow developing young, and; 6) thermoregulate by huddling close together (Pulliam 1973, Arora and Kanta 2009, Legault et al. 2012). Pulliam (1973) highlighted that there is a higher probability of predator detection when feeding close to other individuals, and therefore flocking can be advantageous. To add to this, those animals that position themselves in the centre of a group are further protected from predators than those on the periphery (Hamilton 1971). Rubenstein et al. (1977) concluded that flocking is generally advantageous because foraging in groups facilitates locating clumped resources. They also suggested that more energy than necessary could be expended if a bird solely relies on trial and error learning and past experience to find new foraging areas and refine optimal foraging strategies according to the conditions of the new foraging areas. Rubenstein

et al. (1977) suggested that the energetic costs of such a process could be reduced substantially and feeding efficacy improved if birds utilized other aggregations of birds as indicators of suitable foraging areas, as well as if they copied the feeding patterns used by these birds (Rubenstein et al. 1977). Such processes could apply to individuals within a flock, making flocking advantageous.

Individuals joining others have a better chance of surviving and reproducing than those that do not, and as such, social behaviour evolves (Arora and Kanta 2009). Determining whether group living is advantageous or disadvantageous depends on the species and the time of year (Arora and Kanta 2009). The reasons for flocking, previously mentioned, provide background information into why birds might congregate in the first place. Consequently, communal roosting is an extension of flocking behaviour, although there are additional behavioural and environmental factors that influence communal roosting.

1.1.2 Communal roosting hypotheses

Nocturnal roosting occurs when diurnal bird species, after feeding by day, settle at roost sites when light levels begin to lower toward sunset (Martin 2010). Diurnal birds are mainly active throughout the day and spend the night roosting, however many species also spend parts of the day roosting between bouts of foraging (Martin 2010, de Gruyter 2011). Roosting behaviour can differ considerably between species and throughout the year (Casagrande and Beissinger 1997). Commonly, studies have concentrated on bird species that have conspicuous communal roosts, but there is insufficient knowledge on the properties that motivate this behaviour and what purpose it offers (Smith et al. 2008). There are numerous species of birds that gather in communal roosts year-round and breed communally. Others are solitary breeders and roost communally in the non-breeding season, while there are many birds that are solitary throughout their lives (Ward and Zahavi 1973). Non-breeding season social organisations are classified under the behavioural categories of either territorial or gregarious (Crook 1964). Ward and Zahavi (1973) suggested that flock-feeding birds tend to roost communally and that communal roosts function as "information-centres". "Information-centres" provide information to searching members of the roosting flock as to where food within the area can be obtained (Ward and Zahavi 1973). This can reduce the amount of time an individual bird may spend searching for food as it does not have to start a random search over large areas if it joins a group, or information-centre, that has already found readily available food.

Primary roost sites, or nocturnal roost sites in the case of diurnally active birds, provide a place for birds to congregate and act as information-centres. Information transfer occurs between individuals after staying at nocturnal roosts overnight, for example, if a bird has been unsuccessful in

finding a feeding area, it can follow roost mates the following morning to feeding areas found the previous day (Ward and Zahavi 1973). Ward and Zahavi (1973) proposed that the more individuals that gather at a roost, the wider the search for food, and the greater the chance of discovering all good feeding areas. Along with this theory of information sharing and increased foraging efficiency, communal roosting in birds is also thought to decrease thermoregulation losses, as well as reduce risks of predation (Beauchamp 1999, Smith et al. 2008). In relation to thermoregulation benefits, communal roosts are thought to minimise energetic demands for thermoregulation where companions huddle together, or where the physical structure of the roost provides protection from weather conditions (Beauchamp 1999). Surrounding roost mates, and the physical properties of the roost site also provide anti-predation benefits (Ward and Zahavi 1973, Caccamise and Morrison 1986, Beauchamp 1999). Birds in flocks are able to clump together to deter predators such as hawks because the mass of a group can confuse the predator, making it less successful in catching prey (Arora and Kanta 2009). An avian predator can also be at risk of injuring it's wings if it gets too close to a clumped flock of birds (Arora and Kanta 2009).

Caccamise and Morrison (1986) noted that initial communal roosting arguments and models were formulated for communal nesting which have resulted in a biased view of communal roosting behaviour. They highlighted that the difference between roost sites and nest sites is that nesting sites are fixed by the presence of immobile eggs and young, whereas roost sites are not (Caccamise and Morrison 1986). Morrison and Caccamise (1985) suggested predation pressure to be less important in European Starling's roosts as opposed to nesting colonies due to the absence of the vulnerable eggs and nestlings. They marked and radio-tracked individual roost-mates of European starlings and found that individuals made use of a variety of roosts but then, for months, returned day after day to their own "diurnal activity centre" (1-2 km^2 area) to feed. In contrast to Ward & Zahavi's (1973) information-centre hypothesis, Caccamise and Morrison (1986) suggested that roosting and foraging is centred around a diurnal activity centre, which is a stable feeding area, rather than around a roost (Morrison and Caccamise 1990). The starlings were more faithful to their feeding sites compared to their roosting sites. They continued to utilize diurnal activity centres as their primary food source even when using distant roosts, but also made brief stops at food sources close to the distant roost (Morrison and Caccamise 1990). Starlings joined more distant major roosts when the availability of food declined in the diurnal activity centre. Foraging efficiency and reduction of nocturnal predation risks were thought to be advantageous when joining the distant major roosts (Caccamise 1991). Starlings are able to decrease commuting costs by roosting overnight within close proximity to food patches that are far from their diurnal activity centres (Morrison and Caccamise 1990). Both the

information-centre hypothesis and the diurnal activity centre provide acceptable explanations into the adaptive significance of roosting, and as to why birds might roost.

Chapman et al. (1989) proposed another function for communal roosting, but did not preclude functions such as the information-centre hypothesis and diurnal activity centre. They observed that flocks of parrots (White-fronted Parrots *Amazona albifrons*, Orange-fronted Parakeets *Aratinga canicularis*, Orange-chinned Parrots *Brotogeris jugularis*, and Yellow-crowned Amazon parrots *Amazona ochrocephala*) avoided following preceding groups from the roost, which was believed to be a means of reducing the chances of groups arriving at fruit trees with other conspecific competitors. From this observation, they proposed their *Foraging Dispersion Hypothesis*, whereby roosts could serve to assist in dispersion of foragers so as to reduce intraspecific competition for food resources (Chapman et al. 1989). Not mutually exclusive, the three hypotheses are all explanations that relay the importance of the roost as a centre to radiate to or from each day for foraging, as well as for protection purposes. The Foraging Dispersion Hypothesis, information-centre hypothesis and diurnal activity centres can aid in a deeper understanding behind the roosting habits of other animals and birds, allowing for better management and/or protection of these species.

1.1.3 Communal roosting in Bats

Bats are animals that roost communally and reasons and factors associated with this behaviour, can provide insight into why Carnaby's Black-Cockatoos might choose to roost communally. Many birds and bats use information transfer between group members, a behaviour believed to be an important component in the evolution of coloniality (Kerth and Reckardt 2003). Studies have found information transfer being used in bats; for example, the evening bat *Nycticeius humeralis* was found to exchange foraging information with other roost mates, and the spear-nosed bat *Phyllostomus hastatus* was found to recruit colony mates to rewarding food sites (Kerth et al. 2001). A study by Kerth and Reckardt (2003) found that female Bechstein's bats *Myotis bechsteinii* recruited other significantly naïve females to more suitable roosts rather than unsuitable roosts. They concluded that information transfer, in relation to roosts, has two purposes: 1) to provide communal knowledge of novel roosts, or a large group of roosts (Bechstein's bats rely on a variety of roosts, and for this reason communal knowledge of day roosts could be a significant resource for a colony); and 2) to assist in prevention of colony fission whilst switching roosts (Kerth and Reckardt 2003). Kerth and Reckardt (2003) proposed that by recruiting other colony members, recruiters are able to receive thermoregulation benefits, whereby raised temperatures appear to be an important factor in successful reproduction.

4

Selection of suitable roosts by groups is based on important roost tree characteristics in order to sustain population persistence (Garroway and Broders 2008). A study by Hahn et al. (2014) examined roost site characteristics of the Flying fox *Pteropus giganteus* and found that roost trees were usually canopy trees and were taller, with greater diameters when compared to non-roost trees. Larger colonies were found in densely forested regions and colonies were found to be smaller where areas had been flood-affected and annual precipitation was lower. Human population density was also higher at roost locations in comparison to non-roost sites. Hahn et al. (2014) also observed that: 1) food proximity and food availability had a strong influence on *Pteropus* roost selection; 2) roost sites were often in close proximity to large ponds, thought to be used as a drinking source; 3) preferred roost sites were closely located alongside areas of high human population, believed to be due to the greater diversity of food provided by homestead gardens that might not have been present in the native habitat and 4) preferred roost site canopy trees were taller and larger possibly because large colonies have more space available to them. Their findings related bat colony size to tree species composition within the roost site and they speculated this was due to architectural differences. A greater number of bats were observed to congregate in those tree species which provided a larger number of branches (Hahn et al. 2014).

Pierson and Rainey (1992) suggested that large bats select tall trees as roost sites because they require the space to free-fall during take-off. They also proposed that some *Pteropus* species select roost sites according to certain tree characteristics, as well as basing the roost site close to food resources. It was noted however, that feeding and roosting sites were kept separate (Pierson and Rainey 1992). Hahn et al. (2014) identified the roosts in their study as having been occupied for more than a decade, confirming high roost fidelity in colonial megabats and those genera which roost communally (Marshall 1983). Some studies have noted that *Pteropus* spp. show fidelity to a home range rather than a single roost. With increasing human activities some colonies have been displaced and have been forced to move from traditional roost sites (Pierson and Rainey 1992). However, human pressures are not all detrimental since species like *P. giganteus* prefer roosting in forests within close range of high human density. This is thought to be as a result of the diverse food resources and water sources found in anthropogenic landscapes (Hahn et al. 2014). The information gathered about bats and their roosting habits and requirements provides some interesting insights into communal roosting behaviour and factors involved in communal roosting which may also apply to bird roosts.

1.1.4 Communal roosting in birds

The persistence of communal roosting in several avian families is thought to be an ancestral trait (Beauchamp 1999). Communal roosting has been defined by Beauchamp (1999) as a group of two or more birds that sleep in the same area, and that this form of social behaviour goes beyond paired bonds. Gregarious behaviour forms part of the daily lives of most parrot species, with communal roosting being an important component (Davies et al. 2012). This communal roosting characteristic has been useful in assessing parrot population sizes since individuals can be counted as they enter or leave roost sties (Cougill and Marsden 2004). A citizen science project in south-west Western Australia (WA), the Great Cocky Count, is a good example of nocturnal roost counts undertaken on an annual basis (2010 to present) to assess Carnaby's Black-Cockatoo *Calyptorhynchus latirostris* and Forest Red-Tailed Black-Cockatoo *Calyptorhynchus banksii* populations (Finn et al. 2014).

Cougill & Marsden (2004) investigated roost size variability in Red-tailed Amazon parrots *Amazona brasiliensis* and found evidence that suggested that some of the birds abandoned the central roost in anticipation of the breeding season. This study recommended that roost count surveys be conducted in the period prior to the start of movement from the roost toward the breeding season. They also found that the nearest adjacent roost site used by the Red-tailed Amazons was over 8 km away, and assumed the day-to-day movements to be relatively low between the established roosts (Cougill and Marsden 2004). Other parrot species, such as the Green-rumped Parrotlet *Forpus passerines*, exhibit extensive daily movements between roosts (Casagrande and Beissinger 1997). Baker (2000) found that the movements of Australian Ringneck parrots *Barnardius zonarius*, to and from their roost sites, were gradual. The fundamental year-round social unit of ringnecks from WA is the mated pair, however, during the non-breeding season, Australian ringnecks assemble in traditional roost sites in the late afternoon (Baker 2000). Many ringnecks accumulate at night-time roosts and range outward in the mornings, perhaps an example of the information centre hypothesis and/or Foraging Dispersion Hypothesis. Baker (2000) suggested that, where pairs were faithful to a roost locale, they ranged out from each other during the day and used roost-specific flight calls to regain contact at their evening roost site. He proposed that the pairs may be able locate each other by returning to a traditional area of the roost site.

Different parrot species choose roost locations according to specific landscapes. The landscapes chosen may be natural or urban or most commonly a mix of the two. Many Australian parrot species have adapted to urban landscapes, particularly those that are nectarivorous such as Rainbow lorikeets *Trichoglossus haematodus* (Legault et al. 2012, Davis and Wilcox 2013). Cities however, when compared to other urbanised or suburban zones, have lower parrot abundances and

diversity which is most likely due to lack of vegetation resulting in fewer feeding, nesting and roosting sites. Some species have managed to adapt to cityscapes, such as Rainbow lorikeets in Australia, Ring-necked parakeets *Psittacula krameri* from Europe, and Monk parakeets *Myiopsitta monachus* in North America (Legault et al. 2012, Davis and Wilcox 2013). They have successfully colonised major cities, often appearing to favour built-up areas more than natural environments. This may be because the cities provide many anthropogenic cavities suitable for nesting which can be utilised by the smaller-bodied parrots, whereas the cities may lack appropriately sized hollows for larger parrots like cockatoos (Davis 2013).

Rainbow lorikeets being gregarious birds, form large flocks especially when searching for nectar (Legault et al. 2012). Legault et al. (2012) found that Rainbow lorikeets had relatively consistent flock sizes throughout the day, however the flock size increased toward the end of day which was related to communal roosting. Lorikeets regularly form large nocturnal roosts, favouring thickly foliaged trees, which can contain more than 1000 individuals (LeCroy et al. 1992, Jaggard et al. 2014). Some parrot species such as Horned parakeets *Eunymphicus cornutus* and New Caledonian parakeets *Cyanoramphus saisseti* form small flocks; this may be because their granivorous diet has seemingly not had an evolutionary incentive to form larger food sourcing flocks (Legault et al. 2012). Brereton (1971) suggested that gregariousness, and thus flock size, of Australian parrots such as cockatiels *Nymphicus hollandicus* and budgerigars *Melopsittacus undulatus*, increases (from dozens to thousands of individuals) with increased habitat aridity. He also noted that parrots in higher rainfall areas, such as king parrots *Alzsterus scapularis* and crimson rosellas *Platycercus elegans*, generally occur in small groups of three or four individuals (Brereton 1971). Cannon (1984) referred to these notes by Brereton in her study regarding differences in parrot flock patterns and size, but she points out that lorikeets generally form very large flocks even though they are in higher rainfall areas. She deduced that this may be because, as flower-feeding birds, they may gain advantages from flock feeding (indicative of the information centre hypothesis) due to the widely dispersed and ephemeral food sources (Ward and Zahavi 1973, Cannon 1984). Diurnal flock size can be influenced by foraging efficiency and it is important for animals to meet their energetic requirements whilst foraging over an area (Chapman et al. 1989). Research into size, density and distribution of diurnal flocks of parrot species can provide knowledge on their foraging requirements, of which roost information is a contributing factor (Chapman et al. 1989).

Flocks of Sulphur-Crested cockatoos *Cacatua galerita* often have permanent roosting sites to which they may exhibit fidelity for many years, despite landscape changes (Lindenmayer et al. 1996). They can travel substantial distances between nocturnal roosting sites and other areas where they are able to forage. Preferred roost trees, in south-eastern Australia, include Eucalypts, Casuarinas,

Leptospermums and Melaleucas. Extensive night-time spotlighting surveys of *C. galerita* were undertaken by Lindenmayer et al. (1996) in the remnant patches of Buccleuch State Forest, New South Wales. *Cacatua galerita* was found to strongly prefer large *Eucalyptus viminalis* trees as roosting sites (96 % of 173 observations of *C. galerita* were in these trees) due to factors such as suitability for nesting (which may influence the use of these trees as roost sites), branching patterns and angles, bark colour, the density of foliage and trunk height. Lindenmayer et al. (1996) noted that the bark colour of other Eucalypt and understorey trees found in their study sites were dark, whereas *E. viminalis* is characterised by mostly smooth, white bark of the branches and trunk. The authors suggested that the lighter bark colour could provide camouflage for the white-plumaged *C. galerita* whilst roosting, thus avoiding predator detection (Lindenmayer et al. 1996). There have been a number of nocturnal roosting studies done on parrot species outside of WA (Lindenmayer et al. 1996, Lowry and Lill 2008, Jaggard et al. 2014), however there is limited research on the nocturnal roosting habitat requirements of parrot species native to WA.

Carnaby's Black-Cockatoo is a parrot species that forms large nocturnal communal roosts in the non-breeding season on the Swan Coastal Plain, and to date their roosting habitat has not been extensively studied. The aforementioned roosting hypotheses may provide insight into some of the roosting behaviour and consequent roost selection of Carnaby's Black-Cockatoo, however this study focused on the characteristics associated with nocturnal roosting habitat. Tree structure (LeCroy et al. 1992, Lindenmayer et al. 1996, Jaggard et al. 2014), food, shelter (Ward and Zahavi 1973, Morrison and Caccamise 1990, Caccamise 1991, Beauchamp 1999) and water availability (Hahn et al. 2014) are likely to be driving determinants of the nocturnal roost selection by Carnaby's Black-Cockatoo. The nocturnal roost habitat characteristics that were measured in this study were divided into different spatial scales: the roost tree, whereby structural characteristics were measured, and; the roost site and surrounding matrix within which food, water and shelter were measured. The study's basis and methodology for characterising roosting habitat may be applicable to other parrot species to indicate what characteristics may be associated with suitable roost sites.

Changes in landscape composition within the Swan Coastal Plain dictate the need for understanding and characterising Carnaby's Black-Cockatoo roost site selection and habitat. Carnaby's Black-Cockatoo nocturnal roosts have more recently been identified as important components of their non-breeding habitat (Department of Parks and Wildlife 2013) and little research has been carried out in characterising Carnaby's Black-Cockatoo roost sites on the Swan Coastal Plain. This study sought to gain further insight into the characteristics of Carnaby's Black-Cockatoo nocturnal roosting habitat. The study has been separated into 5 chapters: Chapters 1–2 address the general introduction into flocking and communal roosting behaviour (Chapter 1), as well as the study

region and study species (Chapter 2), and; Chapters 3–5 address the objectives of the study. The objectives of the study are to: characterise the nocturnal roosting habitat of Carnaby's Black-Cockatoo in terms of the tree species and structural characteristics, roost site characteristics, and landscape characteristics in order to establish what makes up a suitable nocturnal roost based on the study sites (Chapter 3); develop a model of Carnaby's Black-Cockatoo roosting habitat in order to understand what landscape characteristics might be drivers of nocturnal roost abundance and fidelity within three different spatial scales (Chapter 4), and; synthesize the results and discussion of Chapters 3 and 4, provide management recommendations, and conclude the general outcomes and implications of the study (Chapter 5).

1.1.5 Scope and objectives of the study

Carnaby's Black-Cockatoos congregate at dusk to rest overnight in roost trees at various roost sites throughout the Swan Coastal Plain, and a roost site can be made up of a number of roost trees within close proximity to each other (usually neighbouring or nearby trees). Mature trees are a "keystone structure" to any environment because they provide important resources (Lindenmayer et al. 2014) for Carnaby's Black-Cockatoo, as well as other species. Once old large trees are gone, it can take centuries to restore them, and it is for this reason that existing large trees are retained and maintained (Lindenmayer et al. 2014). Many Australian state councils have street tree protection policies in place or policies that prevent landowners from removing mature trees without approval (WA Local Government Association n.d.). The general trend of recent redevelopment within the Swan Coastal Plain however, has been to build larger dwellings on smaller lots (Brunner & Cozens, 2012). Gardens have become smaller which has reduced tree retention and minimised plantings as part of landscaping trends. Decking and paving are examples of hard surfaces that commonly replace planted areas (Brunner & Cozens, 2012). Continued reduction of urban gardens and overall tree cover is likely to adversely impact Carnaby's Black-Cockatoo nocturnal roost site availability. Protecting and enhancing roosting habitat is one of the ways the species can be protected. This can be done by identifying the characteristics associated with nocturnal roost sites and incorporating the information into an urban conservation strategy for the species.

Generally, the most significant Carnaby's Black-Cockatoo nocturnal roost sites identified on the Swan Coastal Plain region of WA since 2010 have been in or associated with the Gnangara pine plantation (Finn et al. 2014). Finn et al. (2014) established that significant roosts are found in rural, peri-urban, and densely-populated urban landscapes, similar to the behaviour of Rainbow lorikeets which exploit the ephemeral and widely distributed resources that occur in urban landscapes (Davis

2013). Although Carnaby's Black-Cockatoos have adapted to exploiting resources created by humans, the abundance and range of the species has been in decline. There are numerous anthropogenic causes for their decline, such as car strikes, fragmentation and loss of habitat and, and through habitat loss, there has been an increase in nest hollow competitors (Johnstone et al. 2011, Department of Parks and Wildlife 2013, Groom et al. 2014). The population is unable to recover from the rising mortality rates associated with these threats and as such, the abundance and range has declined, particularly as it is a slow-breeding, long-lived species (Johnstone and Storr 1998).

Environmental factors are likely to have an effect on communal roosting behaviour, at both the regional scale and the individual roost scale, as well as having an influence on communal roosting behaviour over larger spatial areas that contain numerous roosts (Lyon and Caccamise 1981). Understanding the processes behind roost selection by the Carnaby's Black-Cockatoo can provide valuable information on the species and the habitat it requires at a local and landscape scale. The information will help to identify the characteristics of nocturnal roosts used by Carnaby's Black-Cockatoo as well as other avian species.

In the non-breeding season, foraging habitat and night roosting sites are important habitat components for the survival of Carnaby's Black-Cockatoos (Department of Parks and Wildlife 2013). The citizen science project, the Great Cocky Count (GCC) arose from the realisation that counting Carnaby's as they fly into their nocturnal roost sites, was a convenient way to monitor bird numbers (Shah 2006) and has subsequently monitored hundreds of nocturnal roost sites in the south-west of WA. This study utilised data from the GCC (Byrne et al. 2015) which provided records on the characteristics and flock sizes of known roost sites from 2010, up to and including 2015. The aims of the study were met by sampling structural and spatial characteristics of a range of roost sites with varied levels of occupancy, all within the Swan Coastal Plain. Fidelity to any given site was also taken into consideration when the data was analysed (i.e. how many times birds were recorded at each site for each survey year).

There is limited information on the roosting habitat characteristics associated with Carnaby's Black Cockatoo roost trees and roost sites, as well as the landscape surrounding roost sites. It is difficult to determine the most important habitats of the Carnaby's Black-Cockatoo without adequate characterisation of the habitat they use (Legault et al. 2012). This study aims to describe and examine the nocturnal roost habitat preferences of Carnaby's Black-Cockatoo by assessing and analysing roost tree, roost site and roost matrix landscape characteristics to define which nocturnal roost habitat characteristics are important to the species. This will provide a basis for future habitat identification, conservation and regeneration of roosting habitat. Once roosting habitat is defined and mapped,

government agencies like the Environmental Protection Authority (EPA) will be able to use this information to manage important roost sites for the species.

The aim of this study is to identify the habitat characteristics of the roost tree, roost site and surrounding landscape matrix that are associated with Carnaby's Black-Cockatoo nocturnal roosts. The primary objectives of this study were to:

Objective 1: Determine and describe the physical characteristics of Carnaby's Black-Cockatoo nocturnal roost trees and typical roost site attributes, based on a selection of traditional roost sites across the northern Swan Coastal Plain (Chapter 3);

Objective 2: Quantify Carnaby's Black-Cockatoo nocturnal roost characteristics at multiple spatial scales, from individual roost trees at the central roost site, to the surrounding landscape (Chapter 4);

Objective 3: Develop a statistical model which identifies landscape variables which best explain nocturnal roost site cockatoo abundance and fidelity, based on counts of roosting Carnaby's Black-Cockatoo, at three spatial scales (1 km, 6 km and 12 km radii) (Chapter 4);

Objective 4: Use the model results to determine which spatial characteristics are the most likely drivers of the chosen study site's nocturnal roost cockatoo abundance and roost fidelity, and at which spatial scales (Chapter 4);

Objective 5: Interpret the results from the nocturnal roost site modelling in relation to the available literature (Chapter 4 and 5), and;

Objective 6: Recommended conservation management guidelines based on the results of the study (Chapter 5).

Chapter 2 - Study region, study species, site selection and data source, and objectives

2.1 Study region: The Swan Coastal Plain

High levels of floral and faunal endemism are found within the Southwest Australia Ecoregion, situated in the south-western corner of WA, which is recognised as a global biodiversity hotspot (Gole 2006). Rapid changes to the ecoregion over the past century due to large scale clearing and modification of native vegetation have affected almost 90 % of the original vegetation (Saunders et al. 1985, Gole 2006). The Swan Coastal Plain, situated on the western edge of WA, extends from Geraldton south to Dunsborough (Gentilli and Fairbridge 1951). The Swan coastal belt is 20-30 km wide and approximately 563 km in length (Gentilli and Fairbridge 1951), and is restricted to the west by the Indian Ocean and to the east and south by the Darling and Whicher Scarps (Gibson et al. 2000). It is a low-lying coastal plain, largely covered by woodlands. The dominant vegetation is Tuart *Eucalyptus gomphocephala* or *Banksia* spp. on sandy soils, Melaleuca spp. (paperbark) in swampy areas, and Allocasuarina spp. on outwash plains or riverine edges. Where the plain rises to the east, the duri-crusted Mesozoic sediments are dominated by Jarrah *Eucalyptus marginata* woodland while Melaleuca shrublands and *Allocasuarina obesa-Corymbia calophylla* (Marri) woodlands are extensive on the outwash plain of the south (Thackway and Cresswell 1995).

