

**FACTORS INFLUENCING
THE CONSERVATION STATUS OF
THE GLOSSY BLACK-COCKATOO
(*CALYPTORHYNCHUS LATHAMI LATHAMI*)
ON THE GOLD COAST, QUEENSLAND**



A thesis submitted for the
Degree of Doctor of Philosophy

Michelle Murdoch BSc (Hons)

January 2008

Supervisor: Professor Clyde Wild
Associate Supervisor: Dr Guy Castley

Griffith School of Environment
Griffith University, Gold Coast Campus

ABSTRACT

Calyptorhynchus lathami, the Glossy-black Cockatoo, is a highly specialized monophagous bird feeding only on the cones of *Allocasuarina* species. Studies elsewhere have shown that *C. lathami* are restricted by a tight energy budget, forcing them to select high quality food sources, thereby minimizing effort and time in feeding, and resulting in the birds feeding in some trees and ignoring other apparently suitable trees. This specialized feeding habit, in conjunction with recent and ongoing habitat loss, is expected to cause a decline in their population in many localities. This study examined the abundance and distribution of *C. l. lathami* on the Gold Coast, Queensland.

The feeding status and stability of feed trees was examined, comparing between feed and non-feed trees within a site, and between sites, determining why some trees and sites are fed upon, whilst others are ignored. The results indicate that many areas containing *Allocasuarinas* had little to no current potential as a food source due to low cone production. Ultimately, it was found that many birds were feeding in few suitable sites, with most sites being unsuitable. Where trees with adequate cones crops were observed, it was found that *C. lathami* would feed in the areas with abundant cones. Within these areas, the birds were feeding on trees with large cone crops.

This study also used the number of chewings (pieces of cones: *C. lathami* feeding residue) to estimate bird abundance. The population size was calculated using the quantity and age of *C. lathami* feeding in the study area, and their daily food requirements. It was calculated that between 250 and 690 *C. lathami* were been feeding on the Gold Coast. On-going habitat loss on the Gold Coast may suggests that this population is not stable.

Observational data on *C. lathami* was collected, including physical attributes of individual birds, drinking and nesting habitat, a population census and a minor radio-tracking study. As found in other studies, much variation in female colouration was observed in the field, making it possible to identify different family groups. The pattern of yellow facial spotting on female birds was highly variable, as well as the degree and colour of barring of the tail feathers, with some birds' tail feather bars being more yellow than red.

To gain a better understanding of the habitat requirements of *C. lathami*, known drinking and nesting sites were profiled. Only 12 drinking sites were known to be used, but due to drought conditions, many of these were either completely dry or stagnant during the study period. Only three nesting sites were known, with only one actually used during the study period, in which the nesting was unsuccessful. A census was conducted in July 2004: at the time of year when the most observations of *C. lathami* normally occur. Only two birds and some feeding evidence were

observed. A minor radio-tracking study showed that a family of *C. lathamii* only flew approximately 1km per day, between feed and roost trees, and their drinking site.

It is concluded that nesting and drinking sites on the gold Coast may be in critical supply, but it was not clear whether suitable feed trees are limiting in the study region, or not. The future of the species in the region clearly depends on the success of efforts to preserve habitat for the species, especially breeding sites (dead trees with natural hollows) and feed trees (stands of tall, cone-rich *Allocasuarina*).

STATEMENT OF ORIGINALITY

The material presented in this thesis has not previously been submitted for a degree or diploma in any university and to the best of my knowledge contains no material previously published or written by another person except where due acknowledgement is made in the thesis itself.

Michelle Joy Murdoch

ACKNOWLEDGEMENTS

I thank my supervisors, Professor Clyde Wild, Dr Guy Castley and Dr Steve Phillips for guidance and assistance with this work. The significant costs of field work were funded by the Gold Coast City Council (particular thanks to Evan Thomas) and Griffith University, School of Environmental and Applied Sciences. I also thank Fleays Wildlife Park, and specifically Rosie Booth, for organizing much valued bird handling experience.

Valuable help in finding the ever elusive *C. lathami*, financial support and sharing of *C. lathami* anecdotes were generously supplied by colleagues at the Wildlife Preservation Society, Queensland, Glossy Black Cockatoo Branch Inc., especially Nita Wood and Ros Paterson. Various property owners across the Gold Coast provided essential information and assistance which made the field work possible.

I give special thanks to all volunteers — Debra and Keith Murdoch, Simon Hodgkison, Michael Brickhill, Seanan and Francis Wild, Jon Shuker, Laurie and Vic (the Hinze Dam Rangers), Daniel Stock and Skye Page, and surely others — who all helped to make field work easier and at times even possible!

I also thank my parents, Debra and Keith Murdoch, for countless hours of babysitting, support, and encouragement. It would not have been possible without their support.

Contents

Abstract	i
Statement of originality	iii
Acknowledgements	iv
Contents	v
List of Figures	x
List of Tables	xii
1 Introduction	1
Description of <i>Calyptrorhynchus lathamii</i>	3
Conservation status of <i>C. lathamii</i>	4
1.1 <i>Calyptrorhynchus lathamii</i> in woodland areas	6
1.1.1 Previous Research	7
1.2 Research Outline	9
1.3 Study Area	10
1.3.1 Feed Trees of <i>C. lathamii</i> in Southeast Queensland	12
1.3.1.1 <i>Allocasuarina littoralis</i>	12
1.3.1.2 <i>Allocasuarina torulosa</i>	14
1.3.2 Symbiotic relationship between <i>Allocasuarina</i> and <i>Frankia</i> species	14
1.3.3 Pressures on woodland areas on the Gold Coast, Queensland	15
1.3.3.1 Land clearing for development	15
1.3.3.2 Bushfires and hazard-reduction burns in Southeast Queensland	16
1.3.3.3 Drought in Southeast Queensland	17
1.3.3.4 Summary	18
1.4 Study species: Biology of <i>C. lathamii</i>	19
1.4.1 Feeding requirements	19
1.4.1.1 Previous work on selective feeding by <i>C. lathamii</i>	19
1.4.2 Drinking	22
1.4.3 Nesting	23
1.4.3.1 Roosting	27
1.4.4 Habitat requirements of <i>C. lathamii</i>	27
1.4.5 Movements	28
1.5 References	30
2 Determinants and stability of the feeding status of Casuarina trees for <i>C. lathamii</i> ...	39
2.1 Methods – Determinants of feeding status in <i>A. littoralis</i>	41
2.1.1 Classification of Trees	43
2.1.2 Classification of Sites	46
2.1.3 Statistical analysis	47
2.1.4 General environmental variables	48