The typically warm Mediterranean climate of the Swan Coastal Plain is characterised by hot, dry summers and mild wet winters, with an annual rainfall of 600-1 000 mm (Beard 1984, How and Dell 2000). However, rainfall has significantly declined in the south-west of WA since the 1970's with a mean winter rainfall decrease of 17 %, and an increase in mean annual temperature of 0.6 ℃ (Bates et al. 2008, Pitman and Perkins 2008, CSIRO and Bureau of Meteorology 2014).

Perth was established in 1829 following the settlement of Europeans on the Swan River Colony. Following settlement, loss and alteration of native vegetation through urban expansion and farming, led to the modification of natural ecosystems (How and Dell 2000). More than 95% of the fertile soils of the Swan Coastal Plain have been preferentially cleared for agriculture (Gibson et al. 2000). Vegetation complexes of the Swan Coastal Plain are now poorly represented and mostly relegated to isolated remnants through the city and surrounding areas (How and Dell 2000).

2.2 Study species: Carnaby's Black-Cockatoo

Carnaby's Black-Cockatoo is one of three black cockatoo species endemic to the southwest of WA. The species is listed as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, as well as under IUCN Red List of Threatened Species (BirdLife International 2013). In WA they are recognised as a species in need of special protection because they are rare or likely to become extinct under the *Wildlife* Conservation *Act 1999* (Berry 2008, Department of Parks and Wildlife 2013). Saunders (1974) ascertained that the range and abundance of the species had declined by 50 % in the past 45 years, with local extinctions in some regions, largely due to habitat loss. The roosting, foraging and breeding habitat of Carnaby's Black-Cockatoo is frequently recognised as being under threat from clearing for agricultural and urban development (Saunders 1986, 1990, Department of Parks and Wildlife 2013).

The Swan Coastal Plain is a key region for the species, yet little research has been undertaken regarding the effects of current and future urban expansion and habitat loss (Johnstone et al. 2011). Obtaining adequate ecological data of avian species such as Carnaby's Black-Cockatoo allows for easier assessment and monitoring of their populations (Legault et al. 2012). Thus, it is important to carry out studies that provide accurate mapping of the species' habitat requirements in order to influence land use policies and planning decisions (Johnstone et al. 2011).

Carnaby's Black-Cockatoo follow seasonal migratory patterns related to the breeding or non-breeding seasons (Saunders 1990). In the breeding season (typically from July to December), they are primarily found throughout the Avon Wheatbelt Bioregion, and during the non-breeding season (typically from January to June), larger foraging flocks congregate in higher rainfall coastal areas such as the Swan Coastal Plain (Saunders 1990, Johnstone et al. 2011). During the non-breeding season, communal nocturnal roosting forms a part of their daily routine (Williams et al. 2015). Birds spend approximately 8 hours of a 24 hour cycle in various manners of roosting and/or loafing, however this amount of time can vary greatly depending on the species (Amlaner Jr & Ball, 1983). Carnaby's Black-Cockatoos spend about 12 hours roosting nocturnally, but this time can increase or decrease depending on day length over the non-breeding months (Shah 2006). Because a large portion of their daily lives is spent roosting overnight, it can be assumed that this is an integral life history trait of the Carnaby's Black-Cockatoo.

2.3 Site selection and data source

The availability of foraging habitat and night roosting sites in the non-breeding season is important for the Carnaby's Black-Cockatoo and overnight communal roosts are found at sites across the Greater Perth-Peel Region of WA (Saunders 1990, Finn et al. 2014). The population of Carnaby's

Black-Cockatoos in this region has been monitored annually since 2010 through the Great Cocky Count (GCC) (Williams et al. 2015), an annual community-based survey undertaken on one evening each April at up to 300 roost sites simultaneously. The results of the GCC provide data confirming the locations and relative bird numbers at all surveyed roost sites across multiple years. One of the main aims of the GCC survey is to contribute to the conservation of the Carnaby's Black-Cockatoo by identifying roost sites as well as trends in population size (Finn et al. 2014). Without the involvement of a large number of volunteers (up to 700) through the GCC, monitoring roost activity at such spatial and temporal scales would not have been possible (Williams et al. 2015).

It must be noted that there are a number of limitations to the GCC. These include: 1) the GCC is not able to account for all roost sites throughout the Carnaby's Black-Cockatoo non-breeding range, and new roost sites are frequently being found; 2) the cockatoos may not have roosted at an active roost site on the night when the GCC was carried out; 3) the addition of new sites means that the dataset is incomplete for previous years; 4) a number of roost sites were not surveyed every year resulting in an incomplete data set (Noble et al. 2010). Some sites were consistently under-surveyed due to logistical reasons mainly associated with access to remote areas, and other, larger sites were prioritised for survey due to their importance as roosting locations (Williams et al. 2015); 5) survey volunteers may have recorded counts of Carnaby's Black-Cockatoo in forested areas (east of the Swan Coastal Plain) when in actual fact they were Baudin's Black-Cockatoo *Calyptorhynchus baudinii* or a combination of the two species (Williams et al. 2015). A small proportion of Baudin's Black-Cockatoo are potentially included in one of the 11 roost sites included in the study (Figure 2.1, West Swan site to the east), and; 6) birds may not have been detected by observers due to annual and local weather conditions, poor light conditions (birds often arrive at roost sites when the sun has set), and/or obstacles such as trees or buildings may have impeded the observation of birds. The aforementioned limitations can affect mean roost size estimates of surveyed roost sites, and thus, overall trends can be skewed. These limitations would tend to be equally applicable across all sites, and also outweighed by the substantial, comprehensive and long term GCC data set (Dickinson et al. 2010, Williams et al. 2015).

Cockatoo counts and the associated roost site fidelity (fidelity refers to the repeated use of roost sites by Carnaby's Black-Cockatoo) information, over a six-year period, was provided for 11 field sites (Chapter 3) and 18 multi-spatial scale analysis sites (Chapter 4); spread across the Swan Coastal Plain (Figure 2.1). The 11 field sites were defined as being Carnaby's Black-Cockatoo nocturnal roost sites that were visited for collecting roost tree measurements and observations. The 18 multi-spatial scale analysis sites were modelled to determine which spatial characteristics are the most likely drivers of nocturnal roost cockatoo abundance and fidelity, and at which spatial scales.

Although the GCC survey only collects data from one night of the year it provides a spatial "snapshot" of the usage of nocturnal roost habitat by Carnaby's Black-Cockatoo at the peak of the non-breeding season. No other equivalent data could be sourced for this study on roost site characteristics.
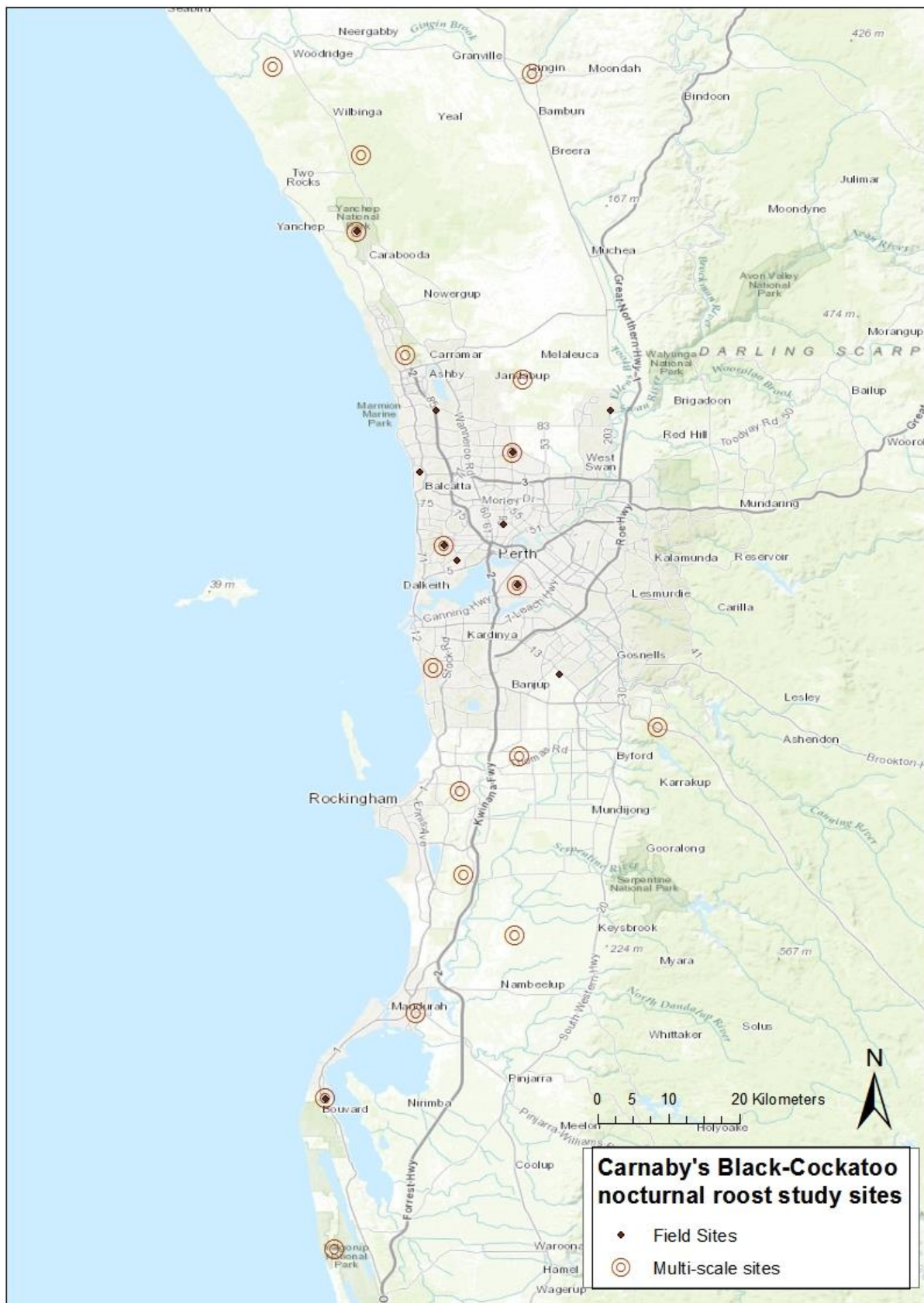
Figure 2.1 Map showing the spatial distribution of the 11 field and 18 multi-scale spatial analysis Carnaby's Black-Cockatoo roost sites investigated in this study. The roost sites were found within the Swan Coastal Plain region located in the southwest of Western Australia. All roost sites have been identified using a code associated with each site as documented by the citizen science project, the Great Cocky Count (GCC) (Byrne et al. 2015).

Chapter 3 – Attributes of Carnaby's Black-Cockatoo nocturnal roost trees and roost sites

3.1 Introduction

A number of studies investigating avian sleep have found that it allows for the development of long-term imprinting memory in chicks (Jackson et al. 2008, Vorster and Born 2015). It has also been found that consolidation of auditory memory has been enhanced by sleep in European Starlings (Brawn et al. 2010, 2013). As such, the sleep state during nocturnal roosting periods may also contribute to memory consolidation in Carnaby's Black-Cockatoo. Nevertheless, sleep is thought to serve an important function because sleep occurs daily, even under circumstances of potential risk (Lima et al. 2005). Cody (1985) described roost selection by animals as similar to selecting a nest site in terms of the basic requirements, organisation process and fitness consequence. The importance of roosting as a daily function highlights the necessity for nocturnal roosting habitat for Carnaby's Black-Cockatoo. Negative impacts on nocturnal roosting habitat could thus have an effect on fitness outcomes for the species, such as reproductive success in the subsequent breeding season (Antczak 2010).

In addition to understanding roosting behaviour is the question of what characteristics are associated with suitable roost sites. Roost tree and roost site measurements found to be important for explaining roosting behaviour in bird species include tree height (Warburton and Perrin 2005, Boyes and Perrin 2009, Jaggard et al. 2014), tree size (diameter at breast height (DBH)) (Warburton and Perrin 2005, Boyes and Perrin 2009, Jaggard et al. 2014), density of trees (Warburton and Perrin 2005, Boyes and Perrin 2009), distance between roost trees (Cougill and Marsden 2004, Jaggard et al. 2014), distance to first branch (Jaggard et al. 2014), canopy extent (Jaggard et al. 2014), foliage density (Lindenmayer et al. 1996, Jaggard et al. 2014), branch architecture (Lindenmayer et al. 1996), tree crown connectivity (Davis 2013), bark colour (Lindenmayer et al. 1996), tree species identity (Lindenmayer et al. 1996, Boyes and Perrin 2009), and roost tree landscape location (Jaggard et al. 2014).

The aim of this chapter is to identify and describe the attributes that characterise Carnaby's Black-Cockatoo roost trees and roost habitat. Confirmed nocturnal roost sites were identified through the GCC (Byrne et al. 2015). Confirmed nocturnal roost sites are identified as any site where black-cockatoos have been recorded roosting during a formal roost survey. Formal roost surveys are defined as black-cockatoo roost counts carried out using the standard GCC survey protocol and completed by

BirdLife Australia staff and volunteers, Department of Biodiversity, Conservation and Attractions (DBCA) (formerly known as Department of Parks and Wildlife (DPaW)) staff, or WA Museum staff (Byrne et al. 2015). At each study site, the structural arrangement and properties of each of the roost trees were determined. Based on previous studies of other parrot species, it was hypothesised that Carnaby's Black-Cockatoo would: 1) select tall, large, relatively densely foliaged trees with single stem, higher first branches (Boyes and Perrin 2009, Jaggard et al. 2014) and dark bark (Lindenmayer et al. 1996); 2) have strong tree species preferences (Lindenmayer et al. 1996, Boyes and Perrin 2009), and; 3) that the roost site would have a relatively high tree density and a dense canopy (Lindenmayer et al. 1996, Boyes and Perrin 2009, Davis 2013).

3.2 Materials and methods

3.2.1 Study sites

Eleven confirmed nocturnal roost sites were selected from the GCC database (Byrne et al. 2015). Due to the time restraints of this study, only eleven sites were chosen as field study sites. Criteria used to select roost sites included a variety in the average number (low < 1; medium < 100; high > 100, and; very high > 200) of birds using each roost and fidelity (defined as repeated use of roosts by Carnaby's Black-Cockatoo) over the 6 year GCC survey period, and that they needed to be widely dispersed across the Swan Coastal Plain (Field sites, Figure 2.1). A list of the roost sites chosen for this study includes sites in Floreat, Como, Yanchep, Dawesville, Harrisdale, Ballajura, Menora, Nedlands, North Beach, The Vines, and Edgewater (Figure 2.1), while Table 3.1 identifies the roost site names, codes and associated information. The study sites Menora and The Vines have zero GCC counts, however, personal observations found that Carnaby's Black-Cockatoo were using these sites on numerous occasions outside the GCC survey period. The full methodology of the GCC survey can be found in the 2010 to 2015 reports (Burnham et al. 2010; Byrne et al., 2015; Finn et al., 2014; Kabat, Barrett, & Kabat, 2012). This study did not compare roost trees with non-roost trees (trees in which Carnaby's Black-Cockatoo did not roost overnight), a method carried out in other parrot roosting studies (Clergeau and Quenot 2007; Jaggard et al., 2014). Carnaby's Black-Cockatoo are a highly mobile species and for this reason the study could not be certain as to whether a non-roost tree has not been a roost tree at some point in time, or has the potential to become a roost tree.

Table 3.1 Details for the 11 Carnaby's Black-Cockatoo roost sites at which habitat attributes were measured. The roost site codes originate from the Great Cocky Count (Byrne et al. 2015) report. Latitude and longitude are based the geographic coordinate system (datum) World Geodetic System 84.

GCC roost site code (2014)	Suburb	Decimal latitude (S)	Decimal longitude (E)	Roost site landmarks
CAMFLOR001	Floreat	31.9475	115.79139	Save the Children/CSIRO car park/Perry Lakes new development corner walkway - corner Brockway Rd/Brockdale St and Underwood Avenue
SOUCOMR001	Como	31.99806	115.88444	DBCA, Pines on the corner of Hayman Rd and Kent Street, Kensington
WANYANR006	Yanchep	31.54853	115.6816	Yanchep National Park Volunteer Centre and Yanchep National Park golf course entrance
MANDAWR002	Dawesville	32.649	115.6416	Timbers Edge Estate
ARMHARR001	Harrisdale	32.11194	115.93833	Hatch Court Drive
SWABALR001	Ballajura	31.83	115.8788	Park with lake next to, but still connected to Ballajura Lions Oval
STIMENR001	Menora	31.9216	115.8663	Ron Stone Park
NEDNEDR001	Nedlands	31.9666	115.8077	3 micro-roost sites: Dot Bennett Park, car park of Hollywood Primary School, and car park of Hollywood Hospital (near Kitchener St, on Verdun St side)
STINORR001	North Beach	31.8547	115.7605	Hope St, close to the corner of Hale St, North Beach (on the border of Watermans Bay)
SWAVINR002	The Vines	31.776	116.0021	Corner of Millhouse Rd and Chateau Pl, Belhus
JOOEDGR001	Edgewater	31.776	115.78056	Lake pines at Edith Cowan University, Joondalup

3.2.3 Roost tree and site attributes

A minimum of five and maximum of ten individual trees were assessed at 11 roost sites with an overall total of 95 roost trees sampled. All study trees had been observed to be the actual roost trees by observers during the GCC surveys or were confirmed by further observations undertaken in 2015. Measurements and observations recorded were: tree height (m), tree trunk circumference (m), DBH (diameter at breast height) (m), distance to nearest roost tree (m) (distance from the base of the roost tree trunk to the nearest roost tree), height of lowest canopy (height of the first branch that diverged) (measurement taken from base/bole of roost tree trunk up to first branch) (m), density of foliage (%) (0 % = no foliage, 50 % = medium foliage, 100% very dense foliage), branch architecture (^{0}) was a visual estimation, which took into consideration the average branch angles of each roost tree. Branch angles were assigned into four categories of: $0 - 45^0$, $0 - 90^0$, $45 - 90^0$, and $0 - 90^0 +$. Bark colour, and the tree species used as a roost were identified. Roost site characteristics were also observed along with each of the roost tree measurements and observations. These were: density of trees (a visual estimation of whether the measured tree is located in a forest, woodland or open habitat where forest (f) category was a closed canopy (80 – 100 % cover), woodland (w) a less dense canopy (10 – 80 % cover), and, open (op) consisted of scattered trees (0 – 10 % cover), tree crown connectivity (where a record of "0 %" indicates that the roost tree is isolated, and higher values show the crown was overlapping or touching another tree), and what land-use type each roost tree was located within (this was based on visual observation of the location).

Standard error of the mean was calculated for tree height, tree circumference and DBH, height of first branch, foliage density, tree crown connectivity, and distance to next nearest roost tree. Based on the 95 roost trees that were measured, percentage was calculated for branch architecture, bark colour, and land-use type.

3.2.4 Roost counts and fidelity

Carnaby's Black-Cockatoo roost counts for each of the six years from 2010 to 2015 for each of the selected roost sites were obtained from the GCC 2015 report (Byrne et al., 2015) (Table 3.2). These data were summed to get a total count per roost and then averaged (± Standard Error), and the number of years birds were recorded was taken as a measure of roost site fidelity. The percentage of roost site fidelity was also calculated (% years with birds present). A minimum and maximum roost count was also included.

3.2.5 Roost tree species identification and roost tree counts

The 95 study roost tree species were identified and categorised into whether they were of Western Australian (WA) native, Australian (Australian, but not WA endemic) native, or introduced (non-Australian or exotic) origin (Table 3.3). The number of roost tree species was recorded at each roost site, and the percentage of each roost tree species was calculated (Table 3.4).

3.3 Results

3.3.1 Roost counts and fidelity

Roost sites at Floreat, Como, Dawesville, and Nedlands had high total and average counts, with Como having the highest total and average counts (Table 3.2). All of these sites also had high fidelity percentages (fidelity was considered high if ≥ 80 %) with birds recorded for each annual census (GCC report (Byrne et al., 2015)). Of all the GCC years, Como had the highest number of birds (645 birds) in 2011. The total average fidelity was over 50 % at roost sites Floreat, Como, Dawesville, Nedlands, Ballajura, Nedlands, and North Beach (Byrne et al. 2015), suggesting that these are long-term preferred roost sites. The Vines and Menora had zero counts in every year they were surveyed (birds, however may not have been present or observed on the night of the survey. These sites are confirmed nocturnal roost sites and have been witnessed to be used by Carnaby's Black-Cockatoo on non-survey evenings).

Table 3.2 Shown are the study roost sites and their associated Great Cocky Count (GCC) (Byrne et al. 2015) total count, average GCC count, range, standard error, number of years Carnaby's Black-Cockatoo were present in relation to how many times the site was surveyed, and fidelity data. The total GCC count was calculated using the GCC survey roost counts for each year from 2010 to 2015. Carnaby's Black-Cockatoos were not present on the evening of the survey where a year has a "0" count, and, in some years, at some roost sites, surveys were not carried out (n/c (no count)). For this reason there is a column indicating the number of years Carnaby's Black-Cockatoo were present, in relation to how many times a site was surveyed, from which roost site fidelity was calculated.

GCC roost site location	Total GCC count	Average GCC count	Mininmum GCC count and year	Maxinmum GCC count and year	Standard Error	Number of years Carnaby's Black-Cockatoo were present in the survey period	Roost site fidelity (%)
Floreat	938	156.3	86 (2015)	237 (2010)	19.6	6/6	100
Como	2774	462.3	301 (2013)	645 (2011)	50.0	6/6	100
Yanchep	776	129.3	0 (2013-2015)	342 (2010)	64.9	3/6	50
Dawesville	973	162.2	0 (2013)	371 (2010)	58.8	5/6	83
Harrisdale	1	0.3	0 (2011, 2012, & 2014)	1 (2015)	0.3	1/4	25
Ballajura	167	27.8	0 (2010, 2012, & 2014)	92 (2013)	14.9	3/6	50
Menora	0	0	0 (2013-2015)	n/c	0.0	0/3	0
Nedlands	883	147.2	73 (2010)	304 (2012)	34.7	6/6	100
North Beach	503	83.8	0 (2010, 2012, & 2014)	267 (2013)	52.3	3/6	50
The Vines	0	0	0 (2014)	n/c	n/c	0/1	0
Edgewater	23	4.6	0 (2010, 2011, 2013 & 2014)	23 (2015)	4.6	1/5	20
Total average		106.7	42	207	30	3/5	52.6

3.3.2 Roost tree species and roost tree counts

There were 11 different roost tree species in total across all sites (Table 3.3), and of these, 7 were Australian natives (but not endemic) (*Corymbia citriodora, Eucalyptus cladocalyx, Corymbia maculata, Eucalyptus punctata, Eucalyptus grandis, Eucalyptus saligna,* and *Eucalyptus camaldulensis*), 3 of the roost tree species were endemic to WA (*Eucalyptus rudis, Eucalyptus gomphocephala,* and *Allocasuarina fraseriana*). There was only 1 introduced (non-Australian) species (*Pinus pinaster*) (Table 3.4). The number of times that the species types occurred across all study sites was: WA native species, 8 (found at 6 different sites); Australian native species 17 (found at 8 different sites), and; introduced species only twice (found at 2 different sites) (Table 3.3).

Table 3.3 Roost tree counts, species identities and species origins were recorded at 10 known Carnaby's Black-Cockatoo roost sites on the Swan Coastal Plain. Species have been categorised as Western Australian (WA) native (1), Australian (Aus) (but not WA native) native (2), or introduced (exotic) species (3). The number in brackets indicates the origin of the species.

Roost site location	Number of trees counted at each site	Roost tree species identity and origin	Number of roost tree species	Number of WA natives species (1)	Number of Aus natives species (2)	Number of introduced species (3)
Floreat	10	*Corymbia citriodora* (2), *Eucalyptus cladocalyx* (2), *Eucalyptus rudis* (1), *Corymbia maculata* (2), *Eucalyptus gomphocephala* (1)	5	2	3	0
Como	10	*Pinus pinaster* (3)	1	0	0	1
Yanchep	10	*Corymbia citriodora* (2), *Corymbia maculata* (2), *Eucalyptus gomphocephala* (1), *Eucalyptus punctata* (2)	4	1	3	0
Dawesville	10	*Eucalyptus gomphocephala* (1)	1	1	0	0
Harrisdale	9	*Eucalyptus grandis* (2), *Eucalyptus gomphocephala* (1)	2	1	1	0
Ballajura	7	*Eucalyptus grandis* (2), *Eucalyptus saligna* (2)	2	0	2	0
Menora	8	*Eucalyptus grandis* (2), *Eucalyptus gomphocephala* (1), *Allocasuarina fraseriana* (1)	3	2	1	0
Nedlands	10	*Corymbia maculata* (2), *Eucalyptus saligna* (2), *Corymbia citriodora* (2)	3	0	3	0
North Beach	5	*Eucalyptus saligna* (2), *Eucalyptus gomphocephala* (1)	2	1	1	0
The Vines	7	*Corymbia citriodora* (2), *Eucalyptus saligna* (2), *Eucalyptus camaldulensis* (2)	3	0	3	0
Edgewater	9	*Pinus pinaster* (3)	1	0	0	1
Total	**95**	**11 (different roost tree species)**		**8**	**17**	**2**

The Floreat, Como and Nedlands roost sites, with the high numbers of birds and site fidelity, were mixed in terms of tree species composition. The Floreat and Nedlands sites had trees of Australian origin, whereas the Como roost only had an introduced species present. Of these three well used sites, the Floreat site was the only site to have WA native tree species present. The Dawesville site was another roost site with a high fidelity of over 80 %, and high average roost count (> 100) with only one tree species present (a WA species). Non-WA species, Lemon-scented gums *C. citriodora* and Rose gum *E. grandis* and the WA native, Tuart *E. gomphocephala* were well- represented at roost sites with Pinaster pine *Pinus pinaster* being the only introduced species used (Table 3.4).

Table 3.4 The roost tree species were counted and identified and have been categorised as Western Australian (WA) native, Australian (Aus) (but not WA native) native, or introduced (exotic) species. These three categories were given a number between 1 and 3 in order to more easily identify which category the roost tree species belongs to (the number is in brackets next to each category). The table has noted the number of times each of the study roost trees have been present across each of the study sites. The number of each species has also been recorded.

Tree species type	Species	Number of sites species features	Number of each species across all sites (and %)
WA native (1)	*Eucalyptus rudis*	1	1
	Eucalyptus gomphocephala	6	30 (32)
	Allocasuarina fraseriana	1	1
Aus native (2)	*Corymbia citriodora*	4	14 (15)
	Eucalyptus cladocalyx	1	1
	Corymbia maculata	3	6
	Eucalyptus punctata	1	2
	Eucalyptus grandis	3	13 (13)
	Eucalyptus saligna	4	7
	Eucalyptus camaldulensis	1	1
Introduced (3)	*Pinus pinaster*	2	19 (20)

3.3.3 Roost site and roost tree attributes

It was found that Australian native tree species were the most common species of the 95 roost trees. There were 44 (46.32 %) Australian native species, just under half of all the roost trees observed and measured. There were 32 (33.68 %) WA endemic species, and 19 (20 %) introduced (exotic) roost tree species (Table 3.4). Of 95 roost trees measured in this study, the average and standard error of the mean were calculated for the following attributes (Table 3.5): height was 26.6 ± 0.7 m; circumference was 3.07 ± 0.3 m which translates to a diameter at breast height (DBH) measurement of 0.98 ± 0.1 m; distance to the next nearest study roost tree was 15.77 ± 1.6 m; the height of the first branch was 6.94 ± 0.6 m; foliage density was medium density at 50.3 ± 1.7 %, and; tree crown connectivity was 20.58 ± 1.5 %.

Of the 95 trees, 6 (6.3 %) had an average branch architecture of 0-45^0, whereas 89 (93.7 %) of all the roost trees had branch angles of 45-90^0. In terms of bark colour, 39 (41.05 %) roost trees were observed to have very pale bark, (Table 3.5) with the second most prevalent bark colouring being the dark category with 33 (34.74 %) in this category. There were 17 (17.89 %) roost trees with very dark bark, 4 (4.21 %) with mixed bark colouring, and 2 (2.12%) with pale coloured bark.

Parkland was the most common primary land-use type that contained the roost trees with 36 (37.9 %) instances (Table 3.5). Some 31 (32.6 %) roost trees were located in residential areas, 10 (10.5 %) in parking lots, 8 (8.4 %) in a conservation area, 6 (6.3 %) in commercial areas, and 2 (2.1 %) roost trees were found on road verges and golf courses.

Table 3.5 Carnaby's Black-Cockatoo roost tree variables such as bark colour and the primary land-use type that the roost tree was located in, were observed and counted. Of the 95 roost trees observed, a percentage for each variable category has been included (in brackets).

Roost tree attribute	Mean (m)	Mean (%)	Standard Error of the mean
Tree height	26.6		0.7
Trunk circumference	3.07		0.3
DBH	0.98		0.1
Height of first branch	15.77		1.6
Distance to nearest study tree	6.94		0.6
Foliage density		50.3	1.7
Tree crown connectivity		20.58	1.5

Roost tree attribute	Category	Total number of trees (of the 95 study trees)	Percentage (%)
Branch architecture	0-45º	6	6.3
	45-90º	89	93.7
Bark colour	Very pale	39	41.1
	Pale	2	2.1
	Dark	33	34.7
	Very dark	17	17.9
	Mixed colour	4	4.2
Land-use type	Road verge	2	2.1
	Parking lot	10	10.5
	Parkland	36	37.9
	Golf course	2	2.1
	Conservation	8	8.4
	Residential	31	32.63
	Commercial	6	6.32

3.4 Discussion

3.4.1 Roost tree characteristics

To date there have been no studies that have investigated Carnaby's Black-Cockatoo roost tree structure to establish what characteristics of a tree make it a suitable roost tree. Most observations have suggested that roost trees are tall and are found close to food and drinking water sources. Various tree species have been identified as having been used as roost sites by Carnaby's Black-Cockatoo (Berry 2008, Finn et al. 2009, Groom 2011, Stock et al. 2013, Groom et al. 2014),

however it is important to have a more comprehensive understanding about the tree structure itself as a roost site.

Generally cockatoos do prefer certain types of roosts, and according to Glossop et al. (2011), a tree has the potential to be a roost tree as long as it is ≥ 8m tall. Although roost tree species is not necessarily a consistent Carnaby's Black-Cockatoo roost site factor, some trees may offer more suitable places of rest than others. In terms of this study, Eastern Australian (Australian native) species were found to be the most favoured roost tree species used by the Carnaby's Black-Cockatoo. This may be because Carnaby's Black-Cockatoo tend to forage in, and around urban landscapes on the Swan Coastal Plain, within which non-native trees have been introduced (Berry 2008, Groom et al. 2014). It is understood that Carnaby's Black-Cockatoos have the ability to adapt to novel ecosystems (Groom et al. 2014), and as such, they have adapted to using suitable non-indigenous trees to in which to roost (Berry 2008, Groom et al. 2014). Many Eastern Australian and exotic tree species have replaced native trees as a result of urbanisation, whether they be in suburban gardens, road verges, parks, golf courses or other such urban environments. Their use of suitable non-native species as suitable roost trees has somewhat offset the loss of their natural nocturnal roosting habitat, and it is for this reason, that these non-native species should be acknowledged in conservation planning and practice (Hobbs et al. 2013, Groom et al. 2014). Pine trees for example are suitable as roost trees because they are planted to form closed or dense canopies (for optimum biomass productivity), and they grow up to 40 m in height (Western Australian Herbarium 1998, Fernandes and Rigolot 2007, Finn et al. 2009). As well as providing a good food source within close reach for the cockatoos, the Pinaster pine structure is thus able to provide very tall heights and dense canopies for overnight stays, and even a residence over several months.

The well-occupied sites (based on the high fidelity (> 80%) to the roost sites by the birds within the study survey period) of Floreat, Como, Nedlands and Dawesville each had different tree species types (WA endemic, Australian native, and introduced) present, all with varied bark colour. The variation demonstrates that Carnaby's Black-Cockatoos do not necessarily have a preference for WA native species or trees with specific bark colouring. The Carnaby's were recorded roosting in a variety of tree species, with different bark colouring, at sites with large counts and high site fidelity over the GCC survey period. These sites are also known to be well-occupied throughout the non-breeding season, and not just the GCC survey nights (Shah 2006, Berry 2008, Finn et al. 2014). Considering that the aforementioned sites have a variety of tree species between them, it is clear that any single roost site does not appear to be associated with

any particular variety of roost tree species, or any specific single roost tree species. If roost sites such as these are well-occupied through the non-breeding season, it can be assumed that other factors, such as landscape and tree structure, are more important than what the specific tree species is. Like the Carnaby's Black-Cockatoo, other parrot species such as rainbow lorikeets and red-rumped parrots *Psephotus haematonotus* also prefer to roost in tall trees with medium to dense foliage (Lowry and Lill 2008, Jaggard et al. 2014). Large trees are thought to allow birds to perch comfortably and offer protection from unfavourable weather conditions (Clergeau and Quenot 2007). Trees with higher first branches also provide security from predators as well as allow easier detection of danger (Peh and Sodhi 2002). The roost trees chosen by Carnaby's Black-Cockatoo did not have extreme branch angles and thus the trees may provide many branches with comfortable angles to perch on.

Although only 1 River Red Gum was found to be used in this study, a study by Johnstone et al. (2011) reported a flock of > 300 Carnaby's Black-Cockatoo using tall River Red Gums as roost trees around the township of Eneabba whereby they foraged in surrounding farmland and remnant vegetation. It appears that the tall heights (20 - 45m) (Boland and McDonald 2006) of River Red Gums makes them suitable roost trees when they are surrounded by sufficient foraging sites and accessible water. In general, it appears that roost selection by Carnaby's Black-Cockatoo is governed by factors other than tree species type and bark colour.

A dominant WA endemic species in this study was the Tuart, which had the highest count of one particular tree species across all study sites, and was found to be used as a roost tree across more than half of all the study roost sites. This may be a popular WA native roost tree for Carnaby's Black-Cockatoo because of the protective structure they offer. They are very tall, and have a very dense, spreading canopy, and as such are considered one of the largest tree species found on the Swan Coastal Plain (Edwards 2004). This is consistent with Edwards (2004) who concluded that Tuarts provide suitable roost trees because they can grow from 10 to 40m tall. Tuarts may also be more appealing roost trees because they bear flowers, or blossoms, which Carnaby's Black-Cockatoo have been recorded consuming (Shah 2006, Valentine and Stock 2008). Tuart inflorescences develop between January and April (Edwards 2004), which coincides with the Carnaby's Black-Cockatoo movements throughout the Swan Coastal Plain in the non-breeding season. The Tuart blossoms may also harbour insect larvae which are a known source of food for Carnaby's Black-Cockatoo (Mawson 1995, Shah 2006). Tuart is listed as a high priority species for Carnaby's Black-Cockatoo because they are used as feeding, nesting and roosting trees (Groom, 2011). Tuarts are ideal roost trees for Carnaby's Black-Cockatoo, however there are

concerns that the health and population of this WA indigenous Eucalypt is in decline (Edwards 2004, Taylor et al. 2009). The Tuart was once wide reaching across the Swan Coastal Plain, and has been reduced from the pre-European scale of over 111,600 ha to just 30,300 ha largely due to clearing for mining, agriculture and urban development (Department of Conservation and Land Management et al. 2003, Wentzel 2010). In the breeding season, Tuart hollows have also been used by Carnaby's Black-Cockatoo as nesting sites (Cale 2003, Johnstone et al. 2011). If, as it appears, Tuarts are an important component of Carnaby's Black-Cockatoo habitat, then there should be more emphasis on protecting this endemic species of Eucalypt.

Although Tuarts were a relatively well-favoured WA endemic roost tree species in this study, the greatest percentage of roost tree species were introduced species. Lemon-scented gum and Rose gum were the most prominent of the species originating from the eastern parts of Australia with Pinaster pine the only exotic introduced species (Table 3.3 and 3.5). Lemon-scented gum and Pinaster pine are medium priority planting species because they are used for feeding and roosting (Groom 2011). The nuts, seeds and flowers of Lemon-scented gums are known to be eaten by Carnaby's Black-Cockatoo, whereas the Rose gum has not been recorded as a food source (Shah 2006, Groom 2011). Rose gums may not provide a food source to Carnaby's Black-Cockatoo, however they grow to very tall heights. They are generally 45 - 55m in height, with some exceptional specimens reaching heights of 75-80m tall (Boland and McDonald 2006).

Spotted gums reach heights of 35 - 45m, which is likely to be one of the reasons it was recorded as a roost tree for Carnaby's Black-Cockatoos in this study, and is consistent with other research (Shah 2006, Berry 2008). Both Berry (2008) and Shah (2006) recorded Red Spotted gums being used as roost trees at Hollywood Hospital, Nedlands, which is a roost patch associated with the Nedlands roost site. Although height of this species may be one of a number of characteristics that make it a consistently appealing roost tree, it is important to consider this tree species (along with the other roost trees at these sites) as a vantage-point within the landscape. Lemon-scented gums have been recorded to flower in January, April, May, June, July, August, October and December, thus coinciding with the non-breeding season (Centre for Plant Biodiversity Research (Canberra) and Slee 2006). The species is generally 25 – 35 m tall, and can even reach heights of up to 60 m, making it an ideal roosting species because of how tall they can grow (Boland and McDonald 2006). Given that Lemon-scented gums provide flowers as a source of food in the non-breeding season, as well as ideal roost tree heights, it can be seen why more than 10 % (14.74 %) of the roost tree species in this study were Lemon-scented gums, found at four different sites. Like the Tuart, the Lemon-scented gums and pines may be popular roost tree choices for the cockatoos

because they have the advantage of bearing an appropriate roost structure, as well as supplying either adequate, or some sources of food. *E. cladocalyx,* WA sheoak *A. fraseriana, E. punctata*, and *E. saligna* were species in this study that were not listed by Groom (2011) as plants used by Carnaby's Black-Cockatoo. It should be considered that these 4 species be included in any future updates made to the Groom (2011) list, whereby they can be listed as low priority roosting tree species.

According to Pepper (1997), trees taller than 10 m were deemed large enough to provide shelter and a roost site for Glossy Black-Cockatoos *Calyptorhynchus lathami halmaturinus*, however the roost data collected for the study was in relation to the species' breeding habitat. The only other characteristics mentioned by Pepper (1997) in relation to roosting trees and distribution, are that large Eucalypts provide a suitable structure for roosting, and that it was observed that the Glossy Black-Cockatoos avoided dense young stands of regrowth. Similarly, Eucalypts made up the majority of roost trees used by Carnaby's Black Cockatoo in this study, and generally roost trees appeared to not to be in dense stands. It was suggested by Pepper (1997) that this was because dense stands of young trees would impede the cockatoos' flight, and that mature stands offered slightly higher food density.

3.4.2 Roost site characteristics

Carnaby's Black-Cockatoos were found to roost in a range of location types, supporting other studies (Groom et al. 2014) that show that Carnaby's Black-Cockatoos are able to use roost sites within the varied landscapes of the Swan Coastal Plain. Parklands and residential areas may be popular roost sites locations (Table 3.5) for the Carnaby's Black-Cockatoo because these areas often contain a variety of introduced trees and shrub species (Berry 2008, Berry and Owen 2010, Johnstone et al. 2011, Groom et al. 2014) which offer suitable roost characteristics or food sources (Jaggard et al. 2014). Generally vegetation in urbanised areas is also well watered and thus provides a reliable and relatively abundant food source compared with natural food resources which may be negatively impacted in times of drought (delays, dormancy or abortion of flowering and seeding in plants may occur) (Law et al. 2000, Burgin and Saunders 2007, Lowry and Lill 2008, Davis et al. 2011, Legault et al. 2012, Davis 2013).

Drinking sources and tall trees

Urban roost sites also offer reliable drinking sources because of the presence of ponds, bird baths and regular reticulation systems in residential gardens, parks and sporting ovals (Berry 2008, Groom et al. 2014). At four of the study sites (Como, Ballajura, Edgewater and Menora) Carnaby's were observed to be drinking at sunset from artificial lakes within 100 m of the study roosting trees (personal observation). The lakes observed being used were part of, or beside ovals or a golf course, both of which are land-use types that include tall trees often along their perimeters. These observations are an indication that Carnaby's Black-Cockatoo are opportunistic and can take advantage of reliable water sources provided by urban environments (Groom et al. 2014). A combination of tall trees and reliable water sources in an area is likely to encourage traditional use of a site. If roost sites can act as information centres (Ward and Zahavi 1973), then naïve vagrants may be recruited by more knowledgeable individuals (Marzluff et al. 1996a) to roost sites within close proximity to reliable drinking sources at sunset, as well as to aid in finding food sources more easily the following day (Ward and Zahavi 1973, Marzluff and Heinrich 1991, Marzluff et al. 1996).

Urbanisation effects

Urban roost sites are often located beside or within close proximity to urban lighting such as street lights (residential roosts, Table 3.5) or sports ground lighting (parkland roosts, Table 3.5), and, the tree crown connectivity was on average relatively low (Table 3.5). It may be easier for the cockatoos to enter and exit where roost sites are not densely vegetated or open, and where they are in well-lit areas. Similarly Jaggard et al. (2014) observed that Rainbow lorikeets roosted in trees that were further away from neighbouring trees, and closer to urban lighting and areas of human activity when compared to non-roost trees. They argued that urban environments may offer protection from predators because they (the predators) generally avoid areas of human activity, and, that in some cases predation is reduced in urban environments (Peh and Sodhi 2002, Rodewald et al. 2011, Jaggard et al. 2014). Well-spaced trees may aid in scanning for predators, and roost trees that were situated on open or concrete surfaces offer few hiding places for predators (Peh and Sodhi 2002, Jaggard et al. 2014).

Roost sites located on or close to concrete or tar might also provide micro-climates of warmth due to the "heat-island effect" whereby urban areas retain heat (Jaggard et al. 2014) although this is unlikely on the Swan Coastal Plain in summer and autumn when daily temperatures can often exceed 40ºC. Such environments may be offering more comfortable "overnight stays" to Carnaby's Black-Cockatoos in the cooler months of the non-breeding season.

Lighting could also be advantageous to the cockatoos where they need to change roosts due to threats, and threats would be more easily detected (Gorenzel and Salmon 1995). Furthermore, well-lit roost sites could assist with orientation to the roost during low-light levels at nightfall, which could aid in extension of foraging time (Jaggard et al. 2014).

Conclusion

Based on the findings of this chapter, Carnaby's Black-Cockatoo nocturnal roosting trees can be described as tall with medium density foliage, and relatively high first branches which could be providing protection from unfavourable weather conditions and any threats from predators. It appears that provided the trees are tall enough and within close proximity to water, they will roost in a variety of tree species in various land-use type areas. The findings of this study highlight the importance of conserving tall tree species within the urban landscape of the Swan Coastal Plain. There is the tendency for large trees to be removed within urban environments, but there should be careful consideration of how necessary their removal is. WA local governments and councils that fall in the Carnaby's Black-Cockatoo non-breeding range should seek to put urban forestry strategies and street tree preservation policies in place, particularly for sites recorded to have high abundance and fidelity. Such policies would aid in retaining and maintaining valuable habitat that is important to the species.

Chapter 4 - roost site attributes at multiple scales

4.1 Introduction

Feeding and roosting habitats for Carnaby's Black-Cockatoos on the Perth-Peel Coastal Plain are subject to development pressure, and impacts from climate change and other processes (Finn et al. 2014, Johnston et al. 2016). Landscape composition may play a vital role in the foraging and roosting habitat selection by Carnaby's Black-Cockatoos because they are a wide-ranging species. The Swan Coastal Plain landscape needs to be able to sustain the current and future population of cockatoos during the non-breeding season (Groom et al. 2014). The complex responses of organisms, landscapes, ecosystems, and ecosystem processes vary in time and space, making them multi-scaled (Lindenmayer 2000). There is the possibility that roost site abundance or fidelity could be driven by different landscape variables in different quantities. The roosting habitat model developed in this study will provide a deeper understanding of Carnaby's Black-Cockatoo roosting and habitat requirements at multiple scales of resolution. Land-use planning will be informed by the outcomes of this study to further aid in the conservation Carnaby's Black-Cockatoo at different spatial levels.

Geographical gaps in ecology can be filled by means of coupling geographical information systems (GIS) technology with statistical modelling of biological survey data. This combination can be applied across large geographical expanses that include various environmental variables (e.g. landcover, substrate, terrain or climate variables), ultimately providing spatially-complete data (Ferrier et al. 2002). Analysis of habitat and landscape data has been revolutionized by GIS because of its computer-based capacity to manipulate and analyse spatially-distributed data (Johnson 1990). Analysis of spatial relationships is made possible by GIS because it has the ability to cope with large volumes of spatial data. For this reason, the number of variables that can be included in an analysis and spatial extent can be increased when analysis is being carried out (Burrough 1986, Haslett 1990). For this study, GIS was used as a tool to manipulate spatial data in order to understand the spatial relationships between roost sites and environmental variables associated with the roost sites that were found across the Swan Coastal Plain.

In the non-breeding season, foraging habitat (Johnston et al. 2016) and night roosting sites are important habitat components for the survival of Carnaby's Black-Cockatoo (Department of Parks and Wildlife 2013). The annual citizen science project, the Great Cocky Count (2010 - 2015) (Byrne et al. 2015), has provided information on the numbers of Carnaby's Black-Cockatoos using

nocturnal roost sites as well as an indication of nocturnal roost fidelity data across a six year period. Roost sites are widely distributed across the Swan Coastal Plain and there are a large number of landscape variables that may potentially influence the location of Carnaby's Black-Cockatoo nocturnal roost sites, as well as how often they frequent these roost sites. Survival of the species is most likely to be dependent on habitat structure that offers shelter and protection, foraging habitat and water availability. Based on the literature, landscape variables considered to be potentially important in determining roost choice and fidelity chosen for the study were: urban pressures where the concentration of roads and the introduction of non-native ground cover vegetation may impact upon roost sites; food availability of native and non-native vegetation, particularly *Banksia* species and pine trees; roost tree characteristics with regard to tree height and the area of potential roost trees, and; water availability. The variables were measured within buffers of various radii (1, 6 and 12 km) around each study site. This was in order to gauge the strength of each of the variables as a driver of nocturnal roost counts and fidelity based on generalised linear modelling. The aim is that this knowledge will aid in understanding Carnaby's Black-Cockatoo roosting habits and ecology at different spatial scales in the urban landscape.

4.1.1 Urban pressures

One of the most detrimental anthropogenic habitat disturbances is urbanisation because it results in local extinctions and great loss of native species (McKinney 2002, Lowry and Lill 2008b). Urbanisation could therefore negatively impact on Carnaby's Black-Cockatoo nocturnal roost habitat. Road length and introduced ground cover vegetation can result in altered (directly or indirectly) native vegetation and natural land systems, and these urban pressure indices are considered potentially important in determining roost choice and fidelity (Medley et al. 1995, McKinney 2006). Road length represents matrix quality because it indirectly represents the potential increase in human population density and structures (Smith et al. 2011) that may affect where Carnaby's Black-Cockatoos choose to roost. Urban pressure indices provide insights into how disturbed the natural landscape is around nocturnal roost sites, where higher values indicate greater urban pressures through habitat degradation, fragmentation and loss (Medley et al. 1995, Burgin and Saunders 2007). Ford et al. (2001) found that fragmented landscapes resulted in declines and losses of bird species, even where vegetation linkages were present. They reasoned that this was because the linkages were not of the right structure, being either too narrow or too few. Travel by birds between remnants could also put them at risk of injury or death from predation, powerlines, and vehicle strikes (Ford et al. 2001, Benítez-López et al. 2010). Carnaby's

Black-Cockatoos often drink from puddles on roads that have formed after rain, and they have also been known to feed on low road verge or roadside vegetation (Groom et al. 2014). In such circumstances, they are at increased risk of injury or death from vehicle collisions as a result of slow response times and flying low over roads (Groom et al. 2014).

Native vegetation that has been replaced by non-native ground cover vegetation results in greater patchiness and disconnection of quality native vegetation, which disrupts the quality and quantity of foraging vegetation for Carnaby's Black-Cockatoos. Disturbed native vegetation can limit the way Carnaby's Black-Cockatoos move through foraging habitat (Saunders 1990) because patches of remnant vegetation connected by corridors aid in guiding the birds from one patch to another (Saunders 1990, Hobbs and Hopkins 1991). Saunders (1990) also suggested that corridors between isolated patches increases the energy efficiency of foraging because the food source is continuous rather than in discrete patches that may be out of sight as a result of distance. Ground cover is comprised of either non-native understorey vegetation, or vegetation that has been modified for human purposes such as golf courses, sporting ovals, and grazing pastures (Saunders 1990). Disconnection or patchiness of remnant native vegetation can result from the introduction of non-native ground cover vegetation into the landscape. Carnaby's Black-Cockatoo is a mobile species (Berry 2008) and there is the potential for them to locate remnant vegetation patches that are within a fragmented landscape of ground cover. This is a suggestion that is supported by Lindenmayer et al. (1996) who found that Sulphur-Crested Cockatoo were able to locate remnant patches of Eucalypt forest in which to roost. They also suggested that albeit with major landscape changes, groups of birds may have maintained fidelity or traditional use of habitat patches as roost sites (Lindenmayer et al. 1996). The Rainbow lorikeet is another parrot species that is abundant in many Australian cities where they form communal roosts in urbanised, fragmented landscapes, from the central city to the outskirts (Jaggard et al. 2014). Based on the insight of these parrot roost studies, Carnaby's Black-Cockatoo roost sites with greater areas of ground cover may not necessarily result in lower roost count abundances, although non-native ground cover vegetation itself is highly unlikely to be used for roosting and would provide limited foraging or roosting habitat.

Fragmentation as a result of urbanisation has direct (through impaired pollination and seed dispersal (Tilman et al. 1994, Aguilar et al. 2006)) and indirect effects (via changes to anthropogenic and natural disturbance regimes, as well as environmental conditions (Hobbs and Yates 2003) on remnant vegetation (Ramalho et al. 2014)). Nevertheless, some bird species such as the Olive Whistler *Pachycephala olivacea* and Australian Raven *Corvus coronoides* have been

found to be more abundant in fragments rather than continuous forest vegetation (Lindenmayer et al. 2002), and a tolerance to fragmentation has been shown in parrot species such as Sulphur-Crested Cockatoo, Rainbow lorikeet, and New Caledonian Parakeet *Cyanoramphus saisseti* (Lindenmayer et al. 1996, Legault et al. 2012, Jaggard et al. 2014). Studies have shown that fragments of all shapes and sizes have significant conservation value (Lindenmayer et al. 2002, Antongiovanni and Metzger 2005, Uezu et al. 2005). Carnaby's Black-Cockatoo have been observed to follow optimal foraging theory, since they prefer to forage in areas with high densities of food resources, thus reducing the need to be constantly moving between food patches of lower quality (Johnston 2013).

Some Australian parrot species, such as Rainbow lorikeets and Sulphur-Crested Cockatoo, seem to thrive in landscapes impacted by urban disturbance (Shukuroglou and McCarthy 2006, Burgin and Saunders 2007, Legault et al. 2012). Rainbow lorikeets are thought to choose roost trees in urban areas partly because of warmth and enhanced visibility as a result of surrounding man-made or concrete surfaces, as well as street lighting that offers predator detection (Legault et al. 2012). Lowry and Lill (2008) found that the widespread occurrence and the timing of seeding of various food resources throughout their urban environments facilitated the red-rumped parrot during winter months. Along with the availability of food resources, the red-rumped parrot was also facilitated during winter by the presence of suitable roosting trees (Lowry and Lill 2008). Suitable roost trees and the presence of abundant food resources during the non-breeding season are likely to also be key factors that facilitate Carnaby's Black-Cockatoo on the Swan Coastal Plain, both of which are often available in urbanised areas. Although it has been demonstrated that Carnaby's Black-Cockatoo has, in various ways, adapted to the urban landscape (Groom et al. 2014), it was expected that increased urban pressures would ultimately impact negatively upon the species as a result of reduced foraging area, roosting trees and nesting habitat (Saunders 1977, Berry and Owen 2010, Groom et al. 2014, Johnston et al. 2016).