2.1.4.1	Presence and distance to anthropogenic factors	49
2.1.4.2	Understorey and/or groundcover	50
2.1.4.3	Presence or absence of fire	51
2.1.4.4	Soil pH, type and colour	51
2.1.5	Measurements of all <i>A. littoralis</i> within each Quadrat	52
2.1.5.1	Flowers abundance	52
2.1.5.2	Cone abundance	52
2.1.5.3	Chewings – quantity and age	53
	Cone colour and softness	53
	Cone Colour	53
	Seed Viability	54
	Cone Softness	54
2.1.6	<i>Allocasuarina torulosa</i> data	56
2.1.7	Stability of the feeding status of <i>A. littoralis</i>	57
2.2	Results	57
2.2.1	Vegetation types	61
2.2.2	Comparison of foraged and non-foraged sites	62
2.2.2.1	Number of cones prior to <i>C. lathami</i> feeding	64
2.2.2.2	Clay content of Horizon A	64
2.2.2.3	Male flowers	65
2.2.2.4	Other variables	65
2.2.2.5	Comparisons of female <i>A. littoralis</i>	67
	Comparison of trees within foraged sites	67
	Comparison of trees between foraged and non-foraged sites	69
2.2.2.6	Cone colour and softness	70
	Cone colour	71
	Cone softness	72
2.2.3	<i>Allocasuarina torulosa</i> data	73
2.2.3.1	Comparison of trees within foraged sites	74
2.2.3.2	Comparison of trees between foraged and non-foraged sites	76
2.2.4	Stability of the feeding status of <i>A. littoralis</i>	77
2.3	Discussion – Feeding determinants and stability	79
2.3.1	Casuarina health	79
2.3.2	Significant factors affecting forage resources	81
2.3.2.1	Soil – Clay content	81
2.3.2.2	<i>Allocasuarina littoralis</i> female trees	82
	Summary	83
2.3.3	<i>Allocasuarina torulosa</i>	84
2.3.4	Feeding stability	84
2.3.5	Summary	86
2.4	References	87

3	Abundance and Distribution of <i>Calyptorhynchus lathami</i> on the Gold Coast	91
3.1	Methods	93
3.1.1	<i>Calyptorhynchus lathami</i> foraging ecology on the Gold Coast	94
3.1.1.1	Number of chewings produced from individual cones and handling time	94
3.1.1.2	Percentage time spent feeding per day	95
3.1.1.3	Average duration <i>C. lathami</i> drink prior to Sunset	97
3.1.2	Estimation of the abundance of feeding evidence by <i>C. lathami</i> on the Gold Coast	97
3.1.2.1	Sub-sampling of chewings	99
3.1.2.2	Aging chewings	101
3.1.3	Estimation of the number of birds on the Gold Coast	102
3.2	Results	105
3.2.1	<i>Calyptorhynchus lathami</i> feeding rates	105
3.2.1.1	Chewings per cone	105
3.2.1.2	Mean handling time per cone	109
3.2.1.3	Time spent feeding per day	114
3.2.1.4	Average duration <i>C. lathami</i> drink prior to Sunset	114
3.2.2	Estimation of the abundance of feeding evidence by <i>C. lathami</i> on the Gold Coast	115
3.2.2.1	Aging chewings	116
3.2.2.2	Estimation of the number of birds on the Gold Coast	116
3.3	Discussion	117
3.3.1	<i>Calyptorhynchus lathami</i> feeding ecology	118
3.3.2	Estimate of abundance of <i>C. lathami</i> on the Gold Coast	120
3.4	References	123
4	<i>Calyptorhynchus lathami</i> Field Observations	127
4.1	Introduction	127
4.2	Methods	128
4.2.1	Morphological characteristics	128
4.2.2	Drinking	130
4.2.3	Nesting	132
4.2.4	Census of <i>C. lathami</i> numbers	133
4.2.5	Radio-tracking	133
4.2.5.1	Pre-test – Determining the mode of transmitter attachment	133
4.2.5.2	Trapping methods	135
4.3	Results	136
4.3.1	Morphological characteristics	136
4.3.2	Drinking sites	139
4.3.3	Nesting	141
4.3.3.1	Active nest	141

4.3.3.2	Previously-known and current nest sites	142
4.3.4	Census	143
4.3.5	Radio-tracking	144
4.3.5.1	Physical attributes of radio tracked bird	147
4.4	Discussion	149
4.4.1	Morphological characteristics	149
4.4.2	Drinking	149
4.4.3	Nesting	150
4.4.4	Radio-tracking	150
4.4.4.1	Distance travelled	151
4.4.4.2	Morphological features of radio-tracked <i>C. lathamii</i>	151
4.4.5	Distribution of <i>C. lathamii</i> requirements on the Gold Coast	152
4.5	References	153
5	Overall Discussion and Recommendations	157
5.1	Discussion	157
5.2	Recommendations	160
5.3	References	163
6	Appendices	165
6.1	Appendix 1	
	Mathematical modelling for determining the accuracy of the non-foraged status for sites	165
6.2	Appendix 2	
	Aging chewings by colour	166
6.3	Appendix 3	
	Rate of chewing loss: the logic behind the estimation of total birds based on chewings	169
6.4	Appendix 4	
	Database of <i>C. lathamii</i> studied on the Gold Coast	171
6.5	Appendix 5	
	Raw data for <i>A. littoralis</i>	174
	General site data for <i>A. littoralis</i>	174
	Horizon A soil data for <i>A. littoralis</i>	175
	Horizon B soil data for <i>A. littoralis</i>	178
	Female <i>A. littoralis</i> tree data	179
	Male <i>A. littoralis</i> trees data	183
6.6	Appendix 6	
	Raw data for <i>A. torulosa</i>	184
	General site data for <i>A. torulosa</i>	184
	Female <i>A. torulosa</i> tree data	185
6.7	Appendix 7	
	Raw data for <i>A. littoralis</i> cone softness and colour	188

	Tree Details	188
	Cone Details	189
6.8	Appendix 8	
	Raw data for <i>C. lathami</i> feeding	199
	Feed Rates for <i>A. littoralis</i> cones	199
	Feed Rates for <i>A. torulosa</i> cones	212
6.9	Appendix 9	
	Raw data for <i>C. lathami</i> daily activities	213