4.1.2 Food resources and water availability

Berry (2008) suggested that it is highly probable that diminishing food resources during the non-breeding season, as a result of loss of native vegetation on the Swan Coastal Plain, would contribute to a decrease in the population. Carnaby's Black-Cockatoo undergoes a partial or full moult during the non-breeding season which would be nutritionally costly (Berry 2008). A poor locality, as well as insufficient quantity and quality (high energy and protein content) of foraging habitat in the non-breeding season is likely to negatively impact the pre-breeding condition of

Carnaby's Black-Cockatoo. This could ultimately affect breeding success, particularly where there is loss and degradation of native vegetation (Saunders 1990, Berry 2008, Stock et al. 2013). *Banksia* species on the Swan Coastal Plain supply food resources to Carnaby's Black-Cockatoo year-round, particularly in February at the beginning of the non-breeding season (Johnston et al. 2016). *Banksia* fragmentation is considered to be an important landscape indicator because *Banksia* vegetation is a critical foraging source for Carnaby's Black-Cockatoo (Saunders 1980, Valentine and Stock 2008, Johnston 2013, Johnston et al. 2016).

Fragmentation of *Banksia* woodland into isolated patches can affect the vegetation in terms of productivity and even resistance to disease. Ramalho et al. (2014) found that the negative impacts of fragmentation on *Banksia* woodland were most rapid in smaller remnants, and that in the smaller remnants, native species richness was halved in just a few decades after isolation. They therefore suggested an underlying rapid reduction in habitat quality (Ramalho et al. 2014). The loss of *Banksia* woodland quality, due to fragmentation, could therefore negatively impact upon the nutritional intake of Carnaby's Black-Cockatoo, particularly where patch size is reduced.

The number of *Banksia* vegetation patches and their area gives insight into the number and size of foraging patches that are available to Carnaby's Black-Cockatoo within the landscape. It is expected that Carnaby's Black-Cockatoos would prefer roost sites that were surrounded by a few large patches rather than roost sites that had buffers with numerous, small, often widely separated *Banksia* vegetation patches (Turner 1989).

Since the 1940s, introduced pine trees have become an important alternative food source for Carnaby's Black-Cockatoo largely due to the extensive clearing of native foraging vegetation on the Swan Coastal Plain (Perry 1948, Saunders 1974, 1980, Finn et al. 2009, Johnston 2013, Stock et al. 2013). Pine cone seeds hold an easily obtainable, valuable food source for Carnaby's as they have relatively short processing times, and contain a higher energy content than native myrtaceous and proteaceous species (Perry 1948, Saunders 1980, Cooper et al. 2002, Shah 2006, Stock et al. 2013). Studies have suggested that pines are more intensely frequented between February and September (cones ripen January to February, coinciding with the non-breeding season) because of the increased availability of mature pine seeds (Finn et al. 2009, Stock et al. 2013). This period of maturation of pine seeds is ideal timing for breeding pairs that have returned to the Swan Coastal Plain needing nutritional and energetic replenishment after the demands of gestating, brooding and fledging chicks (Saunders 1974, Valentine and Stock 2008, Finn et al. 2009).

According to counts reported in GCC 2015 (Byrne et al. 2015) report, each year at least 2000-4000 Carnaby's Black-Cockatoos forage on pine within the Gnangara pine plantation. Other studies that have observed Carnaby's Black-Cockatoos in the Gnangara plantation system have reported similar abundances (Finn et al. 2009, Johnstone et al. 2011, Stock et al. 2013). By 2009, 9000 ha (40%) of 24,000 ha of pine plantations in the Swan Coastal Plain region had been cleared, which would have been a substantial food source loss for the Carnaby's Black-Cockatoo. The reduction in pine plantations is one of several factors (another being the greatly reduced *Banksia* spp. food sources) contributing to the decline in the population of Carnaby's Black-Cockatoo (Stock et al. 2013, Williams et al. 2015). Pines will continue to be cleared, without replacement, until the majority of remaining pine has been harvested by 2030 (Valentine and Stock 2008). This large reduction in food source is likely to negatively impact upon the cockatoos as well as further strain the carrying capacity of the region (Stock et al. 2013).

There are a number of roost sites that are often associated with pine trees, with the trees themselves often being used as overnight roost trees (Valentine and Stock 2008, Finn et al. 2009, Byrne et al. 2015). The loss of pine stands will likely affect some of the roost sites that have been used, depending on whether a few remnant clumps of pine are retained (examples of pine used as nocturnal roost sited have been observed at Edith Cowan University, Joondalup, and at the DBCA and Collier Golf Course grounds in Kensington). Thus, it would be expected that roost sites surrounded by a greater area of pine cover would be associated with greater roost counts and fidelity.

It has been suggested that reliable access to water in close proximity might be one of the characteristics associated with preferred roost sites (Saunders 1980, Berry 2008, Weerheim 2008, Berry and Owen 2010). There are a variety of water sources that Carnaby's Black-Cockatoos drink from opportunistically, many of which are artificially created or modified (Finn et al. 2009, Johnstone et al. 2011, Lee et al. 2013, Stock et al. 2013, Groom et al. 2014). Groom et al. (2014) observed that popular water sources within the urban environment used by Carnaby's Black-Cockatoos were bird baths and puddles. On a larger scale, they have also been observed to use streams, swamps, lakes and dams (Saunders 1980, Groom et al. 2014). Therefore, water cover would be an important consideration when Carnaby's Black-Cockatoos select roost sites. Roost selection might also be related to the area of water cover, the number of water sources and seasonality of availability within the near-roost scale.

4.1.3 Potential roost trees

A number of studies have shown that various parrot and non-parrot species prefer taller trees when compared to non-roost trees (Boeker and Scott 1969, Clergeau 1990, Higgins 1999, Everding and Jones 2006, Lowry and Lill 2008b). Jaggard et al. (2014) found that larger flocks of rainbow lorikeets were found in trees between 6 m and 14 m in height. Groom et al. (2014) found that Carnaby's Black-Cockatoos roosted in tall trees, most of which were planted more than 20 years ago. Berry (2008) has observed Carnaby's Black-Cockatoos for more than 26 years and has recorded birds using a group of large Lemon-scented gums as nocturnal roost trees. Where tree height is concerned, tall trees and a greater area or number of trees, are likely to be strong drivers of nocturnal roost count and fidelity.

Based on the aforementioned insights, it was expected that roost abundance and fidelity would be higher at a site associated with: i) decreased urban pressures such as roads and non-native ground cover vegetation; ii) increased area of food resources such as *Banksia* and pine vegetation, and a greater number of water sources, and; iii) a greater area of tall trees (≥ 8 m).

4.2 Objectives

The main objective of this chapter is to develop a model of Carnaby's Black-Cockatoo nocturnal roosting habitat within three distance radii around known roost sites to establish which of the landscape variables would be the most likely drivers of nocturnal roost count and roost fidelity. The outcomes of the models will provide a snapshot of what combination and strength of landscape variables are associated with abundance and fidelity of the study roost sites, and at what scales that this association is strongest.

4.3 Methods

Site selection and data source

A total of 18 widely dispersed roost sites on the Swan Coastal Plain were chosen for this study including Baldivis, Ballajura, Bedfordale, Como, Coodanup, Dawesville, Floreat, Gingin, Keysbrook, Melaleuca, Oakford, Preston Beach, Spearwood, Tamala Park, Wellard, Woodridge, Yanchep, and Yeal (Table 4.1). The climate of the study region is as described in Chapter 2. Each location has been named according to the town or suburb that the central roost site is located in

and each site is part of the citizen science survey, the Great Cocky Count (Byrne et al. 2015). The total number of Carnaby's Black-Cockatoos roosting at each site was counted at sunset in April each year from 2010 to 2015 (Table 4.2) (Byrne et al. 2015). Mean totals for each site were calculated from the 2010 to 2015 data and a roost site fidelity index was calculated as the proportion of years where birds were present at the roost (Table 4.2).

Table 4.1 Eighteen Carnaby's Black-Cockatoo roost sites selected for this study based on confirmed Great Cocky Count (GCC) 2015 (Byrne et al. 2015) roost sites within the Swan Coastal Plain. The roost sites have been referred to by their GCC code. Carnaby's Black-Cockatoos are counted at sunset as they enter and settle into overnight roost trees. The suburbs, decimal latitude and longitude, and the roost site landmarks have been included in this table as a locational reference associated with each GCC roost site code. Latitude and longitude are based on the geographic coordinate system (datum) World Geodetic System 84.

GCC roost site code	Suburb	Decimal latitude (S)	Decimal longitude (E)	Roost site landmarks as described by GCC (2015)
ROCBALR003	Baldivis	32.365	115.816	Yulbah Loop and Yate Crt or 61 Yulbah Loop
SWABALR001	Ballajura	31.830	115.879	In the trees surrounding the small Lake at the south end of Bramble Way
ARMBEDR002	Bedfordale	32.178	116.063	Corner Albany Hwy and Narbethong
SOUCOMR001	Como	31.998	115.884	Collier Park golf course, Hayman Rd, Bentley/Como/Kensington junction
MANCOOR002	Coodanup	32.540	115.756	Dean Road and Lakes Way, Jandakot - off southern bend in Lakes Way, and at small lake off side road off Dean Rd near Capricorn Park
MANDAWR002	Dawesville	32.649	115.642	Timbers Edge Estate Fernwood Rd and Timbers Edge Rd
CAMFLOR001	Floreat	31.948	115.791	Perry Lakes Reserve (corner Underwood Ave and Brockway Rd
GINGINR001	Gingin	31.349	115.904	Granville Park (corner of Dewar Rd and Jones St in the middle of Gingin; main roost) plus Shire Office (Brockman and Weld Streets) and Bowling Club (Barlee St between Robinson and Fraser Sts opposite Lot 7 Barlee St)
SERKEYR001	Keysbrook	32.441	115.882	In the introduced gums around a private homestead on the south side of Elliot Rd near the corner of Yangedi Rd.
SWAMELR001	Melaleuca	31.737	115.892	Between Galah & Krake Rd east of Mulga, a location NE of Silver & Warbrook Rds

SEROAKR004	Oakford	32.215	115.887	Between 80 and 90 Tuart Rd
WARPRER001	Preston Beach	32.840	115.653	335 Preston Beach Rd North
COCSPER001	Spearwood	32.103	115.778	Pearce Park corner Spearwood Ave and Adela Pl
WANTAMR001	Tamala Park	31.706	115.743	Watercorp Neerabup Groundwater Treatment Plant
KWIWELR001	Wellard	32.259	115.812	Henley Bushland between Henley Blvd/Lambreth Cres/Lyndhurst Cres, Wellard, and Gilmore Ave/Whitebread Way, Leda
GINWOOR001	Woodridge	31.339	115.575	Corner King Drv and Glenwood Pl, in tall introduced Eucalypts around horse stables
WANYANR006	Yanchep	31.549	115.682	Yanchep National Park Volunteer Centre, Yanchep National Park Golf Course entrance
GINYEAR002	Yeal	31.452	115.688	Acacia Rd

The nocturnal roost sites were chosen so that they were spread out relatively evenly across the Swan Coastal Plain (although some roost sites fell just outside of the Swan Coastal Plain boundary) (Figure 2.1, Chapter 2). GCC roost sites are often located at short distances from each other. The roost sites for this chapter were carefully selected to ensure overlap of the 1 km radii buffer did not occur based on Glossop et al. (2011) definition of a nocturnal roost site (described in section 4.3.4.1). Selecting sites at random was not a suitable option because overlap of 1 km buffers was likely to occur.

Landscape scale

Data for all the landscape variables were quantified within buffers which included radii of 1 km, 6 km, 12 km, 1 - 6 km, and 6 - 12 km distances around each of the study roost sites. The buffer radii 1 km, 6 km and 12 km were chosen based on reported foraging distances of up to 12 km by Carnaby's Black-Cockatoo (Saunders and Ingram 1987). The 1 km radius scale was a means to reflect the conditions at and immediately surrounding the roost site while the 6 km radius was chosen because it is half the maximum distance of 12 km and gives an indication of conditions at intermediate ranges around the roost. Kabat et al. (2012) also showed that the number of roosting birds per roost was most strongly associated with the percentage of remnant vegetation within a 6 km radius of the roost site. Landscape variables were quantified in the 0 - 1 km, 0 - 6 km and 0 - 12 km buffers while another set of non-overlapping buffers (1 - 6 km, and 6 - 12 km) were also assessed. Information for all variables was extracted from relevant data layers using a geographical information system (GIS) (in ESRI ArcMap versions 10.2.2 and 10.3).

Table 4.2 Eighteen Carnaby's Black-Cockatoo roost sites based on confirmed Great Cocky Count (GCC) 2015 (Byrne et al. 2015) roost sites within the Swan Coastal Plain. The GCC is a community science survey that has been carried out on one evening in April of each year since 2010. Carnaby's Black-Cockatoo are counted at sunset as they enter and settle into overnight roost trees. The suburbs, yearly count, total count, count average, and roost fidelity have been included in this table. Roost fidelity and total average did not include years where counts did not occur ("." represents a year where the survey did not occur).

Roost location	GCC yearly count						Total count	Total Average	Roost fidelity (%)
	2010	2011	2012	2013	2014	2015			
Baldivis	.	78	0	4	0	0	82	16	0.40
Ballajura	0	40	0	92	0	35	167	28	0.50
Bedfordale	70	22	.	3	0	.	95	24	0.75
Como	408	645	558	301	402	460	2774	462	1.00
Coodanup	.	.	.	21	0	0	21	7	0.33
Dawesville	371	199	11	0	257	135	973	162	0.83
Floreat	310	254	452	340	273	192	1821	304	1.00
Gingin	392	378	432	686	879	784	3551	592	1.00
Keysbrook	0	.	.	100	3	14	117	29	0.75
Melaleuca	500	41	0	20	480	0	1041	174	0.67
Oakford	45	3	0	0	50	0	98	16	0.50
Preston Beach	.	.	66	330	19	.	415	138	1.00
Spearwood	0	2	.	323	0	0	325	65	0.40
Tamala Park	.	.	0	103	20	10	133	33	0.75
Wellard	.	.	15	50	0	125	190	48	0.75

Woodridge	113	119	0	30	0	0	262	44	0.50
Yanchep	342	321	129	564	0	580	1936	323	0.83
Yeal	49	92	.	.	.	20	161	54	1.00

The landscape variables take into account what Carnaby's Black-Cockatoo are likely to be driven by, based on the literature, in terms of: urban pressures (road length and non-native ground cover vegetation); food resources (*Banksia* and pine vegetation) and water availability, and; roost tree structure (area of tree cover (trees ≥ 8 m which are potential roost trees). The radii acted as spatial scales so as to establish which landscape variables would be important around the nocturnal roost sites, and in which of the distance radii scales (1, 6 or 12 km) they were important.

4.3.1 Urban pressures

4.3.1.1 Roads

For each roost site buffer, the sum of road length was determined from the Main Roads Western Australia (MRWA) Road Hierarchy spatial dataset (currency date: 2012), whereby Landgate are the data custodians. Road length was used in conjunction with the "road types" classification to estimate how busy the roads might be within any roost site buffer. According to MRWA, the Road Hierarchy consists of six types of roads, including: Primary Distributor (built up and rural areas); Regional Distributor (rural areas); District Distributor A (built up areas); District Distributor B (built up areas); Local Distributor (built up and rural areas); Access Road (built up and rural areas) (Main Roads Western Australia 2011). For each roost site buffer, the total length of each road type was calculated (km). A roost site buffer with a high length of primary distributors compared to other road types is typical of a highly urbanized area since this road type is often more prominent in densely urbanised areas.

4.3.1.2 Non-native ground cover vegetation

Non-native or introduced ground cover was calculated by creating a layer that was extracted from Urban Monitor imagery (Caccetta et al. 2012) after native vegetation had been excluded from the area of interest using the native vegetation extent digital data layer compiled by Department of Food and Agriculture, Western Australia (DAFWA) (data currency: beginning date 01/2001, and; end date 11/2014). The ground cover layer was characterised by areas of non-native vegetation < 5m in height. Non-native ground cover is vegetation that has been introduced into the landscape and can be associated with disturbed or transformed areas

of land (i.e. non-native vegetation) such as golf courses or ovals. The total area (ha) of non-native ground cover within each roost site buffer was calculated

4.3.2 Food resources and water availability

4.3.2.1 *Banksia* vegetation

The total area (ha) of *Banksia* vegetation which included vegetation from other genera was calculated. A digital data layer compiled by DAFWA included native vegetation extent in WA (data currency: beginning date 01/2001, and; end date 11/2014) and was used to extract *Banksia* vegetation data. *Banksia* vegetation was extracted based on the NVIS (National Vegetation Information System) hierarchical level VI of the native vegetation layer. Vegetation types such as *Banksia* were defined according to the NVIS hierarchical level VI (or L6, which is a vegetation level classified based on sub-association vegetation i.e. dominant growth form, height, cover and species (5 species) for all layers/sub-strata) vegetation classification included in the attribute table of the "vegetation descriptions look-up table" dataset (Shepherd 2003).

Banksia vegetation data extracted from the L6 category often included other non-*Banksia* species vegetation within the same polygon. Although these polygons were not exclusively *Banksia* vegetation, they were nevertheless included because Carnaby's Black-Cockatoo would still be able to forage in such areas. The results collected for this variable provided an indication as to the area of native vegetation available around the central roost site, and whether it is a driver of nocturnal roost count and fidelity in some or all of the buffer scales.

4.3.2.2 Pine

The year 2010 provides an indication of what area of standing pine was available to Carnaby's Black-Cockatoo in the first year that the GCC was carried out. Since 2010, pine plantations have continued to be cleared to meet the demands of the timber industry, as well as to reduce water uptake by these plantations (Stock et al. 2013, Williams et al. 2015). Area of pine was an important variable to measure in 2010 in order to establish whether it was a driver of nocturnal roost count and fidelity at the onset of the GCC survey period.

For each roost site buffer, the area of standing pine (ha) in 2010 was calculated using a spatial data layer provided by the Forest Product Commission (FPC) (data currency: beginning date 01/01/2010, and; end date 01/07/2015). The layer provided spatial data that included

plantation areas owned and or managed by the FPC. It should be noted that not all area of pine was included in the FPC data due to some of the metropolitan area plantations being harvested and therefore inactive before their data layers were produced.

4.3.2.3 Water availability

February is generally one of the driest, hottest months of the year on the Swan Coastal Plain, and 2012 was one of the hottest years on record (at the time), with below average to near average rainfall (Bureau of Meteorology, 2013). Thus, it would be expected that surface water would be lower than usual at that time. By capturing this period of time, calculations would reflect permanent surface water bodies available to Carnaby's Black-Cockatoo in dry, hot periods of their non-breeding season on the Swan Coastal Plain.

Permanent surface water bodies were counted within each of the buffers using February 2012 aerial imagery of the study area, provided by DBCA. Another DBCA data layer which showed the geomorphic wetlands on the Swan Coastal Plain was used as a guide alongside the aerial imagery so as to highlight where some water bodies might lie. A grid across all the study site buffers was used to aid the visual inspection of permanent water bodies. The 1 km^2 grid cells were checked off after each grid cell was counted. Permanent water bodies were counted manually because there were no suitable datasets available (the dataset would have needed to be at the appropriate resolution, and also include all spring/summer permanent water bodies between 2010 and 2015). The water body counts did not include obvious salt or brackish water bodies (for example the Swan river estuary), however, due to time restraints, there was a limitation to cross-checking every other water body as to whether they were salty or brackish. The results showed at which buffer scales permanent water bodies were important as drivers of nocturnal roost count and roost fidelity.

4.3.3 Potential roost trees

4.3.3.1 Tree height

Based on the study which researched methods for mapping Carnaby's Black-Cockatoo habitat, trees equal to and above 8 m within 1 km of the central roost area provide potential night roost sites to Carnaby's Black-Cockatoo where > 150 birds were recorded at any given time (Glossop et al. 2011). Glossop et al. (2011) also noted that, where there was < 150 birds

recorded, they reduced the buffer from 1 km to 0.5 km. For this study however, a 1 km buffer for ≥ 8m trees from the central roost points for all roost sites was maintained, even in the case of sites that have recorded < 150 birds. This was to remain consistent throughout the study whereby all other variables were measured within a 1 km buffer and not 0.5 km buffers. The results collected for this variable will provide an indication as to the area of potential roost trees that are available around the central roost site, and whether the area of potential roost trees is a driver of nocturnal roost count and fidelity in some or all of the buffer scales.

The area of trees with heights equal to or greater than 8 m were measured within each 1 km roost site buffer (and not the 6 km and 12 km buffers) and were referred to as potential roost trees in this study (ha). Tree height was only measured within the 1 km roost site buffers which corresponds to the definition of the extent of a roost site suggested by (Glossop et al. 2011). A digital data layer, described as "A map of potential Carnaby's Black-Cockatoo cockatoo roost sites within the Perth Peel Strategic Assessment Region" was created using the approach described by Glossop et al. (2011). The custodian of the data layer is DBCA with the most recent dataset delivered in 2014.

There were three study sites, Woodridge, Yeal, and Gingin that were not covered in the tree height data layer provided by DBCA since these sites were not included in their study. The data for these three sites had to be extracted using raster tiles from Urban Monitor (2009) vegetation data, albeit Urban Monitor data was also the foundation of the DBCA tree height dataset. The Urban Monitor raster pixels were originally at the very fine scale resolution of 0.2 m^2, and for the purposes of extracting the missing roost site data, the resolution increased to 1 m^2. The raster mosaic tiles that included the missing roost sites were used to calculate (zonal statistics in ArcMap 10.3.) the area of trees that were ≥ 8 m.

The primary data set that Urban Monitor utilises is digital aerial photography, which has the ability to identify elevation and changes in land condition at a fine scale (spatial resolution of 0.2m). The use of satellite, remotely sensed aerial, and other spatial data allows for fine scale monitoring of complex environments such as vegetation heights on the Swan Coastal Plain. The Urban Monitor data supports analysis within a GIS environment and supplies a raster data set that contains vegetation height pixels relative to the ground (in millimetres) (Caccetta et al. 2012).

It was expected that nocturnal roost counts and roost fidelity would be higher in the 1 km roost site buffers that contained large areas of potential roost trees (≥ 8 m).

4.4 Modelling and statistical analyses

Generalized linear modelling (GLM) was used to investigate which landscape variables would best explain greater nocturnal roost site count and fidelity of Carnaby's Black-Cockatoo at three spatial scales (1 km, 6 km and 12 km radii). GLMs create a means to consistently link together the systematic elements in a model that has random elements (Nelder and Wedderburn 1972). There are a number of studies that use GLM to investigate the relationship between birds and their related habitat or roost sites, which provide support for using GLM in this study (Lindenmayer et al. 1996, Schwab et al. 2006, Weerheim 2008, Johnston 2013).

The GLMs provided numerous candidate models, however selection of the most parsimonious of the models was based on Akaike information criterion (AIC), a method of model selection that adheres to simplicity and the principal of parsimony (Burnham and Anderson 2001). The principal of parsimony and simplicity is based on Occam's razor, a concept that suggests the most likely explanation is the simplest one (Burnham and Anderson 2001, Mazerolle 2004). Burnham and Anderson (2001) asserted that there are no true models, but that they can instead be defined as approximations to unknown truth or reality. The AIC (which includes the maximum likelihood estimation method) provides a method of finding which model best approximates reality whilst minimizing loss of information (Burnham and Anderson 2001, Mazerolle 2004). In order to account for the small sample size of the study, the Akaike Information Criterion was bias-corrected (AIC_c). The AIC_c has been described as a correction that accounts for both precision and bias, and was thus used in this study to compare models and ultimately for the measurement of model fit (Cavanaugh 1997, Burnham and Anderson 2003, Zabel et al. 2003).

The models that were selected as the "best" of the candidate models were then evaluated using structural equation modelling (SEM). A SEM approach is an alternative to regression methods and is able to estimate the structural coefficients in an unbiased and accurate way (Pugesek and Tomer 1995). SEM is a statistical method that can evaluate a network of dependence relationships by means of the analysis of covariance (Grace and Pugesek 1997). It is a multivariate technique that is able to test complex dependency relationships, partitioning of indirect and direct effects, statistical falsification of a model, and provide quantitative predictions (Grace and Pugesek 1997). The advantages of SEM have been a considerable aid to the study of ecological systems by providing the ability to disentangle complex ecological

interactions (Grace et al. 2010, Cubaynes et al. 2012). SEM suited the purpose of this study because it permitted the assessment of a) the direct effects as well as the strength of those effects of landscape variables on Carnaby's Black-Cockatoo nocturnal roost sites and roost site fidelity, and b) indirect effects between the landscape variables. The SEM also provided a visual reference of each of the model results which allowed for efficient recognition of the effects or causal assumptions (Cubaynes et al. 2012).

In the non-breeding season, Carnaby's Black-Cockatoo occupy various parts of the landscape, whether it be for roosting, foraging, or finding water sources (Saunders 1980, Berry 2008, Groom et al. 2014, Johnston et al. 2016). Like most organisms, their interactions with their environment are complex and multi-scaled across the landscape. The variables that were found in the most parsimonious models could then be identified as drivers of either the roost count or roost fidelity, at multiple spatial scales.