List of Figures

Figure 1.	Female and male <i>C. lathamii</i> perching and feeding in <i>A. littoralis</i>	4
Figure 2.	Distribution of the three subspecies of <i>C. lathamii</i> in Australia	5
Figure 3.	<i>Calyptrorhynchus lathamii</i> study region on the Gold Coast, Queensland: recorded sightings and feeding of <i>C. lathamii</i> on the Gold Coast	10
Figure 4.	Podzolics and lithosols on the Gold Coast, with <i>C. lathamii</i> feeding locations	12
Figure 5.	Female cones of <i>Allocasuarina littoralis</i>	13
Figure 6.	Female cones of <i>Allocasuarina torulosa</i>	14
Figure 7.	Drought consequences in <i>A. littoralis</i> on steep slopes near Springbrook (southeast Queensland)	18
Figure 8.	Arrangement of three 20 × 20 m sampling quadrats within 500 × 500 m grid cells	42
Figure 9.	Arrangement of soil samples taken with a hand augur within each quadrat	51
Figure 10.	Cone Crusher: device for measuring cone softness	55
Figure 11.	Foraged, non-foraged and unsuitable field sites on the Gold Coast during 2003 sampling	58
Figure 12.	Location and quantity of chewings at field sites on the Gold Coast	60
Figure 13.	Field sites in different vegetation types on the Gold coast	61
Figure 14.	Comparison of the number of cones on <i>A. littoralis</i> trees prior to <i>C. lathamii</i> feeding, in foraged and non-foraged sites	64
Figure 15.	Tree height, DBH and number of cones on feed and non-feed trees in <i>A. littoralis</i> foraged sites	67
Figure 16.	Abundance of pre-feeding cones on feed and apparently suitable trees in <i>A. littoralis</i> foraged sites	68
Figure 17.	DBH of all trees in <i>A. littoralis</i> foraged and non-foraged sites	69
Figure 18.	Greyness of cones of feed and non-feed <i>A. littoralis</i> trees	72
Figure 19.	Quantity of chewings from feed trees with different cone softness values (averaged for tree)	73
Figure 20.	Total abundance of pre-feeding cones in foraged and non-foraged sites	74
Figure 21.	Height and cone abundance of feed and non-feed trees in <i>A. torulosa</i> foraged sites	75
Figure 22.	Abundance of cones pre-feeding on feed and non-feed trees in <i>A. torulosa</i> foraged sites	76
Figure 23.	Map of the vegetation types containing <i>A. littoralis</i> or <i>A. torulosa</i> on the Gold Coast	99
Figure 24.	Diagrammatic representation of sub-sampling method of <i>A. littoralis</i> chewings	100
Figure 25.	Comparison of the number of chewings derived from one cone between breeding and non-breeding <i>C. lathamii</i> , feeding on <i>A. littoralis</i> and <i>A. torulosa</i>	106

Figure 26. Comparison of the number of chewings derived from a single <i>A. littoralis</i> cone between gender and breeding status	107
Figure 27. Comparison between adult (breeding and non-breeding) and juvenile <i>C. lathami</i> for the mean number of chewings per cone	109
Figure 28. Comparison of the time taken to consume one cone, between <i>Allocasuarina</i> species and the breeding status of adult <i>C. lathami</i>	110
Figure 29. Comparison of time taken to consume a cone between gender and breeding status	111
Figure 30. Comparison between adult (breeding and non-breeding) and juvenile <i>C. lathami</i> for the mean <i>A. littoralis</i> handling time per cone	112
Figure 31. Differences in the duration to chew one cone at different times of day	113
Figure 32. <i>Calyptorhynchus. lathami</i> drinking time prior to sunset	115
Figure 33. Tail barring in male <i>C. lathami</i>	129
Figure 34. Differences in tail barring and yellow face feathers in male and female <i>C. lathami</i>	130
Figure 35. Crown Senescence, Dead Branch Order and trunk parts	132
Figure 36. Neck harness with transmitter on <i>C. lathami</i>	134
Figure 37. Distances between observations of groups of birds sighted at different locations	137
Figure 38. Comparison of the red and yellow tail feathers of ♀ <i>C. lathami</i> to <i>C. funereus</i> and <i>C. banksia</i>	138
Figure 39. Female <i>C. lathami</i> with unbarred red tail feathers	138
Figure 40. <i>Calyptorhynchus lathami</i> drinking at a rocky creek	139
Figure 41. Picture of (left) the nest hollow and (right) inside the hollow and 2-3 week old chick	142
Figure 42. Radio-tracking area: aerial photography showing vegetation and development.	145
Figure 43. Radio-tracked <i>C. lathami</i> in Southport – grouped by (a) day and (b) activities	145
Figure 44. Nerang State Forest monitoring area: aerial photography showing vegetation and development	147
Figure 45. <i>Calyptorhynchus lathami</i> feeding habitat in Nerang State Forest	147
Figure 46. Comparison of feeding rates between breeding males	148
Figure 6.2.1 Scatterplot of the hue of chewings of <i>A. littoralis</i> and <i>A. torulosa</i>	166
Figure 6.2.2 Scatterplot of the value of chewings of <i>A. littoralis</i> and <i>A. torulosa</i>	166
Figure 6.2.3 Scatterplot of the chroma of chewings of <i>A. littoralis</i> and <i>A. torulosa</i>	167