4.4.1 Data preparation pre-analysis: Standardisation of landscape variables and calculation of composite scores

The data collected for each of the variables (road length, area of non-native ground cover vegetation, area of *Banksia* vegetation, area of pine vegetation, the number of water bodies, and the area of potential roost trees (≥ 8 m in height)) were standardised in IBM SPSS Statistics 23. The raw data for each variable were standardised by converting them to z-scores (the formula being (score – mean) / standard deviation). The number of variables were reduced by creating unit-weighted z-score composite variables. To create composite variables, the z-scores of: road length and area of non-native ground cover vegetation were added together to form the urban pressures variable, and; area of Banksia vegetation, area of pine vegetation, and the number of water bodies were added together to form the food and water availability variable. The z-score for area of potential roost trees was not grouped with any other variables.

4.4.2 Generalised Linear Modelling (GLM) and Structural Equation Modelling (SEM)

To establish which landscape variables would be included in the most parsimonious model candidates of nocturnal roost count and fidelity, GLMs were constructed using the advanced analytics software, Statistica 13.0. GLMs were constructed using each of the buffer

scale (1, 6 and 12 km) transformed landscape variable data along with the associated roost count or roost fidelity. The normal-link function was specified and an all subsets approach was used. The landscape variables used (subsequent to raw data standardisation) as part of the GLM constructs were: the urban pressures composite variable; the food and water availability composite variable, and; the tree structure variable. The model building facility applied was a best subset regression method where models were selected based on the Akaike Information Criterion (AIC). AIC, based on Kullback-Leibler information loss and statistical maximum likelihood, is a measure of model fit (Bozdogan 1987).

Where a sample size is small (n /K < ~40), a second-order Akaike Information Criterion (AIC$_c$) should instead be used (Burnham and Anderson 2004). The AIC$_c$ is a second-order means of correcting small-sample bias (Burnham and Anderson 2004). The study had a sample size of 18 and as such an AIC$_c$ was computed. The AIC$_c$ calculation is

$$AIC_c = -2(\text{log-likelihood}) + 2K + \frac{2K(K+1)}{(n\text{-}K\text{-}1)}$$

(Mazerolle 2004)

The GLM models generated a number of candidate models which were based on the AIC$_c$ values. The delta AIC (Δ_i), one of two measures (the other being Akaike weights) associated with AIC or AIC$_c$, was used to compare the models. The delta AIC (Δ_i) is a means of measuring each model relative to the "best" model, and is calculated as

$$\text{Delta AIC} = \Delta_i = AIC_i - \min AIC$$

(Burnham and Anderson 2004)

The "best" model had a Δ_i value of 0, and the subsequent models had positive Δ_i values. As the values increased, the models became less plausible as being the best approximating model in the candidate set of models. The candidate models that had Δ_i scores < 2 were considered as the most parsimonious models, however the model with the Δ_i value of 0 was considered to be the "best" model fit which included the variables that were the most likely drivers of the dependent variables. It must be noted that the AIC does not provide a *p*-value and notions of significance do not apply. Instead it expresses the relative strength of evidence in favour of each model in the form of wi and Δi (Burnham and Anderson 2001).

As part of structural equation modelling, the fundamental null hypothesis (H_o) is that the observed variables, $\sum$, within the covariance matrix, is a function of a set of parameters θ (Bollen 1989, Malaeb et al. 2000). Id est,

$$H_o: \sum = \sum(\theta)$$

Here the null hypothesis is accepted, whereas linear models generally reject the null in favour of the alternative hypothesis.

Structural equation models (SEMs) were constructed in IBM SPSS Amos. The structural equations of SEMs are visually displayed by path diagrams which contributed to developing and testing each of the specified models from the GLMs (McCoach 2003). The path diagrams were multiple regression models, each with a number of predictors (the landscape variables of a "best" model), and the associated dependent variable (either the nocturnal roost count or roost fidelity).

The top most parsimonious models (Δi of 0) for nocturnal roost count and roost fidelity were linked to the appropriate sets of independent variables (single headed arrows pointing to the dependent variable) based on each of the top models of each buffer scale (Table 4.3 and 4.4). The independent variables were also linked to each other (double headed arrows) in order to establish covariance. An error term was added to the dependent variable in order to draw the latent variable when each SEM was run. The parameter estimation method used was maximum likelihood in order to establish the likelihood of each parameter (the independent variables) generated by the average roost count or fidelity, that is, maximum likelihood estimation (MLE) is a technique used to find the most likely function that explains the observed data. The SEMs supply an indication of: the goodness of fit of each of the models; whether the landscape variables have a significant link to the dependent variables (average nocturnal roost count, or, percentage roost site fidelity) and the strength of each of the relationships, and; whether there are significant correlations between independent variables and the strength of those correlations.

4.4.3 Spatial scale comparison of the landscape variables

The composite landscape variables (food and water availability, and urban pressure) of each of the buffer scales were used to compare the differences in the influence of each of the variables between the 1 km, 6 km and 12 km spatial scales. The values of the landscape

variables were also extracted from the buffer range to prevent overlap or duplication. Ranges included 0 - 1 km, 1- 6 km, and 6 - 12 km. In this way, the differences in the spatial scales would not be comparing the overlap of data, that is, where 1 km radius data would not be included within the 6 km data, and where 1 km and 6 km data would not be included in the 12 km radius spatial scale data.

The data values (from the scales that do not overlap i.e. 0 - 1 km, 1 - 6 km, and 6 - 12 km buffers) of each of the spatial scales were standardised in order to provide an average per km^2 that was relative to each scale. This was done by calculating the area of each of these non-overlapping buffers, that is,

Area = π x r^2

Where π = 3.1416 and r is the radius (1 km, 6 km or 12 km). In order to remove overlapping areas, the area of the 1 km buffer was deducted from the 6 km buffer area, and then the 6 km buffer area from the 12 km buffer area. The area of each of the buffers was then divided by each of the landscape variable's average site total value, where each total value of each site was added together and then divided by the total number of sites (18), as per the following:

Each of the landscape variable's mean area per km^2 value for non-overlapping buffers = Buffer area (of either the 1 km, 1 - 6 km or 6 - 12 km area)/μ (of the average landscape variable of the total area of either 1 km, 1 - 6 km or 6 - 12 km buffer)

The results from this calculation for each of the buffers was then presented graphically. The graphs provide a visual means of comparing the differences between the standardised means of each of the landscape variables of each of the spatial scales. The potential roost trees landscape variable could not be compared over the all 3 spatial scales because it was only measured within a 1 km radius and not throughout the 6 and 12 km radius spatial scales. The vegetation variables (non-native ground cover, *Banksia*, pine, and potential roost trees) were graphed together because the unit of measurement (ha) was the same for each.

4.5 Results

4.5.1 Generalised linear models (GLMs)

4.5.1.1 Parsimonious models

Based on the AICc, the GLM models generated 7 candidate (most likely combination of landscape variables that are drivers of the response variables) models for each spatial scale of the associated dependent variables (nocturnal roost count and roost fidelity). The "best" model for each set of candidate models has a Δi value of 0, and the subsequent models (as the Δi values increase) are relative to the "best" model (Table 4.3).

For average roost count (Table 4.3) associated with: the 1 km buffer, 6 most parsimonious models (models with Δi score of < 2) were generated. The "best" model (K = 2, AICc = 238.464, Δi = -0.815) included food and water availability, and potential roost trees; the 6 km buffer included 5 most parsimonious variables and again the "best" model (K = 2, AICc = 237.837, Δi = 0.000) included food and water availability, and potential roost trees, and; the 12 km buffer generated 3 most parsimonious models where urban pressure and potential roost trees were included in the "best" (K = 2, AICc = 237.190, Δi = 0.000) of the most parsimonious models.

Each spatial scale (1 km, 6 km and 12 km buffers) associated with the percentage of roost fidelity (Table 4.4) generated the same "best" model (K = 1, AICc = -2.274, Δi = -0.000) which included only the potential roost trees variable and was the only most parsimonious model generated for the 6 and 12 km buffers. The 1 km buffer generated 2 most parsimonious models.

Table 4.3 Models built using generalised linear model analyses which includes the number of parameters (landscape variables) selected (K), the Akaike Criterion Correction (AICc) score and the delta (Δi) value. The data were modelled according to the average nocturnal roost count in relation to landscape variables. This was done in order to see how much, if at all, the landscape variables explain the variation of roost count within the radii buffers of 1 km, 6 km or 12 km. Rows are in bold where a model has a delta score of < 2.

Buffer	Average roost count models			K	AICc	Δi
1	**FoodWater**	**PotentialRoostTrees**		**2**	**238.464**	**-0.815**
	UrbanPressure	**PotentialRoostTrees**		**2**	**238.620**	**-0.658**
	UrbanPressure	**FoodWater**	**PotentialRoostTrees**	**3**	**239.278**	**0.000**
	PotentialRoostTrees			**1**	**239.609**	**0.331**
	UrbanPressure			**1**	**240.119**	**0.840**
	FoodWater			**1**	**241.049**	**1.771**
	UrbanPressure	FoodWater		2	242.417	3.139
6	**FoodWater**	**PotentialRoostTrees**		**2**	**237.837**	**0.000**
	UrbanPressure	**PotentialRoostTrees**		**2**	**238.055**	**0.219**
	UrbanPressure	**FoodWater**	**PotentialRoostTrees**	**3**	**238.866**	**1.029**
	UrbanPressure			**1**	**239.562**	**1.725**
	PotentialRoostTrees			**1**	**239.609**	**1.773**
	FoodWater			1	240.280	2.443
	UrbanPressure	FoodWater		2	241.863	4.026
12	**UrbanPressure**	**PotentialRoostTrees**		**2**	**237.190**	**0.000**
	UrbanPressure			**1**	**238.229**	**1.039**
	FoodWater	**PotentialRoostTrees**		**2**	**238.895**	**1.705**
	UrbanPressure	FoodWater	PotentialRoostTrees	3	239.316	2.126
	PotentialRoostTrees			1	239.609	2.419
	UrbanPressure	FoodWater		2	240.767	3.577
	FoodWater			1	240.893	3.703

Table 4.4 Models built using generalised linear model analyses which includes the number of parameters (landscape variables) selected (K), the Akaike Criterion Correction (AICc) score and the delta (Δi) value. The data were modelled according to the percentage roost fidelity in relation to landscape variables. This was done in order to see how much, if at all, the landscape variables explain the variation of the percentage roost fidelity within the radii buffers of 1 km, 6 km or 12 km. Rows are in bold where a model has a delta score of < 2.

Buffer	Percentage roost fidelity models			K	AICc	Δi
1	**PotentialRoostTrees**			**1**	**-2.274**	**0.000**
	FoodWater	**PotentialRoostTrees**		**2**	**-0.758**	**1.516**
	UrbanPressure	PotentialRoostTrees		2	0.165	2.439
	FoodWater			1	1.137	3.411
	UrbanPressure	FoodWater		2	1.739	4.013
	UrbanPressure	FoodWater	PotentialRoostTrees	3	1.776	4.050
	UrbanPressure			1	3.681	5.955
6	**PotentialRoostTrees**			**1**	**-2.274**	**0.000**
	FoodWater	PotentialRoostTrees		2	-0.217	2.057
	UrbanPressure	PotentialRoostTrees		2	0.274	2.547
	UrbanPressure	FoodWater	PotentialRoostTrees	3	2.662	4.936
	UrbanPressure			1	3.459	5.733
	FoodWater			1	3.706	5.980
	UrbanPressure	FoodWater		2	5.976	8.250
12	**PotentialRoostTrees**			**1**	**-2.274**	**0.000**
	FoodWater	PotentialRoostTrees		2	0.126	2.399
	UrbanPressure	PotentialRoostTrees		2	0.148	2.422
	UrbanPressure	FoodWater	PotentialRoostTrees	3	2.986	5.259
	FoodWater			1	3.623	5.896
	UrbanPressure			1	3.870	6.144
	UrbanPressure	FoodWater		2	6.033	8.307

4.5.2 SEMs

Model 1 (Fig. 4.1.1)

The landscape variables were not statistically significant ($p = > 0.05$) drivers of nocturnal roost count within a 1 km radius (Fig. 4.1.1). Urban pressure and food and water availability were the only coefficients to show significant correlations to each other ($p = 0.013$) with a strong positive relationship ($r = 0.760$). The results of the analysis indicate that the landscape variables explain 22.4 % ($R^2 = 0.224$) of the variability of average nocturnal roost count.

Model 2 (Fig. 4.1.2)

A 1 km radius of potential roost trees was shown to be a statistically significant ($p = < 0.05$) landscape variable driver of roost fidelity within a 1 km radius (Fig. 4.1.2). The standardised regression weight of potential roost trees had a moderate positive effect on roost fidelity ($p = 0.021$, $\beta = 0. 464$). Urban pressure and food and water availability were the only coefficients to show significant correlations to each other ($p = 0.013$) with a strong positive relationship ($r = 0.760$). The results of the analysis indicate that the landscape variables explain 40.0 % ($R^2 = 0.400$) of the variability of the percentage of roost fidelity.

Model 3 (Fig. 4.1.3)

A 1 km radius of potential roost trees was a statistically significant ($p = < 0.05$) driver of nocturnal roost count within a 6 km radius (Fig. 4.1.3). The standardised regression weight of potential roost trees had a moderate positive effect on roost fidelity ($p = 0.010$, $\beta = 0. 533$). None of the landscape variables had coefficients that showed significant correlations to each other ($p = > 0.05$). The results of the analysis indicate that the landscape variables explain 33.6 % ($R^2 = 0.336$) of the variability of average roost count.

Model 4 (Fig. 4.1.4)

A 1 km radius of potential roost trees was a statistically significant ($p = < 0.05$) landscape variable driver of roost fidelity within a 6 km radius (Fig. 4.1.4). The standardised regression weight of potential roost trees had a moderate to strong positive effect on roost

fidelity ($p => 0.006$, $\beta = -0.580$) within a 6 km radius of the roost. There were no significant ($p => 0.05$) correlations between coefficients. The results of the analysis indicate that the landscape variables explain 32.5 % ($R^2 = 0. 325$) of the variability of percentage of roost fidelity.

Model 5 (Fig. 4.1.5)

A 1 km radius of potential roost trees was a statistically significant ($p = < 0.05$) landscape variable driver of roost count within a 12 km radius (Fig. 4.1.5). The standardised regression weight of potential roost trees had a moderate positive effect on roost fidelity ($p =>$ 0.030, $\beta = -0.450$) within a 12 km radius of the roost. There were no significant ($p => 0.05$) correlations between coefficients. The results of the analysis indicate that the landscape variables explain 31.5 % ($R^2 = 0. 315$) of the variability of average roost count.

Model 6 (Fig. 4.1.6)

A 1 km radius of potential roost trees was a statistically significant ($p = < 0.05$) landscape variable driver of roost fidelity within a 12 km radius (Fig. 4.1.6). The standardised regression weight of potential roost trees had a strong positive effect on roost fidelity ($p =>$ 0.006, $\beta = -0.567$) within a 12 km radius of the roost. There were no significant ($p => 0.05$) correlations between coefficients. The results of the analysis indicate that the landscape variables explain 32.2 % ($R^2 = 0. 322$) of the variability of percentage of roost fidelity.
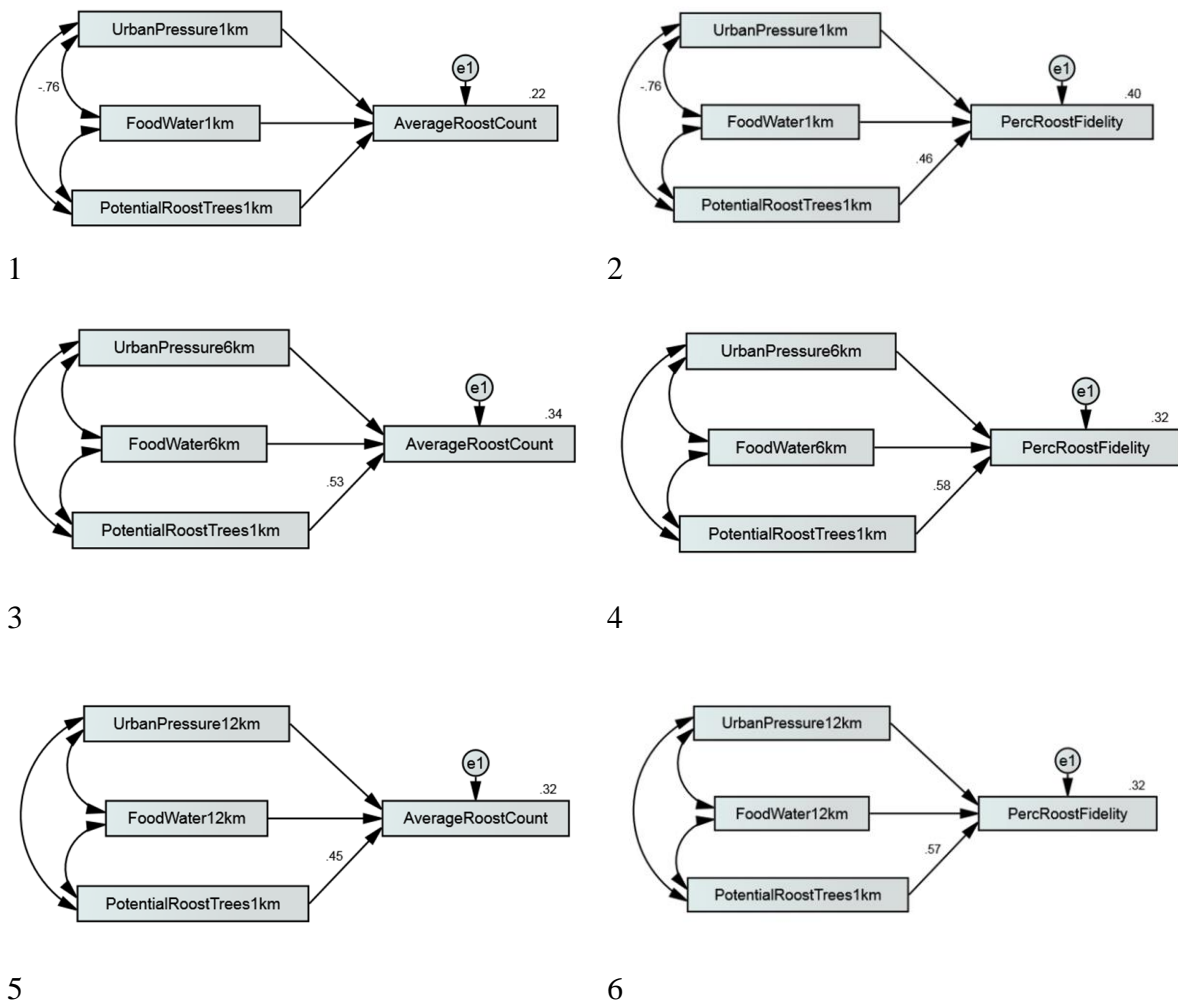
Fig. 4.1.1-4.1.6 Structural equation model SEM of various landscape drivers on Carnaby's Black-Cockatoo average nocturnal roost counts and average nocturnal roost fidelity within a 1 km, 6 km and 12 km radius (around the centre of each roost site). The single headed arrows represent hypothesised landscape drivers of the dependent variables, whereas double headed arrows depict potential correlations among the landscape variables. An error term was added to the dependent variable in order to draw the latent variable when each SEM was run and has been displayed as e1. Standardised regression weights and correlation indices were only retained in the figure where they had significant ($p < 0.05$) paths.

4.5.3 Scale comparison of the landscape variables

4.5.3.1 Urban pressure

The mean road length (km) per km^2 within the total area of each of the buffer scales, 1 km, 1 - 6 km and 6 - 12 km, showed a decrease in length as the area of the spatial scales increased (Figure 4.2.1). The average road length in relation to the total area of each of the

buffers, was greatest at the 1 km scale (4.61 km per km^2), and decreased by 29.28% in the 1 to 6 (3.26 km per km^2), and 36.44% at the 12 km (2.93 km per km^2) buffer scales.
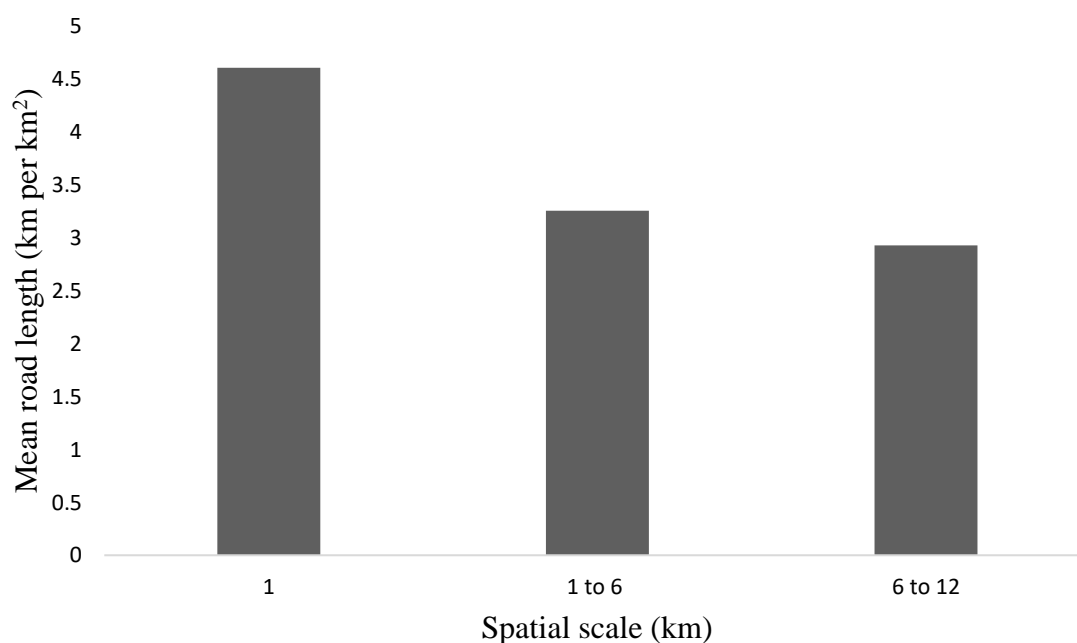
Figure 4.2.1 Bar graphs showing the differences between standardised road length mean (km per km^2) of Carnaby's Black-Cockatoo nocturnal roost landscape variables within three different non-overlapping spatial scales. The spatial scales were separated into 1 km, 1 - 6 km, and 6 - 12 km radius buffers around central nocturnal roost sites.

The mean area of non-native ground cover (ha) within each of the buffers, 1 km, 1 - 6 km and 6 - 12 km, decreased in area as the area of the spatial scales increased (Figure 4.2.2). Ground cover vegetation was greatest per km^2 in the 1 km (8.01 ha per km^2) buffer scale, decreased by 41 % in the 1 - 6 km (4.71 ha per km^2) scale, and by 76.9 % in the 6 - 12 km (1.85 ha per km^2) scale.

4.5.3.2 Food resources and water availability

The average area of *Banksia* (ha) was greatest in the 1 to 6 km buffer scale (68.90 ha per km^2) which was 150.27 % more than the mean area per km^2 of *Banksia* vegetation in the 1 km scale (27.53 ha per km^2). The 6 to 12 km buffer scale had the lowest mean area per km^2 of *Banksia* vegetation (7.90 ha per km^2, 71.30 % less than the 1 km scale and 88.53 % less than

the 1 – 6 km scale). *Banksia* vegetation had the greatest area per km^2 of all the other vegetation types (although the potential roost tree variable was not measured in the 1 – 6 and the 6 -12 km buffer scales).

The average area of pine in relation to the total area of each of the buffers, was greatest per km^2 in the 1 km (7.24 ha of P per km^2) scale, and decreased by 22.24 % in the 1 - 6 km (5.63 ha per km^2), and by 58.29 % in the 6 - 12 km (3.02 ha per km^2) buffer scales (Fig. 4.2.2).
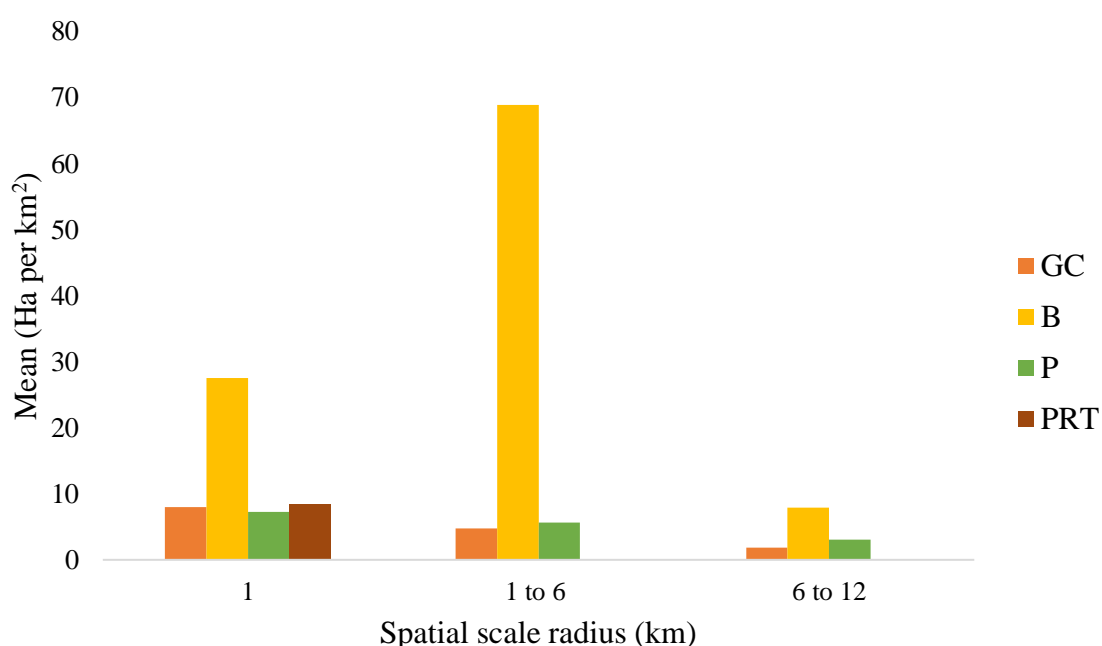
Figure 4.2.2 Bar graphs showing the differences between standardised means of Carnaby's Black-Cockatoo nocturnal roost landscape vegetation types (GC = non-native ground cover, B = *Banksia*, P = pine, PRT = potential roost trees) (ha per km^2) within three different non-overlapping spatial scales. The spatial scales were separated into 1 km, 1 - 6 km, and 6 - 12 km radius buffers around central nocturnal roost sites.

The water body count in relation to the total area of each of the buffers, was greater per km^2 in the 1 km scale (0.88 water bodies per km^2), and decreased by 27.27 % in the 1 - 6 km (0.64 water bodies per km^2), and by 26.14 % in the 6 - 12 km (0.65 water bodies per km^2) buffer scales (Figure 4.2.3).
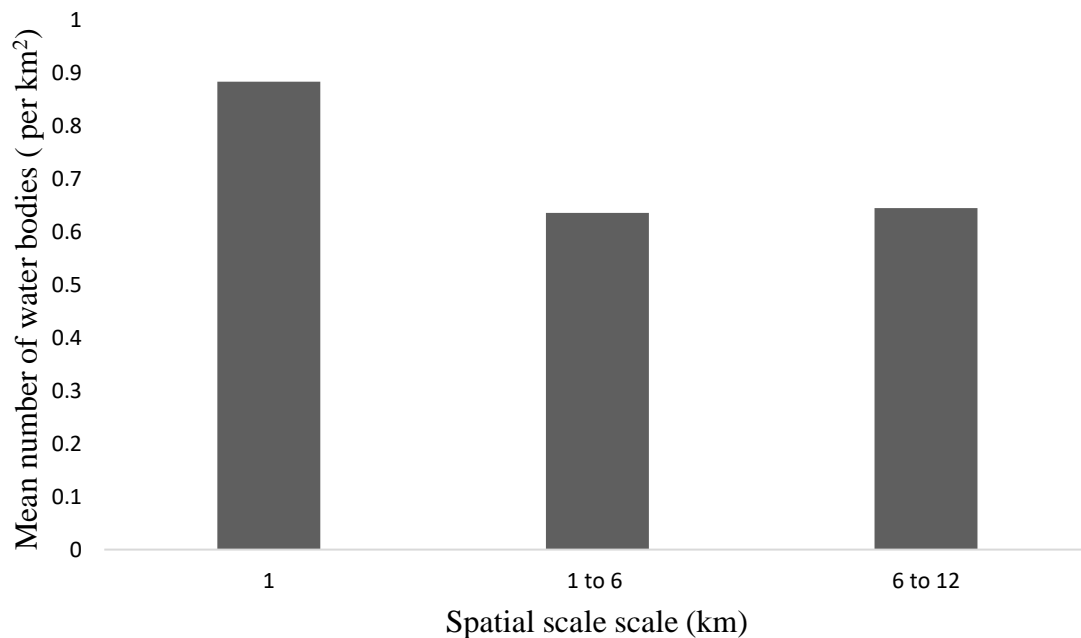
Figure 4.2.3 Bar graphs showing the differences between standardised means of the number of water bodies within three different non-overlapping spatial scales. The spatial scales were separated into 1 km, 1 - 6 km, and 6 - 12 km radius buffers around Carnaby's Black-Cockatoo central nocturnal roost sites.

4.5.3.3 Potential roost trees

The area of potential roost trees (measured only in the 1 km buffer scale) was slightly greater per km^2 (8.45 ha per km^2) than that of ground cover (which was less than the area of potential roost trees by 5.21 %) and pine vegetation (less than 14 .32 %) within the 1 km buffer scale. Potential roost tree area was less by 69.31 % ha per km^2 than *Banksia* vegetation in the 1 km buffer scale.

4.6 Discussion

4.6.1 Urban pressure

Urbanisation has deleterious consequences for native vegetation (How and Dell 2000) which may result in less roosting and/or foraging habitat. Urban pressure was not a driver of roost fidelity at any spatial scale (Table 4.4). A greater area of potential roost trees was the key driver of roost fidelity at all spatial scales. Sites with greater fidelity had a greater area of potential roost trees perhaps partially because those roost sites were less densely urbanised. The

urban pressure variable featured in candidate parsimonious models that were associated with average roost count. There was a model with a delta score of zero in the 12 km buffer, and there were models with delta scores close to zero in the 1 and 6 km buffers (Table 4.3). Cockatoo abundance at more densely urbanised sites did not appear to be negatively impacted if those sites correspondingly had a greater area of potential roost trees.

Aside from having a greater area of potential roost trees, the results may also suggest that densely urbanised roost sites could be somewhat advantageous to greater abundances of Carnaby's Black-Cockatoo. Such urban sites may provide more opportunities to exploit novel food and artificial water sources (Groom et al. 2014, 2016, Jaggard et al. 2014) which have been introduced into urban environments. Roads however are a problem for Carnaby's Black-Cockatoo because of the increased potential for vehicle strikes (Groom et al. 2014). Another explanation for higher abundances found at more urbanised roost sites could be for survivorship reasons, whereby larger flocks form due to widely dispersed or scarce resources (South and Pruett-Jones 2000). Individuals are able to more rapidly learn about the location of food sources by joining a larger flock than if they were to forage alone (Cannon 1984).

Roost trees that were associated with greater roost counts were often surrounded by an urban matrix and located alongside areas considered to be ground cover (personal observations). Tall trees are the essential attribute of a roost site (Tables 4.3 and 4.4), and the study roost trees used by cockatoos, whether planted or remnant natives, are possibly more easily accessible because they are situated on or close to open areas of ground cover such as ovals, lawns, or golf courses. Perhaps having accessible, open areas around roost trees as a result of introduced ground cover vegetation (as well as limited obstruction of tree crown connectivity between trees) could also be a way for a greater number of cockatoos to find an appropriate branch on which to roost. A study by Perry et al. (2010) supports this idea of roost trees being chosen for the accessibility. They found that Silverhaired Bats *Lasionycteris noctivagans* typically roosted in taller, more exposed trees which they suggested may be because they are more easily accessible and allow clear areas for navigation by newly volant young. The roost sites of communal roosting birds such as the red-winged blackbird *Agelaius phoeniceus* and European starling have also been shown to roost in insular patches (rather than continuous expanses of forest), or low density tree stands that were adjacent to residential areas (Lyon and Caccamise 1981). The low density tree stands used by the red-winged blackbirds were also thinned and had little underbrush and were described by Lyon and Caccamise (1981) as having a park-like appearance with dense canopy cover. They suggested that ease in finding

the sites would be one of the advantages of the discrete roost vegetation patches (Lyon and Caccamise 1981).

Higher cockatoo counts could be related to increased ground cover because larger groups of birds are more likely to detect predators (Pulliam 1973), as well as locate clumped foraging resources (Rubenstein et al. 1977). Beauchamp (1999) proposed that communal roosting may occur more often as means of anti-predator benefits where roosting habitat was more exposed. Roost sites surrounded by more open, low vegetation, could expose cockatoos to threat from predation, thus a larger flock size of cockatoos may increase the likelihood of predator detectability. Wedge-tailed eagle *Aquilla audax* is an indigenous predator known to prey on Carnaby's Black-Cockatoo (Saunders, 1990). The introduced feral cat *Felis catus* and Fox *Vulpes vulpes* are also potential predators (Saunders and Dawson 2009). Low, open vegetation (non-native ground cover vegetation) might increase a cockatoo's visibility of potential predators because they would be easier to detect, particularly overnight, at dusk, and at dawn, since the vision of diurnal birds is not well adapted to low light (Lahti et al. 1997). However, Zahavi (1971) suggested that anti-predation benefits of communal roosts are secondary to social food-finding. Similarly, Ward and Zahavi (1973) suggested that communal roosts form primarily for the efficient exploitation of patchy-food supply (social food-finding), and act as information-centres, whereas anti-predator adaptations in roosts are secondary.

The sprawl of urban development (of which non-native ground cover vegetation is included) has resulted in extensive loss and fragmentation of *Banksia* woodland within the Swan Coastal Plain which has resulted in a patchy-food supply (Johnstone et al. 2011). In order to more easily find foraging sources (social-food finding), Carnaby's Black-Cockatoos may be found in greater numbers at roost sites where there is a larger area of ground cover; this is because low, non-native vegetation has replaced native vegetation, and thus has partly contributed to the surrounding patchy-food supply.

These explanations support the premise that urban pressure can be a contributing driver of roost count at and around the roost sites. This highlights the potential for large numbers of Carnaby's Black-Cockatoos to roost in trees that are surrounded by disturbed landscapes, provided other important landscape variables are also available particularly within a 1 and 6 km radius (such as potential roost trees, food and water resources). Urban pressure was not shown to be a driver of fidelity. Fidelity to the study roost sites was driven by a greater area of potential roost trees and roost sites surrounded by less urban infrastructure would suggest a

greater area of natural resources to an increased availability of roost trees and surrounding foraging habitat. Roost sites with less urban infrastructure may be provide more overnight roost trees in less disturbed areas, and a consistent supply of foraging habitat that is within close proximity to the roost site, thus reducing energy expenditure (Boyes and Perrin 2009, Berry and Owen 2010).

4.6.2 Food resources and water availability

Greater roost counts at the study sites were driven by food and water resources at the 1 and 6 km radius spatial scales (Table 4.3). These findings support Berry's (2008) observations of Carnaby's Black-Cockatoo roosting at sites within close proximity to known food and water sources. Energy expenditure could be reduced where they are able to feed and drink close to (within a 6 km radius around a roost site) roost sites before and after nocturnal roosting (Berry 2008). A greater area of *Banksia* and pine vegetation was associated with roost sites that had high cockatoo counts. This highlights the importance of *Banksia* and pine to large numbers of Carnaby's Black-Cockatoo that have used the high-count study sites. The importance of *Banksia* and pine as significant food sources has been established in a number of Carnaby's Black-Cockatoo related studies (Perry 1948, Mawson 1995, Valentine and Stock 2008, Finn et al. 2009, Johnston et al. 2016).

Banksia spp. are principal native food sources that possess nutrient rich seeds, as well as nectar and insects (Saunders 1980, Shah 2006, Valentine and Stock 2008, Johnston 2013). There are a variety of *Banksia* species on the Swan Coastal Plain that flower and reach fruit maturity at alternate times which therefore provides an important food source throughout the non-breeding season prior to migrating to breeding sites (Valentine and Stock 2008). Of all the vegetation variables, the area of *Banksia* vegetation was the greatest within a 6 km radius around the study roost sites (Figure 4.2.2). Carnaby's Black-Cockatoo roosting at the study sites would have *Banksia* vegetation available to them in greater quantities more than the other vegetation types (pine and non- native ground cover). The scale comparison of *Banksia* vegetation (when compared to the other vegetation types) results are complementary to the model outcomes and highlight the importance of *Banksia* vegetation within a 6 km radius around the study roost sites.

Non-native trees such as pine could be providing an alternative, consistent food source. Some non-native plant species, such as pine, have become a partial offset to the loss of *Banksia* vegetation as a food source (Stock et al. 2013, Groom et al. 2014). A study by Stock et al.

(2013) states that a high abundance of Carnaby's Black-Cockatoo have been found to feed on pine from February to June. The study showed peak feeding activity was reached in April to May when almost all pine cones had matured, and it is in this period of time that coincides with GCC survey counts (Stock et al. 2013). Carnaby's Black-Cockatoos have been observed to switch over from *Banksia* vegetation to pine (Stock et al. 2013), which increases their feeding opportunities around roost sites with high counts of cockatoos. It is also important to note that pine may have contributed more so to the food and water resources composite variable as a driver of roost count. This is because not all pine within the study area was included in the data extraction process (as noted in Chapter 4, old and inactive pine plantation remnants were not necessarily included in the mapping of the FPC pine data layer).

Water availability also contributed to the food and water resources composite variable as a driver of roost count in the 1 and 6 km spatial scales (Table 4.3). On average, there were more water bodies within a 1 km radius around the study roost sites (Figure 4.2.3). The literature supports the importance of drinking sources close to roost sites whereby Carnaby's Black-Cockatoo drink from nearby water sources pre and post-overnight roosting (Berry 2008, Groom et al. 2014). At the Como roost site, I have observed them drinking from the Collier Golf Course lake (Hayman Road side of the course) before roosting overnight in pine trees less than 200 m away. At the North Beach (Star Swamp), Menora, and Ballajura roost sites (roost sites from Chapter 1), I have seen them drinking from the Star Swamp wetland and artificial lakes in Ron Stone Park, and Ballajura Lions Oval (lake adjacent to the oval), prior to roosting in trees less than 200 m away. At the Dawesville site, a repeat GCC volunteer produced photographic evidence of, the Carnaby's Black-Cockatoo drinking from water baths that she has placed in her front garden. The closest roost tree to her garden was less than 100 m away. The model outcomes (Table 4.3) and the examples provided highlight the significance of reliable water sources close to nocturnal roost sites (within a 1 and 6 km radius of the central roost).

4.6.3 Potential roost trees

Based on the model outcomes, potential roost trees are at the core of roosting habitat (Table 4.3 and 4.4). The potential roost trees variable featured alongside both roost count and fidelity, within each of the spatial scales. There are a number of studies which have indicated that tall trees are generally preferred for nocturnal roosting by Carnaby's Black-Cockatoos, as

well as by other parrot species, which supports the moderate to strong positive effect of potential roost trees on roost count and fidelity (Figures 4.1.2-4.1.6) (Glossop et al. 2011, Johnstone et al. 2011, Groom et al. 2014, Jaggard et al. 2014). Potential roost trees are also likely to provide potential day roost trees between bouts of foraging.

The greater the area of potential roost trees (within a 1 km radius of the central roost) at a roost site, the greater the abundance of birds and roost fidelity by the birds. This may be because roost sites with a larger area of potential roost trees can provide more trees to roost within. A greater abundance of cockatoos occurred at study sites where a greater area of food and water resources was present, in combination with a greater area of potential roost trees. Although only measured within the 1 km radius buffer, the results of this study have shown the importance of tall vegetation on both roost count and fidelity within a 12 km radius around the study roost sites.

The most parsimonious models provide a snapshot as to which landscape variables were the strongest drivers of Carnaby's Black-Cockatoo roost count and fidelity in the month of the Great Cocky Count. The abundance and fidelity of Carnaby's Black-Cockatoo to nocturnal roost sites was influenced by landscape variables at a range of spatial scales from the site-level, through to the surrounding matrix. Similarly, the threatened Superb Parrot *Polytelis swainsonii* uses privately owned, often agriculturally productive land in areas of south-eastern Australia at multiple scales, from smaller scale activities, to wide-ranging seasonal movements (Manning et al. 2006b). The models also evidently show the importance of a variety of vegetation cover types (potential roost trees and *Banksia* and pine vegetation) at different scales around the roost matrix for roosting sites and foraging resources. This evidently highlights the need for conservation and maintenance of scattered trees or patches of vegetation around known roost sites, as well as across the Swan Coastal Plain.

Changes to the roost count and roost fidelity models may occur if they were based on surveys conducted at other times of the year, nevertheless the models from this study offer insights into which landscape variables could potentially drive cockatoo nocturnal roost abundance and fidelity, and at which scales the variables become drivers. Further insights to nocturnal roosting could be acquired by studying individual movements of species where satellite tracking is not possible (a study by Groom (2016) used satellite tracking to follow movements across the Swan Coastal Plain). A recent study by Usher et al. (2016) have described determined methods for identifying individual Carnaby's Black-Cockatoo by way of

natural variations in their markings. The methods could be included in future nocturnal roost research as an additional component to identify individual birds that show yearly fidelity to specific roost sites. A number of studies have found that some species of birds increased in abundance in heterogeneous landscapes, where fragmentation increased or where there were more patches of vegetation (McGarigal and McComb 1995, Trzcinski et al. 1999, Lee et al. 2002). Le Roux et al. (2015) have highlighted the importance of conserving scattered trees and preserving the complex mosaics within the landscape.

With increasing urbanisation on the Swan Coastal Plain, it is critical that we understand the interaction between Carnaby's Black-Cockatoo and the anthropogenic landscape. The outcomes of this study have provided an indication of the driving landscape variables behind roost count and roost fidelity, such as water, tall trees and foraging vegetation within close proximity to the central roost of the study sites. Management of this species needs to consider that every bit of vegetation, in the breeding and non-breeding habitat, whether it be large or small patches, native or non-native, be maintained and preserved in order to maintain and preserve the Carnaby's Black-Cockatoo population.

The results of this study indicate that a combination of landscape variables are able to support greater Carnaby's Black-Cockatoo roost site abundances and roost fidelity at multi-scales. Potential roost trees, and water and foraging sources within a 6 km radius of the roost, was a notable landscape variable combination. There was overlap of the 12 km radius of many of the study roost sites, across the Swan Coastal Plain, which highlights the importance of retaining, maintaining, and rehabilitating any remnant vegetation.

Chapter 5 – Synthesis

5.1 Introduction

Loss of habitat is the greatest factor contributing to the current worldwide species extinction event (Bibby 1994, Pimm and Raven 2000, Fahrig 2001, Thomas et al. 2004). A rapidly growing human population has resulted in the encroachment of human activities on natural areas (Sisk et al. 1994). Natural landscapes have been modified through clearing and fragmentation which poses a major threat to many species (Huxel and Hastings 1999). Some of the greatest challenges for urban dwelling birds are fragmentation and degradation of native habitat (Davis and Wilcox 2013). Their survival within the urban matrix may be dependent on factors such as the ability to utilize and/or move through it, their individual life history and ecology, and in particular, their degree of specialisation (Saunders 1986, Andren 1992, Davis and Wilcox 2013).

The majority of Western Australia's growing population is predicted to reside in and around Perth increasing from a population of 1.9 million in 2012 to between 4.4 million and 6.6 million by 2061 (Australian Bureau of Statistics n.d.). It can therefore be expected that housing and infrastructure on the Swan Coastal Plain will increase in density and extent (Groom et al. 2014). It has been estimated that over 90% of *Banksia* woodland within a 20 km radius of Perth has already been lost with the remaining *Banksia* woodland nominated as a Threatened Ecological Community based on the Commonwealth's Environment Protection and Biodiversity Conservation Act 1999 (Urban Bushland Council and Wildflower Society of Western Australia n.d.). Over-storey communities which include large trees have also been significantly reduced in extent and density due to urbanisation, and any remaining areas that include large trees not secured in conservation reserves are under threat from continual land clearing (Mitchell et al. 2002). The loss of *Banksia* woodland, as an important foraging source, and the reduction in large trees for roosting habitat on the Swan Coastal Plain are partly to blame for the reduction in range and numbers of Carnaby's Black-Cockatoos (Johnstone and Storr 1998, Higgins 1999). Although these and other anthropogenic impacts continue to be major threats to the Carnaby's Black-Cockatoo population, the species has nevertheless demonstrated its ability to adapt to modified and novel landscapes (Weerheim 2008, Groom et al. 2014). It is critical that management of the species identifies which are the most important components of their habitat, how much is required and at which spatial scales and range they are most essential.

5.2 The significance of nocturnal roost trees to Carnaby's Black-Cockatoo

The lack of information on communal roosting in parrot species of Western Australia provided an opportunity to understand the habits and habitat associated with communal roosting of an endangered species endemic to the south-west of WA. This study focused on Carnaby's Black-Cockatoo because it is endangered in the region and forms large nocturnal communal roosts in the non-breeding season throughout the Swan Coastal Plain. It is dependent on much of the urban area during non-breeding periods and has recently been recorded breeding in the Perth metropolitan region for the first time. For this reason, there was a pressing conservation need to understand the roosting requirements of this species. It was also an ideal model species to determine what characteristics or factors are associated with preferred (high roost count and high roost fidelity) study roost sites. The literature relating to roosting helped to provide an explanation as to why Carnaby's Black-Cockatoo roost nocturnally and why they might form large communal roosts.

The roost trees used by Carnaby's Black-Cockatoo in this study had a number of typical structural characteristics (Figure 5.1). The study roost trees on average were tall with a single, thick trunk. Whether the roost trees were in areas of human activity did not appear to be of significance to their utilisation. Some other parrot species such as Rainbow lorikeets form large communal roosts in urban areas potentially due to areas of human activity providing increased availability of water from artificial water sources, increased and diverse foraging sources, as well as decreased predation and easier detection of predators (Jaggard et al. 2014). Parklands and residential areas were likely to be popular choices for Carnaby's Black-Cockatoos for the same reasons. Mawson (1995) suggested that a foraging site was more attractive if there were large trees within close proximity for roosting. He supported this suggestion by noting Saunder's (1979) findings that Carnaby's Black-Cockatoo appeared to favour areas where they could fly into and out of trees that they could sit in before and after foraging. Mawson (1995) proposed that potential feeding sites may be unsuitable if there are a lack of nearby large trees, particularly in suburban areas and gardens. This further highlights the importance of retaining large trees in urbanised areas, especially considering the potential for undiscovered foraging habitat.
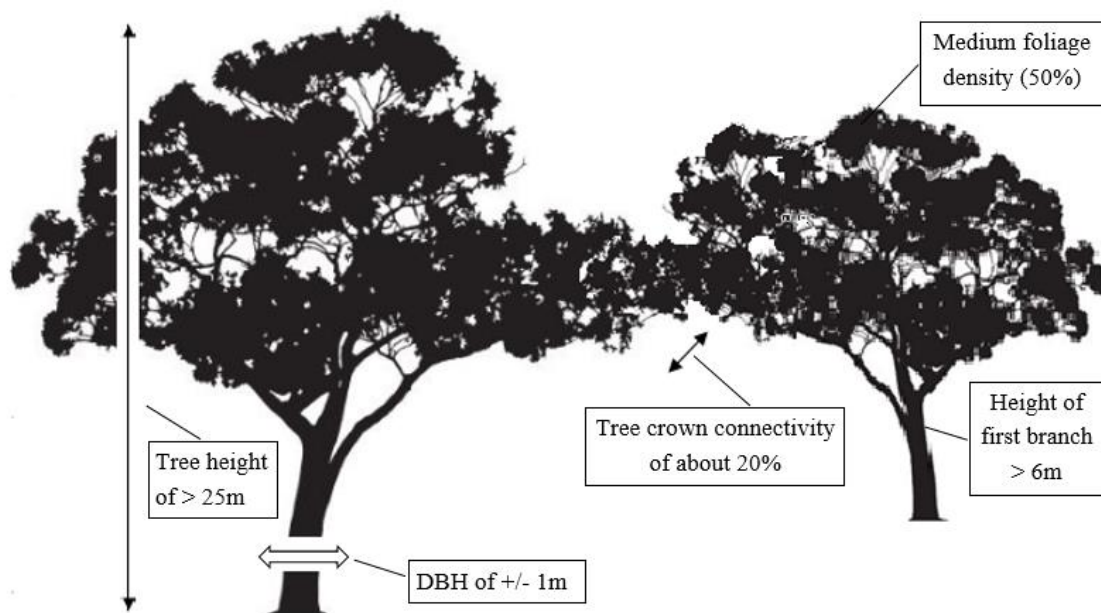
Figure 5.1 The basic characteristics of a preferred Carnaby's Black-Cockatoo nocturnal roost tree

Carnaby's Black-Cockatoo roosted in a variety of tree species rather than having a strong preference for one particular species; this was predicted based on other parrot species such as the Sulphur-Crested Cockatoo (Lindenmayer et al. 1996) and Meyer's parrot *Poicephalus meyeri*. The majority of the study trees used as roosts were Australian and WA native tree species including *C. citriodora* and *E. grandis*, with the WA native *E. gomphocephala* as the single most dominant tree species to be used for roosting. Despite ongoing harvesting operations, the introduced *P. pinaster* was also a favoured roost tree. All these species have been reported to be used as roost trees by Carnaby's Black-Cockatoo (Berry 2008, Groom 2011, Groom et al. 2016), which suggests that the birds are not selecting a small range of tree species but utilise what is available in the landscape. Eucalypt species are known to be favoured roost trees for Australian cockatoo species such as the Red-tailed Black-Cockatoo (Joseph et al. 1991), the Glossy Black-Cockatoo (Chapman and Paton 2005) and the Sulphur-Crested Cockatoo (Lindenmayer et al. 1996). A feature of *Corymbia* and Eucalypt tree species is their structure and ability to grow to very tall heights which may be why they are selected as roost trees for cockatoos Australia-wide.

Not only do mature pine, *Corymbia* and Eucalypt species provide roost sites, but they have the additional advantage of providing food for the cockatoos (Groom 2011, Stock et al. 2013). *Eucalyptus* spp. flower more frequently and more profusely in urban regions than in

natural forest areas which could potentially increase foraging advantages if roosting in urban environments (Davis 2013). Pine cone seeds are an easily acquired source of energy compared with the effort required to consume *Banksia* cones (Finn et al. 2009, Stock et al. 2013). In recent years, Carnaby's Black-Cockatoo have been found nesting in natural hollows of mature trees on the Swan Coastal Plain (Johnstone and Cassarchis 2005) with sites found in densely populated areas such as Joondalup (personal observation 2015, 2016). With the shifting distribution of the species, large, mature trees are becoming increasingly critical as roosts and breeding sites for Carnaby's Black-Cockatoo on the Swan Coastal Plain.

Large, mature trees are at risk of damage or removal by land clearing for urban development, agriculture and forestry industries (Saunders 1990, Gole 2006, Brunner and Cozens 2012). Patches of mature trees as well as individual trees in urban environments are also vulnerable to the effects of disturbances and fragmentation which can lead to altered fire regimes, nutrient flows, fungal pathogens, water availability, weed invasion, insect pests and stress (Manion 1991, Pouyat et al. 1995, Ruthrof et al. 2003, Crosli et al. 2007, Cahill et al. 2008, Wentzel 2010). These factors can contribute to gradual loss of vigour and decreased resistance which can lead to eventual mortality (Christie and Hochuli 2005, Wentzel 2010). Tuarts, a popular roost tree in this study, are particularly susceptible to these issues (Edwards 2004, Taylor et al. 2009, Wentzel 2010).