List of Tables

Table 1.	List of vegetation types on the Gold Coast containing <i>A. littoralis</i>	41
Table 2.	Definitions of tree categories for Casuarinas on the Gold Coast as used in this study	44
Table 3.	Categories for levels of anthropogenic disturbances	50
Table 4.	Clay types	52
Table 5.	Grey scale used to categorise cone colour	54
Table 6.	Foraging status of sites of <i>A. littoralis</i> and <i>A. torulosa</i> on the Gold Coast	59
Table 7.	Quantity of chewings at <i>A. littoralis</i> and <i>A. torulosa</i> <i>C. lathami</i> foraged sites	60
Table 8.	Number of feed and non-feed potential <i>C. lathami</i> feeding sites in different vegetation types	62
Table 9.	Statistical analysis (t-tests) of <i>A. littoralis</i> site data	63
Table 10.	Soil type and clay content in Horizon A supporting <i>A. littoralis</i>	65
Table 11.	Probability of foraging status in high and low clay soils	65
Table 12.	Statistical results of non-parametric <i>A. littoralis</i> site data	66
Table 13.	Summary table of t-tests on feed and non-feed trees within foraged sites	67
Table 14.	Summary table of t-tests on the feed trees and apparently suitable trees in foraged sites	68
Table 15.	Summary table of t-tests on all trees in foraged and non-foraged sites	69
Table 16.	Summary table of t-tests on apparently suitable trees (including feed trees) in foraged and non-foraged sites	70
Table 17.	Cone colour and softness from feed and non-feed trees	71
Table 18.	Skewness and kurtosis of feed and non-feed tree cone greyness data	72
Table 19.	Average cone softness of feed and non-feed trees	73
Table 20.	Summary table of comparisons of foraged and non-foraged sites with <i>A. torulosa</i>	74
Table 21.	Summary table of comparisons on feed and non-feed <i>A. torulosa</i> trees in foraged sites	75
Table 22.	Summary table of comparisons on feed and apparently suitable <i>A. torulosa</i> trees in foraged sites	76
Table 23.	Summary table of comparisons of all <i>A. torulosa</i> trees in foraged and non-foraged sites	77
Table 24.	Summary table of comparisons of apparently suitable <i>A. torulosa</i> trees (including feed trees) in foraged and non-foraged sites	77
Table 25.	2 × 2 Contingency table of feeding status of <i>A. littoralis</i> between 2000 and 2002	78
Table 26.	2 × 2 Contingency table of feeding status of <i>A. littoralis</i> between 2000 and 2004	78
Table 27.	Feeding status of <i>A. littoralis</i> trees during a 5 year study	79

Table 28.	List of vegetation types on the Gold Coast containing <i>A. littoralis</i> and/or <i>A. torulosa</i>	98
Table 29.	Scores observed in the field for the three components of colour (based on the Munsell system)	102
Table 30.	Number of <i>Allocasuarina</i> spp. cones observed consumed by adult and juvenile <i>C. lathami</i> on the Gold Coast	105
Table 31.	Univariate tests of significance for number of chewings per cone (combined for <i>A. littoralis</i> and <i>A. torulosa</i>)	106
Table 32.	Univariate tests of significance for number of chewings per <i>A. littoralis</i> cone	107
Table 33.	Approximate probabilities for <i>post hoc</i> contrasts (unequal N) – number of chewings	108
Table 34.	Comparison of the number of chewings derived from a single cone between adults (breeding and non-breeding) and juveniles	108
Table 35.	Univariate tests of significance for the mean handling time per cone – species × breeding status (<i>A. littoralis</i> and <i>A. torulosa</i>)	110
Table 36.	Univariate tests of significance for the mean handling time per <i>A. littoralis</i> cone – gender × breeding status	111
Table 37.	Approximate probabilities for <i>post hoc</i> contrasts (unequal N) – handling time of <i>A. littoralis</i> cones	112
Table 38.	Comparison of time taken to handle one cone between adults (breeding and non-breeding) and juvenile <i>C. lathami</i>	113
Table 39.	Parameters of the best-fit curve for time <i>C. lathami</i> drink prior to sunset	115
Table 40.	Abundance of <i>C. lathami</i> feeding on <i>A. littoralis</i> and <i>A. torulosa</i> based on chewings quantities on the Gold Coast	117
Table 41.	Variables used in development of the estimate of the regional population	122
Table 42.	Profiles of known <i>C. lathami</i> drinking sites on the Gold Coast	140
Table 43.	Details of <i>C. lathami</i> observations at drinking sites on the Gold Coast	141
Table 44.	Attributes of <i>C. lathami</i> nests on the Gold Coast	143
Table 45.	<i>C. lathami</i> census results from surveys conducted at five locations on the Gold Coast	144
Table 46.	Radio tracked <i>C. lathami</i> - physical details	148
Table 6.2.1	Aging <i>A. littoralis</i> chewings using colour	167
Table 6.2.2	Aging <i>A. torulosa</i> chewings using colour	168

1 INTRODUCTION

An organism's use of available landscapes and constituent habitats is determined by a number of intrinsic and extrinsic factors. An underlying assumption guiding habitat use and habitat selection research is that species' choice should favour habitats that provide sufficient resources to maximise the chances of survival and reproduction, thereby enhancing fitness (Rosenzweig 1991, Block and Brennan 1993). Jones (2001) also makes an important distinction between habitat use and habitat selection, where the latter refers to a hierarchical process whereby behavioural responses of an individual result in the disproportionate use of habitats to maximise fitness.

Previous studies have predominantly considered deterministic models to explain patterns in habitat selection processes (e.g. ideal-free and ideal-despotic distribution models, Fretwell and Lucas 1969). Deterministic models would suggest that the distribution and abundance of a species is driven by some functional relationship between habitat selection and habitat quality, and therefore enable predictive responses in assessing species choice. However, the widespread application of these models may have overlooked the role of stochasticity in shaping habitat use (Campbell *et al.* 2010, Miller and Coll 2010). Fundamentally, Campbell *et al.* (2010) argue that the complexity and dynamic nature of ecological systems undermines the ability of deterministic models to fully explain variation in habitat use. Furthermore, Miller and Coll (2010) argue that deviations from deterministic responses may have a greater prevalence amongst species foraging over large areas where much of this activity may be exploratory and hence driven by random factors.

Avian distribution and abundance is frequently determined from dietary as well as breeding requirements (Cruz-Angón *et al.* 2008, Crampton *et al.* 2011). Food availability, in particular, has long been the focus of ecological studies to determine its importance in affecting habitat use by birds (MacArthur 1958, MacArthur and Pianka 1966, Charnov 1976), with recent studies providing evidence both for and against its importance in habitat use (Champlin *et al.* 2009, Crampton *et al.* 2011). Theoretically, if wild animals have efficient foraging strategies, when faced with a choice they would choose food types that minimise their search, capturing, handling and/or feeding effort, as a means to maximise their overall fitness (MacArthur and Pianka 1966, Schoener 1971, Charnov 1976, Price and Correll 2001, Meyer *et al.* 2009). This 'optimal foraging theory,' has been studied extensively since the late 1960s, with arguments for and against the usefulness of the theory (MacArthur and Pianka 1966, Charnov 1976, Pyke 1984, Pierce and Ollanson 1987, Perry and Pianka 1997). Charnov (1976) found that variables such as breadth of diet, strategies of movement, or use of a patchy environment (including time travelled between patches), which patches to use, and when to leave a patch, affected a species' foraging efficiency.

Factors such as predation risk and nutritional rewards can influence these foraging strategies (Cameron and Cunningham 2006, Inger *et al.* 2006), and this may be most readily observed in those species that have evolved to have specialised dietary preferences. Dietary specialisation is complex, and species generally fall along a continuum of dietary niche breadth ranging from generalists to specialists. Recently, Shipley *et al.* (2009) proposed a framework to provide greater clarity on how vertebrates, in particular, can be classified along this continuum, suggesting that species at each end of the scale can be either ‘obligatory’ or ‘facultative’ in their degree of specialisation.

The preceding review provides the foundation for assessing the combination of habitat features and a species’ life history traits that may influence the conservation status of a obligatory specialist (Shipley *et al.* 2009), such as the Glossy Black-Cockatoo (*Calyptorhynchus lathami* Temminck: Cacatuidae). For a highly adapted monophagous species like the Glossy Black-Cockatoo (Garnett and Crowley 2000, Cameron 2006, Cameron and Cunningham 2006), specialisation increases the dependence on certain resources. As resources decline, for example through habitat fragmentation and loss, habitat specialisation may increase extinction risk (Owens and Bennett 2000, Purvis *et al.* 2000, Safi and Kerth 2004), but the relationship with dietary specialisation is less clear (Safi and Kerth 2004). Consequently, since the Glossy Black-Cockatoo has a combination of specialised diet and habitat requirements (i.e. hollow-bearing trees for nesting), knowing how these resources affect habitat use is important for conservation of the species. Furthermore, such specialisation may compound any existing effects of either a small or declining population (Caughley 1994) with consequences for the conservation of the species.

Furthermore, the specific foraging strategies adopted by Glossy Black-Cockatoo, as well as the distribution and abundance of the resource within a landscape, may affect foraging efficiencies. Previous studies demonstrate how both pollinators and predators alter their foraging strategy depending on resource abundance as well as the spatial arrangement of resources (Bennetts and Kitchens 2000, Andrieu *et al.* 2009, Terraube *et al.* 2012). The distribution of resources affects the number of visits, search duration and food choice; hence poor accessibility to resources can result in extended visitation, particularly after increased search effort within fragmented landscapes (Andrieu *et al.* 2009). These factors could be significant for *C. lathami* where choice appears to be at a fine scale, such as the selection of individual cones on particular trees (Cameron and Cunningham 2006). This potentially explains their observed loyalty to certain trees in some areas i.e. perceived foraging stability (Crowley *et al.* 1996, Garnett *et al.* 1999).

Optimising foraging to increase returns has previously been demonstrated by Chittka and Menzel (1992) who indicated that many insects have adopted efficient foraging strategies based on

reward, i.e. these insects are attracted to certain coloured flowers, where colour is indicative of those that have nectar. Similar discriminating foraging behaviour has been found for hummingbirds (Brown and Gass 1993, Hurly and Oseen 1999, Baum and Grant 2001), American robins (Sallabanks 1993, Murray *et al.* 1993), and other birds (Sorensen 1984, Pedro 1995, Diaz 1996). Optimal foraging strategies could therefore be especially important for species that have highly specialised diets, as a means to minimise extinction risk. How *C. lathami* responds to the distribution of resources in the rapidly urbanising region of the Gold Coast is therefore critical to the species' future conservation, particularly given the complex dynamics of bird populations in urban areas (Shochat *et al.* 2006, Anderies *et al.* 2007).

Description of *Calyptorhynchus lathami*

Calyptorhynchus lathami (Figure 1) are monophagous, having evolved a beak specifically for feeding on cones of Casuarinas (*Casuarina* and *Allocasuarina* spp., Casuarinaceae) (Cameron and Cunningham 2006, Cameron 2007), and therefore have one of the most highly specialised diets amongst global bird species. Their feeding ecology is further restricted by a fine-scale preference for certain *Casuarina* trees over others in the same stand (Cameron and Cunningham 2006), and it's reported that birds will return to the same trees year after year (Pepper *et al.* 2000, Wild *et al.* 2002). Such fine-scale site fidelity needs to be better understood so it can be reflected adequately in management plans.

Extensive studies on Kangaroo Island (South Australia) indicate that the feeding strategy of *C. l. halmaturinus* (Kangaroo Island subspecies), on *A. verticillata* (Lam.) L. Johnson, is strongly influenced by seed quality (Crowley *et al.* 1996, Crowley and Garnett 2001), and Cameron and Cunningham (2006) report similar patterns in New South Wales where cone abundance was also important. However, similar studies conducted on the southeast Queensland population of the subspecies *C. l. lathami*, feeding on *A. littoralis* (Salisb.) L. Johnson and *A. torulosa* (Ait.) L. Johnson revealed that the seed quality variables investigated did not differ between feed and non-feed *Casuarina* (Wild *et al.* 2002). Consequently, other factors may be influencing habitat use by Glossy Black-Cockatoos in this region.

The habitat preferences displayed by *C. lathami* extend beyond their specialised feeding behaviour, as like most other Australian cockatoos (Saunders *et al.* 1985), *C. lathami* are obligate tree-hollow nesters, with suitable hollows usually found in *Eucalyptus* species (Crowley *et al.* 1996). *Calyptorhynchus lathami* also require suitable drinking sites as daily access to water is essential (Pepper 1996). Nesting and drinking sites are therefore important factors contributing to the success of *C. lathami*, but they will not be a major focus of this research.

The present study will concentrate on examining further parameters that may distinguish between feed and non-feed *Allocasuarina* spp. in southeast Queensland, as well as use the quantity of feeding observed on the Gold Coast to estimate *C. lathami* abundance. Due to their highly specialised diet *C. lathami* leave telltale signs of their feeding activity within the landscape (Joseph 1982, Clout 1989). These signs can be related to measures of habitat selection based on foraging activity (see Cameron and Cunningham 2006), but are also useful to make inferences about the relative abundance of the species (Harrington *et al.* 2008a). Despite the extensive literature on *C. lathami* there appear to be no studies that attempt to estimate such parameters from the feedings signs of the cockatoo. A more detailed understanding of *C. lathami* abundance estimates is particularly important given that the determination of subspecies population size and distribution was highly recommended in the Action Plan for *C. lathami* by Garnett and Crowley (2000).