Many roost sites on the Swan Coastal Plain include only pine trees, usually as part of plantations, and can attract thousands of Carnaby's Black-Cockatoo for overnight roosting and food (Stock et al. 2013, Byrne et al. 2015). However mature pines are subject to clearing by 2020 under the State Government's "Perth and Peel Green Growth Plan" (Government of WA 2015, Peck et al. 2016). The loss of large portions of pine plantations and large Eucalypt species on the Swan Coastal Plain places extreme pressure on Carnaby's Black-Cockatoo because the replacement of roosting, foraging and even suitable nesting habitat will be too slow to sustain the current population. Although a single tree can provide a roost for dozens of birds (Higgins 1999), the concern is that the consistent removal of suitable roost trees will put pressure on the locations that Carnaby's Black-Cockatoo are able to roost. This would place stress on the population if preferred roost trees are removed from well-favoured roost sites because it is likely that such roost sites are chosen because of their close proximity to water and food sources (Berry 2008, Lowry and Lill 2008b, Groom et al. 2014, 2016).

A study by Groom et al. (2016) in which Carnaby's Black-Cockatoo were tracked using satellites revealed that there is connectivity within a network of nocturnal roost sites on the Swan Coastal Plain, particularly around the greater metro area. Study birds were found to move between these roosts over consecutive nights with the birds spending 66% of the study period (565 of 854 nights) at key roosts (Groom et al. 2016). This emphasises the importance of roost trees scattered throughout the Swan Coastal Plain because Carnaby's Black-Cockatoo are using a variety of locations as roost sites which may be driven by food resource availability. The study indicated that study birds travelled across the Swan Coastal Plain and reached roost sites outside of a 12 km roost site radius (which is considered the critical foraging distance based on Saunders and Ingram's (1987) nesting to foraging distance findings). The findings from Groom et al. (2016) highlight the species' mobility and that resources are used over great distances. Consequently, a spatial analysis using a 12 km radius around any roost site may not be taking into consideration enough of the landscape used by Carnaby's Black-Cockatoo. Groom et al. (2016) did however consider that the foraging areas (likely to drive roost use) used around roosts varied greatly in composition and size, and for this reason they recognised the importance of identifying key roosts and their surrounding habitat.

5.3 The significance of Carnaby's Black-Cockatoo nocturnal roost sites and the surrounding matrix

There are an increasing number of studies that have researched the influence of environmental predictor variables on abundance and landscape use by mammals and birds, and many have also looked at which spatial scales the landscape variables influence population sizes and persistence (Barbaro, Couzi, Bretagnolle, Nezan, & Vetillard, 2008; Hostetler & Holling, 2000; Lindenmayer, 2000; Manning, Lindenmayer, Barry, & Nix, 2006). There have been no studies to determine which of the landscape variables influence the abundance and fidelity of Carnaby's Black-Cockatoo to nocturnal roost sites on the Swan Coastal Plain. The models (based on Akaike Information Criterion) investigating landscape variables associated with this study cockatoo abundance and roost fidelity varied with scale (Chapter 4). The nocturnal roost study sites had greater fidelity and numbers of cockatoos with a combination of landscape variables at different scales, which are based on habitat structure, food availability and water availability. The models (Tables 4.3 and 4.4, Chapter 4) highlighted that:

- urban pressure played a role in driving roost count (within 12 km radius) potentially due to the advantages of forming food sourcing flocks in more fragmented landscapes. Roost sites that have more urban structures such as roads and non-native ground cover could also offer roost tree and roost site accessibility as well as predator avoidance and/or detection;

- roost count and roost fidelity increased if the study sites had a greater area of foraging and drinking sources within a 6 km radius. *Banksia* vegetation was a particularly prominent variable within the 6 km radius of a roost site (Figure 4.2.2). Pine within the 6 km radius was likely to be an additional source of food where *Banksia* food sources became depleted. A great number of water bodies within a 1 and 6 km radius also contributed to driving roost count and roost fidelity, and;

- a greater area of potential roost trees within a 1 km radius and within the greater landscape (up to 12 km radius).

Understanding the relationship between animal and bird species and their habitat requirements provides insights into habitat features, at different temporal and spatial scales, that may attract threatened species to cities (Savard et al. 2000, Fernández-Juricic and Jokimäki 2001). Consideration of the factors that influence the occurrence of birds in urban environments can assist with the management of species within the urban landscape (Fernández-Juricic and Jokimäki 2001). The interactions and distributions of animal species are strongly influenced by vegetation assemblages which determine the physical structure of the environment (Bell et al. 1991). In the case of Carnaby's Black-Cockatoo, certain variables related to habitat structure influence the abundance and fidelity to nocturnal roost sites. Different species can be dependent on the presence of a single 'keystone structure' within an ecosystem (Tews et al. 2004). Manning et al. (2006) argued that scattered trees within disturbed landscapes are keystone structures because they contribute to ecosystem functioning and provide a benefit which is disproportionately large considering the small area they occupy, the low biomass of individual trees, and the low density of scattered trees. Many species, including birds, depend on scattered trees for nesting sites, as a food resource, and for shelter (Tews et al. 2004). For Carnaby's Black-Cockatoo, tall trees are the keystone structure of their roosting habitat, as well as the surrounding landscape. In terms of potential roost tree habitat, a greater area of tall vegetation ($\geq$ 8m potential roost trees), within a 1 km radius surrounding the roost, was an important driver of cockatoo abundance and roost fidelity at all scales (Tables 4.3 and 4.4, and Figures 4.1.2-4.1.6, Chapter 4). This highlights the importance of tall trees, and that where there is a greater number of tall trees, more suitable roosting habitat is available to a greater number of cockatoos.

Lindenmayer et al. (1996) suggested that a larger number of Sulphur-Crested Cockatoos were observed at roost sites where there were more of their preferred Eucalypt roost tree species. As well as suitable tall trees, there are other driving factors at the landscape scale that attract Carnaby's Black-Cockatoo to the habitat structure of nocturnal roost sites.

The model outcomes in this study (Chapter 4) indicated that Carnaby's Black-Cockatoo have adapted to the modified landscapes of the Swan Coastal Plain. An example of a habitat structure variable associated with modified landscapes was non-native ground cover or green open spaces, which were linked to high abundances within a 12 km radius around the study sites (Table 4.3, Chapter 4). Roost sites that are surrounded by low ground cover vegetation have some advantages such as: greater accessibility and navigation into and out of roost trees and roost sites that are discreet, open patches (Lyon and Caccamise 1981, Perry et al. 2010), and; increased visibility of predators and reduced predation pressure. Peh and Sodhi (2002) suggested that highly disturbed areas may provide protection from predators because they avoid areas of human activity.

The urban pressure variables were somewhat drivers of roost abundance, however, this is more likely to be partly coincidental rather than necessarily a preferential component of a roost site. It is more likely that the roost trees themselves are located in suitable locations that are close to water and foraging sites. Larger flocks of Carnaby's Black-Cockatoo may congregate at the more urbanised nocturnal roost sites to gain information on where foraging sites are the following day. The chances of finding foraging sites are increased in patchy fragmented landscapes where there are more individuals in a searching flock (Ward and Zahavi 1973, Legault et al. 2012).

The urban environment of the Swan Coastal Plain offers Carnaby's Black-Cockatoo benefits such as reliable water sources (Berry 2008, Groom et al. 2014), exotic food or supplementary food sources when remnant vegetation food sources are in short supply (Stock et al. 2013, Groom et al. 2014, Jaggard et al. 2014). In terms of food availability, the models constructed in this study indicated that: more cockatoos were attracted to sites that had a greater area of *Banksia* vegetation associated with their roost sites within a 6 km radius, and; where there was a greater area of *Banksia* vegetation within a 1 km radius there was higher roost fidelity (Table 4.3 and 4.4, and Figure 4.2.2, Chapter 4). It is possible that the *Banksia* vegetation is of mature age in some urban sites and thus could be providing more inflorescences, cones and even larvae (seed-eating weevil *Alphitopis nivea* found in young

infructescences (fruits) of *Banksia attenuata* trees (Scott and Black 1981)). Furthermore, there may also be a concentration of fire suppression resources and fragmented fuel loads in urban environments (resulting in lower fire frequencies at high population densities) (Syphard et al. 2009), as well as lack of prescribed fires of *Banksia* stands within close proximity to nocturnal roost sites may also be possible.

Carnaby's Black-Cockatoo depends on *Banksia* species found within *Banksia* heaths and woodlands throughout the Swan Coastal Plain, however they have had to broaden their daily search for alternative food sources throughout the landscape due to the extensive development of areas supporting these vegetation types (Saunders 1980, Valentine and Stock 2008, Groom et al. 2016, Johnston et al. 2016). Carnaby's Black-Cockatoo are known to feed on, and roost in, a variety of non-native species including pine (Berry & Owen, 2010; Groom, Mawson, Roberts, & Mitchell, 2014; Jackson et al., 2008; Perry, 1948; Valentine & Stock, 2008) and as such it appears that this cockatoo has become partly dependent on a combination of native and non-native vegetation throughout the Swan Coastal Plain.

Roost sites can act as information centres which can aid in finding food sources more efficiently in a landscape with patchy food supply. The communal roosting behaviour which occurs at nocturnal roost sites can be an aid for information exchange whereby those birds that have found foraging sites on previous days could possibly recruit less experienced or searching members to known foraging sites and thus reduce energy costs the following day (Ward and Zahavi 1973). The greater the number of cockatoos at a roost site, the greater the chance of finding foraging vegetation when moving across the landscape particularly when food sources close to nocturnal roost sites become scarce.

As the surrounding *Banksia* vegetation becomes exploited by the cockatoos, they are then able to move across the landscape in search of native or non- native alternative sources, as they become seasonally available or where they are in abundance (Saunders 1980, Stock et al. 2013, Groom et al. 2014, Jaggard et al. 2014). For this reason it is critical that Carnaby's Black-Cockatoo foraging and roosting vegetation is retained, maintained, rehabilitated and restored throughout the Swan Coastal Plain in order to sustain the current and future populations of Carnaby's Black-Cockatoo. Considering the models from this study highlighted a number of structural and landscape components associated with them, it is therefore important to ensure that the essential roosting habitat components, such as tall trees and foraging vegetation are protected from disturbance or removal.

It is also likely that preferred roost sites are chosen because they are within close proximity to water sources which are critical for Carnaby's Black-Cockatoo, particularly in the dry season (Berry 2008, Groom et al. 2014). Urban roost sites have the advantage of artificial water sources (Berry 2008, Groom et al. 2014) and based on the models produced in this study, water is a strong driver of fidelity at the central roost scale (1 km radius) (Figures 4.1.2, Chapter 4) and less important at the larger scales. The need for water sources in close proximity to roost sites has been noted by other studies. Berry (2008) has observed Carnaby's Black-Cockatoo drinking from gravestone vases in a cemetery every evening apporximately 1 km away from the Hollywood roost site. Reliable water sources within close proximity to roost sites could be a means of extending foraging time during the daylight hours. If so, then the cockatoos would have little need to search for drinking sources before or after roosting over-night because reliable drinking sources are likely to be associated with the well-used roost sites.

5.4 Recommendations for management of Carnaby's Black-Cockatoo habitat

It is recommended that the findings of this study be used as a guideline for management and protection of Carnaby's Black-Cockatoo. Local governments should be made aware of the importance of roosting sites and their surrounding matrices, and that even a 12 km radius around roost sites may not be considering all the resources required by the cockatoo (Groom et al. 2016). At the very least, large, mature trees such as Tuarts should be conserved throughout the urban landscapes of the Swan Coastal Plain. *Banksia* vegetation needs to be protected and managed, particularly as it is susceptible to disease, fire, disturbance and removal as result of development. *Banksia* vegetation in urban environments should be assessed before prescribed fires are carried out since managers will need to consider the time it will take for the vegetation to return to peak post-burn production (Johnston et al. 2016).

Educating policy makers and the public can further assist in conserving the species through urban revegetation and rehabilitation programmes (Groom et al. 2014). The Great Cocky Count has been a good example of a means of community education and involvement. This citizen science project has created not only a greater awareness of the cockatoos themselves, but also the habitats that they utilise. Local governments should also encourage the community to retain and plant cockatoo roosting and foraging plant species, as well as provide water baths.

There needs to be a clear understanding that all Carnaby's Black-Cockatoo habitat is essential to sustain the current and future population. The Great Cocky Count (Peck et al. 2016) trend analysis of roost counts for Carnaby's Black-Cockatoo (2010 - 2016) has found that the species is currently estimated to be in decline at a rate of 13.8 % per year. Removal or disturbance of any potential roosting or foraging habitat will ultimately affect the current population. It is therefore recommended that keystone components of roosting (tall tree species) and foraging habitat (intact, unburnt *Banksia* woodland and other non-native tree species such as pine within a 6 km radius) be stringently protected. Biodiversity offsets do not offer a compromise, as the removal of any current native vegetation on the Swan Coastal Plain is removal of essential foraging or roosting habitat. More than ever, loss of habitat on the Swan Coastal Plain is concerning considering that breeding has been observed within this bioregion. Any increase in nesting on the Swan Coastal Plain would result in roosting and foraging habitat becoming more critical in the breeding season.

5.5 Future Research

The results of this study have provided typical structural characteristics of Carnaby's Black-Cockatoo roost trees and roost sites. Other noteworthy characteristics to consider in future studies of Carnaby's Black-Cockatoo roost habitat are: the size of the matrix; the health or condition of the roost tree and surrounds; the bird's position in the roost tree; the number of birds per roost tree, and; a comparison between roost trees and non-roost trees (if one can establish that a tree is not a roost tree or a potential roost tree). Many of the roost trees in this study may also provide sources of food; therefore, it would be of significance/great interest to determine whether Carnaby's Black-Cockatoos often feed on the trees they roost in. Additionally, if possible, identifying if individual Carnaby's Black-Cockatoos return to the same roost tree would determine whether individuals have traditional roost trees within roost sites. In order to further understand Carnaby's Black-Cockatoo habitat usage within urban landscapes, future studies could also investigate the use of roosting habitat in relation to breeding habitat on the Swan Coastal Plain during the breeding season. Confirmed nesting sites on the Swan Coastal Plain could also provide further protection of roosting and foraging habitat in these areas because artificial hollows can be installed in roosting or foraging trees.

5.6 Conclusion

Although Carnaby's Black-Cockatoo has adapted to modified landscapes and urban environments, this should not imply that the species will overcome all associated urban pressures. The ongoing loss of native vegetation across the Swan Coastal Plain poses the single greatest threat to the continued persistence of Carnaby's Black Cockatoo. Nocturnal roost sites are an integral component of the ecology and habitat of the species. Although Carnaby's Black-Cockatoo are able to use a network of roost sites, they are nevertheless using a variety of roost sites based on resource availability around those locations (Groom et al. 2016). If key nocturnal roost sites and the associated habitat are disturbed or lost, Carnaby's Black-Cockatoo would be forced to seek alternative roost sites. Alternative roost sites may not provide advantageous landscape characteristics associated with current roost sites. If for some reason their preferred roost locations are disturbed or destroyed, they may be forced to use alternative roost locations; this could place further stress on the population considering there may be greater distances between roost sites and their water and foraging supplies compared to preferred locations. Large, mature trees cannot be replaced once removed as it can take centuries for them to be restored (Lindenmayer et al. 2014). It is critical that Carnaby's Black-Cockatoo roost sites and their surrounding matrix, particularly those that are traditionally used, are taken into careful consideration before trees are developed around, disturbed, damaged or removed on the Swan Coastal Plain.

This study identified some of the most important components associated with roost sites at multi-scales, such as: large, mature trees at the central roost, and; reliable drinking sources and large areas of *Banksia* and pine vegetation within a 6 km radius of any roost site. The main results of the study highlighted the importance of tall tree species with relatively thick trunks and medium foliage density, and which are not too densely forested amongst other trees. A 1 km area of potential roost trees (tall trees) was important within the greater landscape (across all spatial scales) and low vegetation may be playing a role (within a 1 km radius) in roost tree and roost site accessibility as well as predator avoidance and/or detection. Urban structures such as roads and non-native ground cover vegetation has led to fragmented and patchy food supply and could be resulting in greater cockatoo abundances at roost sites. There should be careful consideration when further developing around roost sites or across the Swan Coastal Plain. Pine and other non-native trees are an additional source of food further from the central roost especially considering that Carnaby's Black-Cockatoo may be forced to move away from *Banksia* food sources which have become depleted close to their roost sites. Understanding the

importance of the various multi-scaled landscape components of a roost site will aid in the management and protection of roosting, foraging and potential nesting habitat on the Swan Coastal Plain, thus ensuring greater odds of survival for this endangered and iconic species into the future.

References

Aguilar, R., L. Ashworth, L. Galetto, and M. A. Aizen. 2006. Plant Reproductive Susceptibility to Habitat Fragmentation: Review and Synthesis Through a Meta-Analysis. Ecology Letters 9:968.

Amlaner Jr, C. J., and N. J. Ball. 1983. A synthesis of sleep in wild birds. Behaviour 87:85–119.

Andren, H. 1992. Corvid density and nest predation in relation to forest fragmentation: a landscape perspective. Ecology 73:794–804.

Antczak, M. 2010. Winter nocturnal roost selection by a solitary passerine bird, the Great Grey Shrike Lanius excubitor. *Ornis Fennica* 87:99–105.

Antongiovanni, M., and J. P. Metzger. 2005. Influence of matrix habitats on the occurrence of insectivorous bird species in Amazonian forest fragments. Biological Conservation 122:441–451.

Arora, M. P., and C. Kanta. 2009. Animal Behaviour. Himalaya Publishing House, Mumbai, IND.

Australian Bureau of Statistics. (n.d.). Population Projections, Australia 2012 (base) to 2101.

Baker, M. C. 2000. Cultural diversification in the flight call of the ringneck parrot in Western Australia. The Condor 102:905–910.

Bates, B. C., P. Hope, B. Ryan, I. Smith, and S. Charles. 2008. Key findings from the Indian Ocean Climate Initiative and their impact on policy development in Australia. Climatic Change 89:339–354.

Beard, J. S. 1984. Biogeography of the Kwongan. Pages 1–26*in* J. S. Pate and J. S. Beard, editors.Kwongan plant life of the sandplain. University of Western Australia Press: Nedlands.

Beauchamp, G. 1999. The evolution of communal roosting in birds: origin and secondary losses. Behavioral Ecology 10:675–687.

Bell, S., E. McCoy, and H. Mushinsky. 1991. Habitat Structure: The Physical Arrangement of Objects in Space. Pages 3–27*in* S. S. Bell, E. D. McCoy, and H. R. Mushinsky, editors.Chapman and Hall, London.

Benítez-López, A., R. Alkemade, and P. A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biological Conservation 143:1307–1316.

Berry, P. F. 2008. Counts of Carnaby's Cockatoo (*Calyptorhynchus latirostris*) and records of flock composition at an overnight roosting site in metropolitan Perth. Western Australian Naturalist 26:1.

Berry, P. F., and M. Owen. 2010. Additional counts and records of flock composition of Carnaby's Cockatoo (*Calyptorhynchus latirostris*) at two overnight roosting sites in metropolitan Perth. Western Australian Naturalist 27:27–38.

Bibby, C. 1994. Recent past and Future Extinctions in Birds. Transactions of the Royal Society of London B: Biological Sciences 344:35–40.

Bijleveld, A. I., M. Egas, J. A. Van Gils, and T. Piersma. 2010. Beyond the information centre hypothesis: communal roosting for information on food, predators, travel companions and mates? Oikos 119:277–285.

BirdLife International. 2013. *Zanda latirostris*. The IUCN Red List of Threatened Species. Version 2014.2.

Boeker, E. L., and V. E. Scott. 1969. Roost tree characteristics for Merriam's turkey. The Journal of Wildlife Management 33:121–124.

Boland, D. J., and M. W. McDonald. 2006. Forest Trees of Australia. CSIRO Publishing.

Bollen, K. A. 1989. Structural equations with latent variables. Wiley, New York.

Boyes, R. S., and M. R. Perrin. 2009. Flocking Dynamics and Roosting Behaviour of Meyer's Parrot (*Poicephalus meyeri*) in the Okavango Delta, Botswana. African Zoology 44:181–193.

Bozdogan, H. 1987. Model selection and Akaike's Information Criterion (AIC): The general theory and its analytical extensions. Psychometrika 52:345–370.

Brawn, T. P., H. C. Nusbaum, and D. Margoliash. 2010. Sleep-Dependent Consolidation of Auditory Discrimination Learning in Adult Starlings. The Journal of Neuroscience 30:609–613.

Brawn, T. P., H. C. Nusbaum, and D. Margoliash. 2013. Sleep Consolidation of Interfering Auditory Memories in Starlings. Psychological Science 24:439–447.

Brereton, J. L. 1971. A self-regulation to density-independent continuum in Australian parrots, and its implication for ecological management. Pages 207–221 *in* E. Duffey and A. S. Watt, editors.The Scientific Management of Animal and Plant Communities for Conservation. Blackwell, Oxford, UK.

Brunner, J., and P. Cozens. 2012. "Where Have All the Trees Gone?" Urban Consolidation and the Demise of Urban Vegetation: A Case Study from Western Australia. Planning

Practice and Research 28:1–25.

Burgin, S., and T. Saunders. 2007. Parrots of the Sydney region: population changes over 100 years. The Royal Zoological Society of New South Wales, Mosman, New South Wales, Australia.

Burnham, K. P., and D. R. Anderson. 2001. Kullback-Leibler information as a basis for strong inference in ecological studies. Wildlife Research 28:111–119.

Burnham, K. P., and D. R. Anderson. 2003. Model selection and multimodal inference: a practical information-theoretic approach. Springer Science & Business Media, New York.

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference understanding AIC and BIC in model selection. Sociological methods & research 33:261–304.

Burrough, P. A. 1986. Principles of geographical information systems for land resources assessment. Clarendon, Oxford.

Byrne, M., G. Barrett, M. Blythman, H. Finn, and M. Williams. 2015. The 2015 Great Cocky Count: a community-based survey for Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) and Forest Red-tailed Black-Cockatoo (*Calyptorhynchus banksii naso*). BirdLife Australia, Floreat, Western Australia.

Caccamise, D. F. 1991. European starling fidelity to diurnal activity centers: role of foraging substrate quality. The Wilson Bulletin:13–24.

Caccamise, D. F., L. A. Lyon, and J. Fischl. 1983. Seasonal patterns in roosting flocks of starlings and common grackles. Condor:474–481.

Caccamise, D. F., and D. W. Morrison. 1986. Avian communal roosting: implications of diurnal activity centers. American Naturalist:191–198.

Caccetta, P., S. Collings, A. Devereux, K. Hingee, D. McFarlane, A. Traylen, X. Wu, and Z. Zhou. 2012. Urban Monitor: Enabling effective monitoring and management of urban and coastal environments using digital aerial photography; Final Report –Transformation of aerial photography into digital raster information product. CSIRO, Australia.

Cahill, D., J. Rookes, B. Wilson, L. Gibson, and K. Mcdougall. 2008. Phytophthora cinnamomi and Australia's biodiversity: impacts, predictions and progress towards control. Australian Journal of Botany:279–310.

Cale, B. 2003. Carnaby's Black Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan, 2002-2012. Department of Conservation & Land Management.

Cannon, C. E. 1984. Flock size of feeding Eastern and Pale-headed rosellas (*Aves:*

Psittaciformes). Wildlife Research 11:349–355.

Casagrande, D. G., and S. R. Beissinger. 1997. Evaluation of four methods for estimating parrot population size. Condor:445–457.

Cavanaugh, J. E. 1997. Unifying the derivations for the Akaike and corrected Akaike information criteria. Statistics and Probability Letters 33:201–208.

Centre for Plant Biodiversity Research (Canberra) and A. V. Slee. 2006. EUCLID eucalypts of Australia. CSIRO Publishing.

Chapman, C. A., L. J. Chapman, and L. Lefebvre. 1989. Variability in parrot flock size: possible functions of communal roosts. Condor:842–847.

Chapman, T. F., and D. C. Paton. 2005. The glossy black-cockatoo (*Calyptorhynchus lathami halmaturinus*) spends little time and energy foraging on Kangaroo Island, South Australia. Australian Journal of Zoology 53:177–183.

Christie, F. J., and D. F. Hochuli. 2005. Elevated levels of herbivory in urban landscapes: Are declines in tree health more than an edge effect? Ecology and Society 10:10.

Clergeau, P. 1990. Flocking behaviour of Starlings (*Sturnus vulgaris*) during the day: a gradual gathering to the roost. Journal für Ornithologie 131:458–460.

Clergeau, P., and F. Quenot. 2007. Roost selection flexibility of European starlings aids invasion of urban landscape. Landscape and Urban Planning 80:56–62.

Cody, M. L. 1985. Habitat Selection in Birds. Academic Press, Orlando.

Conklin, J. R., and M. A. Colwell. 2007. Diurnal and nocturnal roost site fidelity of Dunlin (*Calidris alpina pacifica*) at Humboldt Bay, California. The Auk 124:677–689.

Cougill, S., and S. J. Marsden. 2004. Variability in roost size in an Amazona parrot: implications for roost monitoring. Journal of Field Ornithology 75:67–73.

Crook, J. H. 1964. The adaptive significance of avian social organisations. Animal Behaviour 12:393.

Crosli, R., K. W. Dixon, P. C. Ladd, and C. J. Yates. 2007. Changes in the structure and species dominance in vegetation over 60 years in an urban bushland remnant. Pacific Conservation Biology 13:158–170.

CSIRO, and Bureau of Meteorology. 2014. State of the climate 2014. CSIRO and Bureau of Meteorology.