Figure 1. Female (left: yellow feathers on the ear covers and barred red tail feathers) and male (right: unbarred red tail feathers) *C. lathami* perching and feeding in *A. littoralis*.
Photo: N. Sander

Conservation Status of *C. lathami*

Calyptorhynchus lathami is endemic to Australia, with three described subspecies, each distinctive according to beak and wing morphology (Schodde *et al.* 1993, Garnett *et al.* 1997). The three subspecies are widespread, but generally confined to eastern Australia. *Calyptorhynchus lathami erebus* Schodde occurs in north eastern Australia (mid-Queensland) (Schodde *et al.* 1993), *Calyptorhynchus lathami lathami* Temminck in central and southeastern Australia (mid Queensland to Victoria) and *Calyptorhynchus lathami halmaturinus* Mathews in South Australia (Kangaroo Island) (Garnett *et al.* 1997).

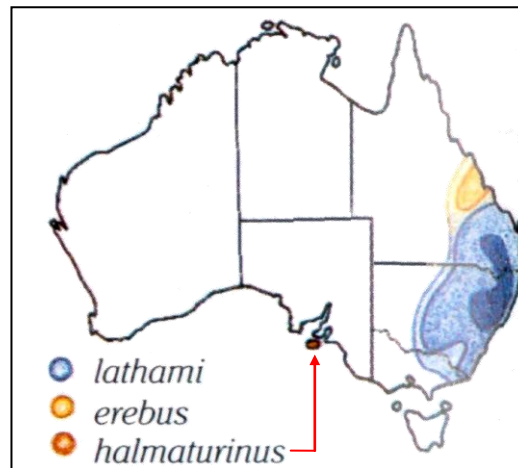


Figure 2. Distribution of the three subspecies of *C. lathami* in Australia (after Morcombe 2000).

The majority of the species' population is believed to occur in northern New South Wales and southeast Queensland (Forshaw and Cooper 1981). In Queensland, *C. lathami* have been reported from Eungella in the north (21°), to the New South Wales border (28°), and many of the near-coastal offshore islands (e.g. North Stradbroke, Fraser, Bribie, Lamb, Macleay, and Russell Islands). All recent reports are from the east of the Great Dividing Range, with *C. lathami* commonly being seen on the Gold Coast, islands of the Redland Shire, Noosa, Boonah and Caboolture (Anonymous 2002). While the species is generally scarce, it can be locally common (Paterson 1997). No actual estimates of the population have been done on *C. lathami* in Queensland, so they may be more or less abundant than has been reported. A group of community members organised the formation of the Glossy Black-Cockatoo Branch of the Wildlife Preservation Society for southeast Queensland. These volunteers were instrumental in keeping records of reported sightings of *C. lathami* between 1996 and 2002. These data records have been used in this work, and were examined by Stock and Wild (2005).

According to Crowley *et al.* (1996) *C. lathami* is classed as *vulnerable* in Victoria and Queensland, *vulnerable/rare* in New South Wales, and they are *critically endangered* in South Australia. They have a limited range within these states, and have not been recorded in Tasmania, Western Australia or the Northern Territory (Figure 2) (Healey 1997, Garnett *et al.* 1997).

The Queensland *Nature Conservation Act 1992* rates that *C. lathami* as “vulnerable”, which under this Act indicates that:

- the population is decreasing because of threatening processes; and
- the species is dependent on a limited habitat that is at risk from threatening processes (Paterson 1997).

These ongoing threats, coupled with the uncertainty over the status of the regional population may compromise the conservation of the species. Understanding extinction risk, particularly in small or declining populations, has been the focus of considerable research effort (Soulé and Wilcox, Caughley 1994, Brook *et al.* 2006, Traill *et al.* 2010). A related concept is therefore the minimum viable population (Shaffer 1981) required to minimise loss through inbreeding, genetic drift and environmental variability (Reed *et al.* 2003). Franklin (1980) originally proposed the 50/500 rule, where effective populations with fewer than 50 individuals are at risk from inbreeding, while the loss of genetic heterozygosity through genetic drift may impact any effective population less than 500 individuals. More recently, however, Traill *et al.* (2010) suggest that these earlier estimates may need to be an order of magnitude greater (i.e. 500/5000), if populations are to maintain evolutionary potential in the face of environmental change. It is clear, therefore, that further information is urgently required on the status of the *C. lathamii* population in southeast Queensland to obtain an estimate of the species' abundance but also to provide base-line information to enable future monitoring of population trends.

1.1 CALYPTORHYNCHUS LATHAMI IN WOODLAND AREAS

Calyptorhynchus lathamii occur almost exclusively in eucalypt forests and woodlands containing stands of *Casuarina*¹ (*Allocasuarina* and *Casuarina* spp.) (Garnett *et al.* 1997, Chapman 2000). Studies have shown that all subspecies of *C. lathamii* have very narrow feeding ecology: only feeding on certain *Casuarina* trees (Marchant and Higgins 1990). The three subspecies feed on different *Allocasuarina* species, according to their geographical locations. Of the subspecies studied, *C. l. lathamii*, feeds on *A. littoralis* and *A. torulosa* in Queensland but also *A. diminuta* and *A. gymnanthera* in NSW; *C. l. erebus* feeds on *A. littoralis*; and *C. l. halmaturinus* feeds on *A. verticillata*. Studies by Crowley *et al.* (1996, 1998) and Garnett *et al.* (1997) confirm observations by this author that *C. lathamii* feeds from only a limited range of available feed trees, and ignores other (“non-feed”) trees of the same species in the stand, despite the presence of cones on these trees.

Due to the difficulty of extracting seeds from *Casuarina* cones, no other bird's staple diet consists of *Casuarina* seeds, and *C. lathamii* are known to leave distinctive remnants of discarded *Casuarina* cones once a cone has been fed upon (Clout 1989). These discarded husks are

¹ In 1982 L.A.S. Johnson separated the 100 or so species of *Casuarina* into four genera, with about 20 remaining in *Casuarina* and 40 transferred to *Allocasuarina*. The two genera are characterised by cone morphology and the preference/tolerance of the latter for impoverished soils (Johnson 1982). Plants in both genera are popularly called Casuarinas and this convention will be used here in reference to the trees in general.

commonly referred to as ‘chewings’. Other parrots do feed on Casuarina seeds, but mainly from dehisced seeds on the ground; Yellow-tailed Black-Cockatoos (*Calyptorhynchus funereus*) have been known to feed on fresh seeds when their preferred food type is limiting, but they disintegrate the cone trying to obtain seeds, lacking the specifically-formed beak *C. lathami* has for this purpose (Schodde *et al.* 1993). Pepper (1996) did not observe any vertebrate competition for *A. verticillata* seeds on Kangaroo Island, South Australia, despite some finches (*Emblema* spp., including *E. bellum*) having been known to extract seeds from partly opened valves of *A. verticillata* (Joseph 1986). In north Queensland, Crowley (1986) saw *C. banksii* (Red-tailed Black-Cockatoos) feeding on *A. torulosa* and *Platycerus elegans* (Crimson Rosellas) feeding on seeds from immature *A. littoralis* cones, as well as *Trichoglossus haematodus* (Rainbow Lorikeet), *T. chlorolepidotus* (Scaly-breasted Lorikeet), *Glossopsitta pusilla* (Little Lorikeets) and *E. temporalis* (Red-browed Firetail), feeding on seeds from cones of *A. littoralis* with open bracteoles; but none of these feeding methods would produce the characteristic ‘chewings’ (Joseph 1982) produced by *C. lathami* and frequently found in large numbers under a preferred feed tree.

Calyptorhynchus lathami, like most cockatoos, are obligate tree-hollow nesters (Crowley *et al.* 1998, Garnett *et al.* 1999, Chapman 2000). Gibbons and Lindenmayer (2002) state that a total of 15% of Australian terrestrial vertebrate species use hollows (31% of mammals, 15% of birds, 10% of reptiles and 13% of amphibians). Furthermore, Gibbons *et al.* (2002) found that more than forty species of hollow-using vertebrates were commonly found within any one woodland area in Australia. Consequently, the conservation of habitat containing tree hollows is an important aspect of maintaining vertebrate biodiversity. If the number of nesting sites is limited for *C. lathami*, it is expected that this limitation would also prejudice breeding opportunities for other large obligate tree-hollow nesters. Due to the time it takes for eucalypts to develop hollows, obligate tree-hollow nesters are expected to be the most severely affected by loss of mature eucalypts and the hollows they often contain (Gibbons and Lindenmayer 2002).

1.1.1 Previous Research

Calyptorhynchus lathami has attracted much research attention, with the isolated subspecies on Kangaroo Island in South Australia being the main focus of previous studies, mainly focusing on their feeding ecology and abundance (Pepper 1993, 1996, Pepper *et al.* 2000, Chapman 2000, Crowley and Garnett 2001, Chapman and Paton 2005, 2006). This large data set has contributed to a comprehensive species recovery plan for this isolated population (Garnett *et al.* 1999). However more recent studies have increased our understanding of populations of the subspecies

in New South Wales (Clout 1989, Coffey 1996, Cameron 2004, 2006, Cameron and Cunningham 2006), and Queensland (Wild *et al.* 2002, Stock and Wild 2005).

The *C. l. halmaturinus* population has declined this century: once being found in mainland South Australia, they are now restricted to Kangaroo Island (Joseph 1982). Studies have shown that there are significant differences between feed and non-feed *A. verticillata* (Pepper *et al.* 2000, Crowley and Garnett 2001) and *A. littoralis* (Clout 1989) cones, making some trees more suitable to *C. lathami* feeding requirements than others. Consequently, the quality and quantity of the seeds of Casuarina species may limit the distribution of *C. lathami*, but not necessarily the population size, since it has been indicated that sufficient *A. verticillata* is available to support a larger population on Kangaroo Island (Garnett and Crowley 2000). It has also been established that *C. l. halmaturinus* has a low recruitment rate, originally thought to be the result of a shortage of nest hollows, and strong competition for these (Crowley *et al.* 1996). However, subsequent investigation has indicated that nest hollows on Kangaroo Island were not limiting, and that low chick survival from predation was the main cause (Crowley *et al.* 1996).

Very little work has been completed on *C. l. lathami* in southeast Queensland. Garnett (1997) and Paterson (1997) have used the information collected from Kangaroo Island to compile conservation plans for the species in southeast Queensland, but the only formal study (Wild *et al.* 2002), examined factors influencing feeding choice by *C. lathami* in southeast Queensland. Specifically, Wild *et al.* (2002) examined habitat and tree variables that may differ between trees within sites; including tree data such as abundance of cones, tree circumference and height; and site data such as azimuth and steepness of slope, and soil type/colour. Considering the consistency with which these birds return to the same trees, and that a large number of variables were examined in that study, it was expected that at least one of them would be a strong discriminator between feed tree types. None of the variables was able to discriminate feeding status very well, suggesting that there are no actual causal differences between ‘feed’ and ‘non-feed’ trees, in contrast to the situation observed elsewhere (i.e. Kangaroo Island). Since the *C. lathami* population in southeast Queensland is suspected to be low, Wild *et al.* (2002) concluded that factors other than the availability of feed trees might be limiting for the southeast Queensland population.

Researchers on Kangaroo Island have been able to complete yearly bird counts of *C. halmaturinus* due to an extensive existing knowledge of the population’s demographics, including known nesting sites. Insufficient knowledge of the southeast Queensland population makes this conventional method of bird counting currently impracticable. Instead, this study uses the abundance and distribution of *C. lathami* feeding evidence to estimate abundance of

C. lathami on the Gold Coast. The use of ‘signs’ to determine the abundance of a species has been used elsewhere, especially when the subject species is particularly elusive (small or camouflaged etc.), occurs at low densities or in difficult terrain, making them difficult to find (Whisson *et al.* 2005, Witmer 2005, Harrington *et al.* 2008a, b). Examples of commonly used signs to determine abundance are scats (Brown and Triggs 1989, Lunney *et al.* 1996, Ball *et al.* 2005, Witmer 2005, Harrington *et al.* 2008a, b), tracks (Harrington *et al.* 2008a, Hass 2009), food removal and open burrow-openings (Witmer 2005). The use of scats to estimate relative abundance has been successful for potoroos and pademelons (Brown and Triggs 1989), American minks (Harrington *et al.* 2008a, b, Harrington *et al.* 2010), bobcats and pumas (Hass 2009) and various macropods (Lunney *et al.* 1996) etc. The majority of these studies have focused on using signs to assess mammalian fauna and there are few similar studies for birds, with the exception of Westcott (1999) with cassowaries.

1.2 RESEARCH OUTLINE

This thesis investigates several factors influencing the conservation status of *C. lathami* in southeast Queensland, particularly determination of their abundance and feeding requirements. The study is separated into three main sections:

Chapter 2 – Determination of what characteristics of Casuarina trees affect whether *C. lathami* feed on them (feeding status) and whether this changes over time (stability of the feeding status):

- a. Feeding status: environmental variables will be examined comparing areas containing *A. littoralis* where *C. lathami* foraging does and does not occur, as well as feed and non-feed trees within foraged areas;
- b. Stability: Sites revisited over 4 years examined whether the feeding status of trees changes over time i.e. determining the extent to which *C. lathami* are loyal to the same trees.