Cubaynes, S., C. Doutrelant, A. Grégoire, P. Perret, B. Faivre, and O. Gimenez. 2012. Testing

hypotheses in evolutionary ecology with imperfect detection: capture–recapture structural equation modeling. Ecology 93:248–255.

Dall, S. R. X. 2002. Can information sharing explain recruitment to food from communal roosts? Behavioral Ecology 13:42–51.

Davies, N. B., J. R. Krebs, and S. A. West. 2012. An introduction to behavioural ecology. John Wiley & Sons.

Davis, A. 2013. Habitat and resource utilisation by an urban parrot community. University of Sydney.

Davis, A., C. E. Taylor, and R. E. Major. 2011. Do fire and rainfall drive spatial and temporal population shifts in parrots? A case study using urban parrot populations. Landscape and Urban Planning 100:295–301.

Davis, R. A., and J. A. Wilcox. 2013. Adapting to suburbia: bird ecology on an urbanbushland interface in Perth, Western Australia. Pacific Conservation Biology 19:110–120.

Department of Conservation and Land Management, Ecoscape, and Tuart Response Group. 2003. An atlas of tuart woodlands on the Swan Coastal Plain in Western Australia. Department of Conservation and Land Management, Perth, Australia.

Department of Parks and Wildlife. 2013. Carnaby's Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan. Perth, Western Australia.

Dickinson, J. L., B. Zuckerberg, and D. N. Bonter. 2010. Citizen science as an ecological research tool: challenges and benefits. Annual review of ecology, evolution, and systematics 41:149–172.

Edwards, T. A. 2004. Environmental correlates and associations of tuart (*Eucalyptus gomphocephala*) decline. Masters Thesis, Edith Cowan University, Perth, Australia.

Everding, S. E., and D. N. Jones. 2006. Communal roosting in a suburban population of Torresian crows (*Corvus orru*). Landscape and Urban Planning 74:21–33.

Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100:65–74.

Fernandes, P. M., and E. Rigolot. 2007. The fire ecology and management of maritime pine (Pinus pinaster Ait.). Forest Ecology and Management 241:1–13.

Fernández-Juricic, E., and J. Jokimäki. 2001. A habitat island approach to conserving birds in urban landscapes: Case studies from southern and northern Europe. Biodiversity and Conservation 10:2023–2043.

Ferrier, S., M. Drielsma, G. Manion, and G. Watson. 2002. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. II. Community-level modelling. Biodiversity & Conservation 11:2309–2338.

Finn, H., G. Barrett, C. Groom, M. Blythman, and M. Williams. 2014. The 2014 Great Cocky Count: a community-based survey for Carnaby's Black-Cockatoos (*Calyptorhynchus latirostris*) and Forest Red-tailed Black-Cockatoos (*Calyptorhynchus banksii naso*). Birdlife Australia, Perth, Western Australia.

Finn, H., W. Stock, and L. E. Valentine. 2009. Pines and the ecology of Carnaby's Black-Cockatoos (*Calyptorhynchus latirostris*) in the Gnangara Sustainability Strategy study area.

Ford, H. A., G. W. Barrett, D. A. Saunders, and H. F. Recher. 2001. Why have birds in the woodlands of Southern Australia declined? Biological Conservation 97:71–88.

Garroway, C. J., and H. G. Broders. 2008. Day roost characteristics of northern long-eared bats (*Myotis septentrionalis*) in relation to female reproductive status. Ecoscience 15:89–93.

Gentilli, J., and R. W. Fairbridge. 1951. The Physiographic Regions of Australia. University of Western Australia.

Gibson, N., G. Keighery, and B. Keighery. 2000. Threatened plant communities of Western Australia. 1. The ironstone communities of the Swan and Scott Coastal Plains. Journal of the Royal Society of Western Australia 83:1–11.

Glossop, B., K. Clarke, D. Mitchell, and G. Barrett. 2011. Methods for mapping of Carnaby's cockatoo habitat. Department of Environment and Conservation. Perth, Australia.

Gole, C. 2006. The southwest Australia ecoregion: jewel of the Australian continent. Southwest Australia Ecoregion Initiative.

Gorenzel, W. P., and T. P. Salmon. 1995. Characteristics of American Crow Urban Roosts in California. The Journal of Wildlife Management 59:638–645.

Government of WA. 2015. Perth and Peel Green Growth Plan for 3.5 million Strategic Assessment of the Perth and Peel Regions Draft Action Plan E: Harvesting of pines and post-harvesting land use. Government of Western Australia, Perth, Australia.

Grace, J. B., T. M. Anderson, H. Olff, and S. M. Scheiner. 2010. On the specification of structural equation models for ecological systems. Ecological Monographs 80:67–87.

Grace, J. B., and B. H. Pugesek. 1997. A Structural Equation Model of Plant Species Richness and Its Application to a Coastal Wetland. The American Naturalist 149:436–460.

Groom, C. 2011. Plants Used by Carnaby's Black Cockatoo. Department of Environment and Conservation, Perth, Western Australia.

Groom, C., P. R. Mawson, J. D. Roberts, and N. J. Mitchell. 2014. Meeting an expanding human population's needs whilst conserving a threatened parrot species in an urban environment. Transactions on Ecology and the Environment.

Groom, C., N. E. White, N. Mitchell, D. J. Roberts, and P. Mawson. 2016. Assessing the spatial ecology and resource use of a mobile and endangered species in an urbanized landscape using satellite telemetry and DNA faecal metabarcoding. Ibis.

de Gruyter, W. 2011. Concise Encyclopedia Biology. Walter de Gruyter, Tubingen, DEU.

Hahn, M. B., J. H. Epstein, E. S. Gurley, M. S. Islam, S. P. Luby, P. Daszak, and J. A. Patz. 2014. Roosting behaviour and habitat selection of Pteropus giganteus reveal potential links to Nipah virus epidemiology. Journal of Applied Ecology 51:376–387.

Hamilton, W. D. 1971. Geometry for the selfish herd. Journal of theoretical Biology 31:295–311.

Haslett, J. R. 1990. Geographic information systems. A new approach to habitat definition and the study of distributions. Trends in Ecology and Evolution 5:214–218.

Higgins, P. J. 1999. Handbook of Australian, New Zealand and Antarctic birds; volume 4. Oxford University Press.

Hobbs, R. J., E. S. Higgs, and C. Hall. 2013. Novel ecosystems: intervening in the new ecological world order. John Wiley & Sons.

Hobbs, R. J., and A. J. M. Hopkins. 1991. The role of conservation corridors in a changing climate. Nature Conservation 2:281–290.

Hobbs, R. J., and C. J. Yates. 2003. Impacts of ecosystem fragmentation on plant populations: generalising the idiosyncratic. Australian Journal of Botany 51:471–488.

How, R. A., and J. Dell. 2000. Ground Vertebrate Fauna of Perth's Vegetation Remnants: Impact of 170 Years of Urbanization. Pacific Conservation Biology 6:198–217.

Huxel, G. R., and A. Hastings. 1999. Habitat loss, fragmentation, and restoration. Restoration Ecology 7:309–315.

Jackson, C., B. J. McCabe, A. U. Nicol, A. S. Grout, M. W. Brown, and G. Horn. 2008. Dynamics of a Memory Trace: Effects of Sleep on Consolidation. Current Biology 18:393–400.

Jaggard, A. K., N. Smith, F. R. Torpy, and U. Munro. 2014. Rules of the roost: characteristics

of nocturnal communal roosts of rainbow lorikeets (Trichoglossus haematodus, Psittacidae) in an urban environment. Urban Ecosystems 18:1–14.

Johnson, L. B. 1990. Analyzing spatial and temporal phenomena using geographical information systems. Landscape Ecology 4:31–43.

Johnston, T. 2013. Food resource availability for Carnaby's cockatoo *Calyptorhynchus latirostris* on the Swan Coast Plain. Masters Thesis, Edith Cowan University, Western Australia.

Johnston, T., W. D. Stock, and P. R. Mawson. 2016. Foraging by Carnaby's Black-Cockatoo in Banksia woodland on the Swan Coastal Plain, Western Australia. Emu.

Johnstone, R. E., and C. Cassarchis. 2005. Review of cockatoo research project and Cockatoo Care. Perth, Australia.

Johnstone, R. E., C. Johnstone, and T. Kirkby. 2011. Black Cockatoos on the Swan Coastal Plain. Report prepared for the Department of Planning, Western Australia, by the Western Australian Museum, Welshpool, Western Australia.

Johnstone, R. E., and G. M. Storr. 1998. Handbook of Western Australian Birds, Volume I, Non-passerines (Emu to Dollarbird). Western Australian Museum, Perth, WA, Australia.

Joseph, L., W. B. Emison, and W. M. Bren. 1991. Critical assessment of the conservation status of the Red-tailed Black-Cockatoo in south-eastern Australia with special reference to nesting requirements. Emu 91:46–50.

Kabat, T. J., G. Barrett, and A. P. Kabat. 2012. Great Cocky Count: Identification of roost sites for Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) and population count for the DEC Swan Region. BirdLife Australia, Perth, Western Australia. Birds Australia, Perth, Western Australia.

Kerth, G., and K. Reckardt. 2003. Information transfer about roosts in female Bechstein's bats: an experimental field study. Proceedings of the Royal Society of London, Series B: Biological Sciences 270:511–515.

Kerth, G., M. Wagner, and B. König. 2001. Roosting together, foraging apart: information transfer about food is unlikely to explain sociality in female Bechstein's bats (*Myotis bechsteinii*). Behavioral Ecology and Sociobiology 50:283–291.

Lahti, K., K. Koivula, and M. Orell. 1997. Dominance, daily activity and winter survival in willow tits: detrimental cost of long working hours? Behaviour 134:921–939.

Law, B., C. Mackowski, L. Schoer, and T. Tweedie. 2000. Flowering phenology of myrtaceous trees and their relation to climatic, environmental and disturbance variables in northern New South Wales: flowering phenology of myrtaceous trees. Austral

Ecology 25:160–178.

LeCroy, M., W. S. Peckover, and K. Kisokau. 1992. A population of Rainbow Lorikeets *Trichoglossus haematodus flavicans* roosting and nesting on the ground. Emu 92:187–190.

Lee, J. G. H., H. C. Finn, and M. C. Calver. 2013. Ecology of black cockatoos at a mine-site in the eastern jarrah-marri forest, western Australia. Pacific Conservation Biology 19:76–90.

Lee, M., L. Fahrig, K. Freemark, and D. J. Currie. 2002. Importance of Patch Scale vs Landscape Scale on Selected Forest Birds. Oikos 96:110–118.

Legault, A., J. Theuerkauf, S. Rouys, V. Chartendrault, and N. Barré. 2012. Temporal variation in flock size and habitat use of parrots in New Caledonia. The Condor 114:552–563.

Le Roux, D. S., K. Ikin, D. B. Lindenmayer, A. D. Manning, and P. Gibbons. 2015. Paper III. The value of scattered trees for biodiversity: contrasting effects of landscape context and tree size. Maintaining and perpetuating habitat structures for wildlife in modified landscapes:85.

Lima, S. L., N. C. Rattenborg, J. A. Lesku, and C. J. Amlaner. 2005. Sleeping under the risk of predation. Animal Behaviour 70:723–736.

Lindenmayer, D. B. 2000. Factors at multiple scales affecting distribution patterns and their implications for animal conservation – Leadbeater's Possum as a case study. Biodiversity and Conservation 9:15–35.

Lindenmayer, D. B., R. B. Cunningham, C. F. Donnelly, H. Nix, and B. D. Lindenmayer. 2002. Effects of forest fragmentation on bird assemblages in a novel landscape context. Ecological Monographs 72:1–18.

Lindenmayer, D. B., W. F. Laurance, J. F. Franklin, G. E. Likens, S. C. Banks, W. Blanchard, P. Gibbons, K. Ikin, D. Blair, L. Mcburney, A. D. Manning, and J. A. R. Stein. 2014. New policies for old trees: Averting a global crisis in a keystone ecological structure. Conservation Letters 7:61–69.

Lindenmayer, D. B., M. P. Pope, R. B. Cunningham, C. F. Donnelly, and H. A. Nix. 1996. Roosting of the Sulphur-crested Cockatoo *Cacatua galerita*. Emu 96:209–212.

Lowry, H., and A. Lill. 2008a. Ecological factors facilitating city-dwelling in red-rumped parrots. Wildlife Research 34:624–631.

Lowry, H., and A. Lill. 2008b. Ecological factors facilitating city-dwelling in red-rumped parrots. Wildlife Research 34:624–631.

Lyon, L. A., and D. F. Caccamise. 1981. Habitat selection by roosting blackbirds and starlings: management implications. The Journal of Wildlife Management 1:435–443.

Main Roads Western Australia. 2011. Road hierarchy for Western Australia: Road types and criteria.

Malaeb, Z. A., J. K. Summers, and B. H. Pugesek. 2000. Using structural equation modeling to investigate relationships among ecological variables. Environmental and Ecological Statistics 7:93–111.

Manion, P. 1991. Tree disease concepts. Page Tree disease concepts. Prentice-Hall, Inc., Upper Saddle River, NJ.

Manning, A. D., J. Fischer, and D. B. Lindenmayer. 2006a. Scattered trees are keystone structures - Implications for conservation. Biological Conservation 132:311–321.

Manning, A. D., D. B. Lindenmayer, S. C. Barry, and H. A. Nix. 2006b. Multi-scale site and landscape effects on the vulnerable superb parrot of south-eastern Australia during the breeding season. Landscape Ecology 21:1119–1133.

Marshall, A. G. 1983. Bats, flowers and fruit: evolutionary relationships in the Old World. Biological journal of the Linnean Society 20:115–135.

Martin, G. 2010. Birds by Night. A & C Black, Huntingdon, GBR.

Marzluff, J. M., B. Heinrich, and C. S. Marzluff. 1996a. Raven roosts are mobile information centres. Animal Behaviour 51:89–103.

Marzlufi, J. M., and B. Heinrich. 1991. Foraging by common ravens in the presence and absence of territory holders: an experimental analysis of social foraging. Animal Behaviour 42:755–770.

Mawson, P. R. 1995. Observations of nectar feeding by Carnaby's Cockatoo *Calyptorhynchus latirostris*. Western Australian Naturalist 20:93–96.

Mazerolle, M. J. 2004. Making sense out of Akaike's Information Criterion (AIC): its use and interpretation in model selection and inference from ecological data. World Wide Web.< http://www. theses. ulaval. ca/2004/21842/apa. html.

McCoach, D. B. 2003. SEM Isn't just the Schoolwide Enrichment Model anymore: Structural Equation Modeling (SEM) in gifted education. Journal for the Education of the Gifted 27:36–61.

McGarigal, K., and W. C. McComb. 1995. Relationships Between Landscape Structure and Breeding Birds in the Oregon Coast Range. Ecological Monographs 65:235–260.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation the impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. BioScience 52:883–890.

McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127:247–260.

Medley, K. E., M. J. McDonnell, and S. T. A. Pickett. 1995. Forest-Landscape Structure along an Urban-To-Rural Gradient. The Professional Geographer 47:159–168.

Michael, E. D., and H. C. Wan-tsih. 1973. Migration and roosting of chimney swifts in east Texas. The Auk:100–105.

Mitchell, D., K. I. M. Williams, and A. Desmond. 2002. Swan Coastal Plain 2 (SWA2 – Swan Coastal Plain subregion). Springs 2:606–623.

Morrison, D. W., and D. F. Caccamise. 1985. Ephemeral roosts and stable patches? A radiotelemetry study of communally roosting starlings. The Auk:793–804.

Morrison, D. W., and D. F. Caccamise. 1990. Comparison of roost use by three species of communal roostmates. Condor:405–412.

Nelder, J. A., and R. W. M. Wedderburn. 1972. Generalized Linear Models. Journal of the Royal Statistical Society. Series A (General) 135:370–384.

Noble, D., S. Davis, A. Joys, S. Eglington, and D. Chamberlain. 2010. The effect of observer experience on English Breeding Bird Survey population trends. Bird Study 57:129–141.

Peck, A., G. Barrett, and M. Williams. 2016. The 2016 Great Cocky Count: a community-based survey for Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) and Forest Red-tailed Black-Cockatoo (*Calyptorhynchus banksii naso*). Floreat, Western Australia.

Peh, K. S. H., and N. S. Sodhi. 2002. Characteristics of Nocturnal Roosts of House Crows in Singapore. The Journal of Wildlife Management 66:1128–1133.

Pepper, J. W. 1997. A survey of the South Australian Glossy Black-Cockatoo (*Calyptorhynchus lathami halmaturinus*) and its habitat. Wildlife Research 24:209–223.

Perry, D. H. 1948. Black cockatoos and pine plantations. Western Australian Naturalist 1:133–135.

Perry, R. W., D. A. Saugey, and B. G. Crump. 2010. Winter roosting ecology of silver-haired bats in an Arkansas forest. Southeastern Naturalist 9:563–572.

Pierson, E. D., and W. E. Rainey. 1992. The biology of flying foxes of the genus Pteropus: a

review. InPacific island flying foxes: proceedings of an international conservation conference 90:1–17.

Pimm, S. L., and P. Raven. 2000. Biodiversity. Extinction by numbers. Nature 403:843–845.

Pitman, A. J., and S. E. Perkins. 2008. Regional projections of future seasonal and annual changes in rainfall and temperature over Australia based on skill-selected AR4 models. Earth Interactions 12:1–50.

Pouyat, R. V, M. J. Mcdonnell, and S. T. A. Pickett. 1995. Soil characteristics of oak stands along an urban-rural land-use gradient. Journal of Environmental Quality 24:516–526.

Pugesek, B. H., and A. Tomer. 1995. Determination of selection gradients using multiple regression versus structural equation models (SEM). Biometrical Journal 37:449–462.

Pulliam, H. R. 1973. On the advantages of flocking. Journal of theoretical Biology 38:419–422.

Ramalho, C. E., E. Laliberté, P. Poot, and R. J. Hobbs. 2014. Complex effects of fragmentation on remnant woodland plant communities of a rapidly urbanizing biodiversity hotspot. Ecology 95:2466–2478.

Rodewald, A. D., L. J. Kearns, and D. P. Shustack. 2011. Anthropogenic resource subsidies decouple predator-–prey relationships. Ecological Applications 21:936–943.

Rubenstein, D. I., R. J. Barnett, R. S. Ridgely, and P. H. Klopfer. 1977. Adaptive advantages of mixed-species feeding flocks among seed-eating finches in Costa Rica. Ibis 119:10–21.

Ruthrof, K. X., W. A. Loneragan, and C. J. Yates. 2003. Comparative population dynamics of *Eucalyptus cladocalyx* in its native habitat and as an invasive species in an urban bushland in south-western Australia. Diversity and Distributions 9:469–483.

Saunders, D. A. 1977. The effect of agricultural clearing on the breeding success of the White-tailed Black Cockatoo. Emu 77:180–184.

Saunders, D. A. 1980. Food and Movements of the Short-Billed Form of the White-Tailed Black Cockatoo. Wildlife Research 7:257–269.

Saunders, D. A. 1986. Breeding season, nesting success and nestling growth in Carnaby's cockatoo, *Calyptorhynchus funereus latirostris*, over 16 years at Coomallo Creek, and a method for assessing the viability of populations in other areas 13:261–73.

Saunders, D. A. 1990. Problems of survival in an extensively cultivated landscape: the case of Carnaby's cockatoo *Calyptorhynchus funereus latirostris*. Biological Conservation 54:277–290.

Saunders, D. A., and R. Dawson. 2009. Update on Longevity and Movements of Carnaby's Black Cockatoo. Pacific Conservation Biology 15:72–74.

Saunders, D. A., and J. A. Ingram. 1987. Factors affecting survival of breeding populations of Carnaby's black-cockatoo *Calyptorhynchus funereus latirostris* in remnants of native vegetation. Pages 249–258*in* D. A. Saunders, G. W. Arnold, A. A. Burbidge, and A. J. M. Hopkins, editors.Nature Conservation: the Role of Remnants of Native Vegetation. Surrey Beatty, Sydney.

Saunders, D. A., I. Rowley, and G. T. Smith. 1985. The effects of clearing for agriculture on the distribution of cockatoos in the southwest of Western Australia. Birds of eucalypt forests and woodlands: ecology, conservation, management:309–321.

Savard, J. P. L., P. Clergeau, and G. Mennechez. 2000. Biodiversity concepts and urban ecosystems. Landscape and Urban Planning 48:131–142.

Schwab, F. E., N. P. P. Simon, and A. R. E. Sinclair. 2006. Bird-Vegetation Relationships in Southeastern British Columbia. Journal of Wildlife Management 70:189–197.

Shah, B. 2006. Conservation of Carnaby's Black-Cockatoo on the Swan Coastal Plain, Western Australia. Project Report, Birds Australia Western Australia, Perth.

Shepherd, D. P. 2003. Implementation of the National Vegetation Information System model in Western Australia. Milestone 6 Report to the Bureau of Rural Sciences, Canberra, ACT.

Shukuroglou, P., and M. A. McCarthy. 2006. Modelling the occurrence of rainbow lorikeets (*Trichoglossus haematodus*) in Melbourne. Austral Ecology 31:240–253.

Sisk, T. D., A. E. Launer, K. R. Switky, and P. R. Ehrlich. 1994. Identifying Extinction Threats. BioScience 44:592–604.

Smith, A. C., L. Fahrig, and C. M. Francis. 2011. Landscape size affects the relative importance of habitat amount, habitat fragmentation, and matrix quality on forest birds. Ecography 34:103–113.

Smith, J. A. M., L. R. Reitsma, L. L. Rockwood, and P. P. Marra. 2008. Roosting behavior of a Neotropical migrant songbird, the northern waterthrush *Seiurus noveboracensis*, during the non-breeding season. Journal of Avian biology 39:460–465.

South, J. M., and S. Pruett-Jones. 2000. Patterns of flock size, diet, and vigilance of naturalized monk parakeets in Hyde Park, Chicago 102:848–854.

Stock, W. D., H. Finn, J. Parker, and K. Dods. 2013. Pine as Fast Food: Foraging Ecology of an Endangered Cockatoo in a Forestry Landscape. PLoS ONE 8:e61145.

Syphard, A. D., V. C. Radeloff, T. J. Hawbaker, and S. I. Stewart. 2009. Conservation Threats Due to Human-Caused Increases in Fire Frequency in Mediterranean-Climate Ecosystems. Conservation Biology 23:758–769.

Taylor, K., P. A. Barber, G. E. St J. Hardy, and T. I. Burgess. 2009. Botryosphaeriaceae from tuart (*Eucalyptus gomphocephala*) woodland, including descriptions of four new species. Mycological Research 113:337–353.

Tews, J., U. Brose, V. Grimm, K. Tielborger, M. C. Wichmann, M. Schwager, and F. Jeltsch. 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography 31:79–92.

Thackway, R., and I. D. Cresswell. 1995. An Interim Biogeographic Regionalisation for Australia: a framework for establishing the national system of reserves, Version 4.0. Australian Nature Conservation Agency. Canberra, ACT.

Thomas, J. A., M. G. Telfer, D. B. Roy, C. D. Preston, J. J. Greenwood, J. Asher, R. Fox, R. T. Clarke, and J. H. Lawton. 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. Science 303:1879–1881.

Tilman, D., M. A. Nowak, R. M. May, and C. L. Lehman. 1994. Habitat destruction and the extinction debt. Nature 371:65–66.

Trzcinski, M. K., L. Fahrig, and G. Merriam. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications 9:586–593.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. Annual review of ecology and systematics:171–197.

Uezu, A., J. P. Metzger, and J. M. E. Vielliard. 2005. Effects of structural and functional connectivity and patch size on the abundance of seven Atlantic Forest bird species. Biological Conservation 123:507–519.

Urban Bushland Council and Wildflower Society of Western Australia. (n.d.). Threatened Ecological Community Nomination: Banksia dominated woodlands of the Swan coastal plain IBRA region.

Usher, K. M., C. Groom, and D. A. Saunders. 2016. Identification of individual Carnaby's Cockatoos "*Calyptorhynchus latirostris*" from distinctive plumage markings. Australian Zoologist 38:62–82.

Valentine, L. E., and W. Stock. 2008. Food resources of Carnaby's black-cockatoo (Calyptorhynchus latirostris) in the Gnangara sustainability strategy study area.

Vorster, A. P., and J. Born. 2015. Sleep and memory in mammals, birds and invertebrates.

Neuroscience & Biobehavioral Reviews 50:103–119.

WA Local Government Association. (n.d.). Street Trees Guidance Report.

Warburton, L., and M. R. Perrin. 2005. Roosting requirements and behaviour of the Black-cheeked Lovebird *Agapornis nigrigenis* (Sclater 1906) in Zambia. Tropical Zoology 18:39–48.

Ward, P., and A. Zahavi. 1973. The importance of certain assemblages of birds as "information-centres" for food-finding. Ibis 115:517–534.

Weerheim, M. S. 2008. Distribution patterns and habitat use of black cockatoos (*Calyptorhynchus spp*.) in modified landscapes in the south-west of Western Australia. Masters Thesis, Edith Cowan University, Perth, Australia.

Wentzel, J. J. 2010. Is tuart (*Eucalyptus gomphocephala*) decline detrimental for fauna? Murdoch University.

Western Australian Herbarium. 1998. FloraBase—the Western Australian Flora. Department of Parks and Wildlife.

Williams, M. R., C. J. Yates, W. D. Stock, G. W. Barrett, and H. C. Finn. 2015. Citizen science monitoring reveals a significant, ongoing decline of the Endangered Carnaby's black-cockatoo *Calyptorhynchus latirostris*. Oryx:1–10.

Zabel, C. J., J. R. Dunk, H. B. Stauffer, L. M. Roberts, B. S. Mulder, and A. Wright. 2003. Northern Spotted Owl habitat models for research and management application in Calfornia (USA). Ecological Applications 13:1027–1040.

Zahavi, A. 1971. The function of pre-roost gatherings and communal roosts. Ibis 113:106–109.