Chapter 3 - Abundance and distribution of *C. lathami*. Development of a novel method of determining *C. lathami* abundance on the Gold Coast, given the difficulty in surveying the species using standard methods. Specifically, the size of the *C. lathami* population on the Gold Coast was estimated using the abundance and distribution of their feeding residue, chewings. Several smaller studies were conducted to determine the quantitative relationships between chewings, their condition, and the number of birds this implies.

Chapter 4 - Observations and movement patterns of *C. lathami*:

- a. Collation of a database on individual observed birds for identification purposes;
- b. Investigation and profiling of known and reported drinking and nesting sites;
- c. Organization of a census to estimate bird numbers and determine their current locations;
- d. Radio tracking of individual birds to gain a better understanding of *C. lathami* movement and daily behavior.

1.3 STUDY AREA

The fieldwork was completed on the Gold Coast, Queensland (latitude 27°40' to 28°15' S, and longitude 153°06' to 153°33' E) from Coomera in the north, to Tweed Heads in the south and Mt Tamborine on the Darlington Range in the west, to the near-coastal islands to the east (Figure 3).

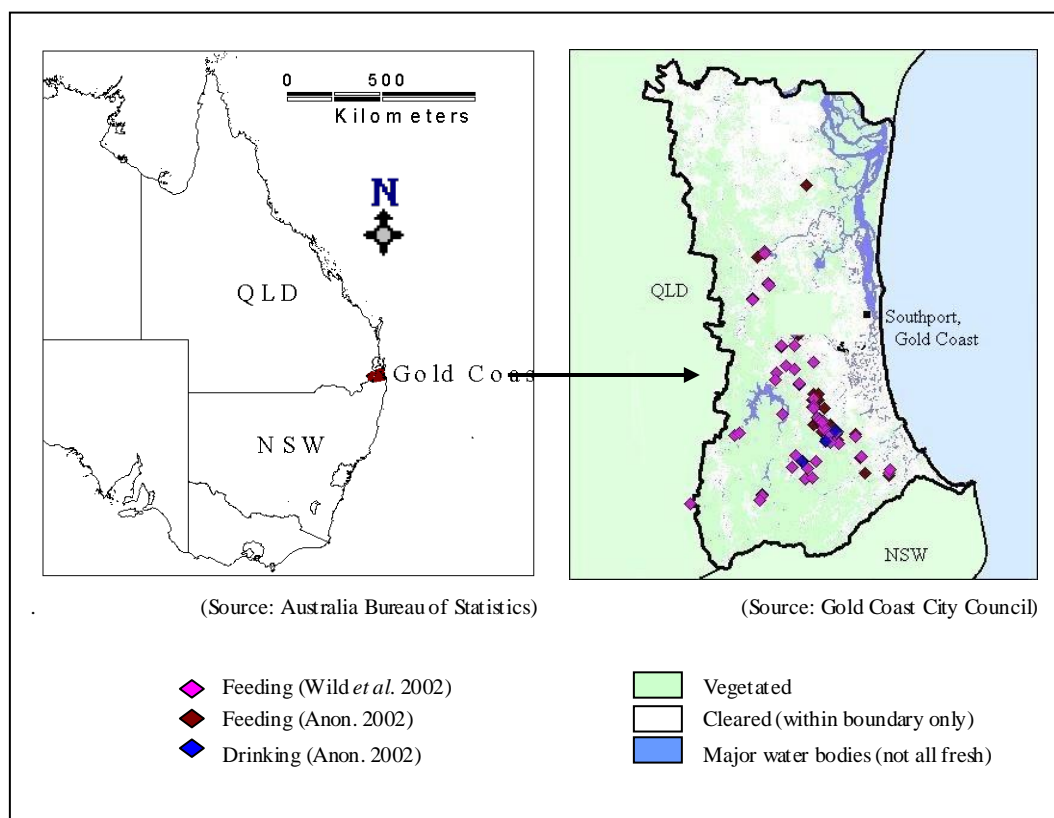


Figure 3. *Calyptorhynchus lathami* study region on the Gold Coast, Queensland: Recorded sightings and feeding of *C. lathami* on the Gold Coast
Source: Gold Coast City Council (vegetation map)

Historical records and evidence suggest that *C. lathami* make regular use of habitats within the Gold Coast region. The majority of known feeding has been reported by property owners, occurring on isolated trees or small stands of *Casuarina* on private property in residential areas;

usually on properties larger than the average house block, including residential properties with several hectares of land. Feed trees are also known in a few areas in National Parks (Tamborine, Lamington, Springbrook) and State Forests (Nerang, Numinbah), and there are unconfirmed reports of feeding in other bushland areas. On the Gold Coast, Queensland, *C. lathami* have been regularly sighted feeding at Elanora, Tallebudgera, Reedy Creek, Mudgeeraba, Bonogin, Tallai, Worongary, Austinville, Little Nerang Dam, Hinze Dam, Springbrook, Gilston, Numinbah, Lower and Upper Beechmont, Nerang, Gaven, Upper Coomera and Guanaba (Garnett 1997, Anonymous 2002, Wild *et al.* 2002).

The coastal region of the Gold Coast has a humid subtropical climate with mean monthly temperatures in the hottest month (January) of 20°C to 29°C (daily minimum and maximum) and in the coolest month (July) of 10°C to 21°C. Annual rainfall varies with location, but is typically 1400-1500 mm *per annum* with most rain in the summer months — 70% of the annual fall occurs in the wettest 6 months (December to May) (Bureau of Meteorology). The soil types on the Gold Coast mainly consist of lithosols, and red and yellow podzolics (Figure 4), with some humic gleys (Isbell 1996).

Vegetation on the Gold Coast is mainly woodland and open forest, with littoral and warm temperate to sub-tropical rainforests near the NSW border and in small patches throughout the area. Some areas of present rainforest and woodland have re-grown on abandoned old pastureland (Monroe and Stevens 1977).

Six species of Casuarina (*A. littoralis*, *A. torulosa*, *C. cunninghamiana*, *A. rigida*, *A. equisetifolia* and *C. glauca*) grow in this area. *Allocasuarina littoralis* and *A. torulosa* have been confirmed as important food sources for *C. lathami*, and there is anecdotal evidence of feeding on *C. cunninghamiana*. Caneris (2006) has observed *C. lathami* feeding on *A. equisetifolia* in park situations, where the trees have been watered and fertilised.

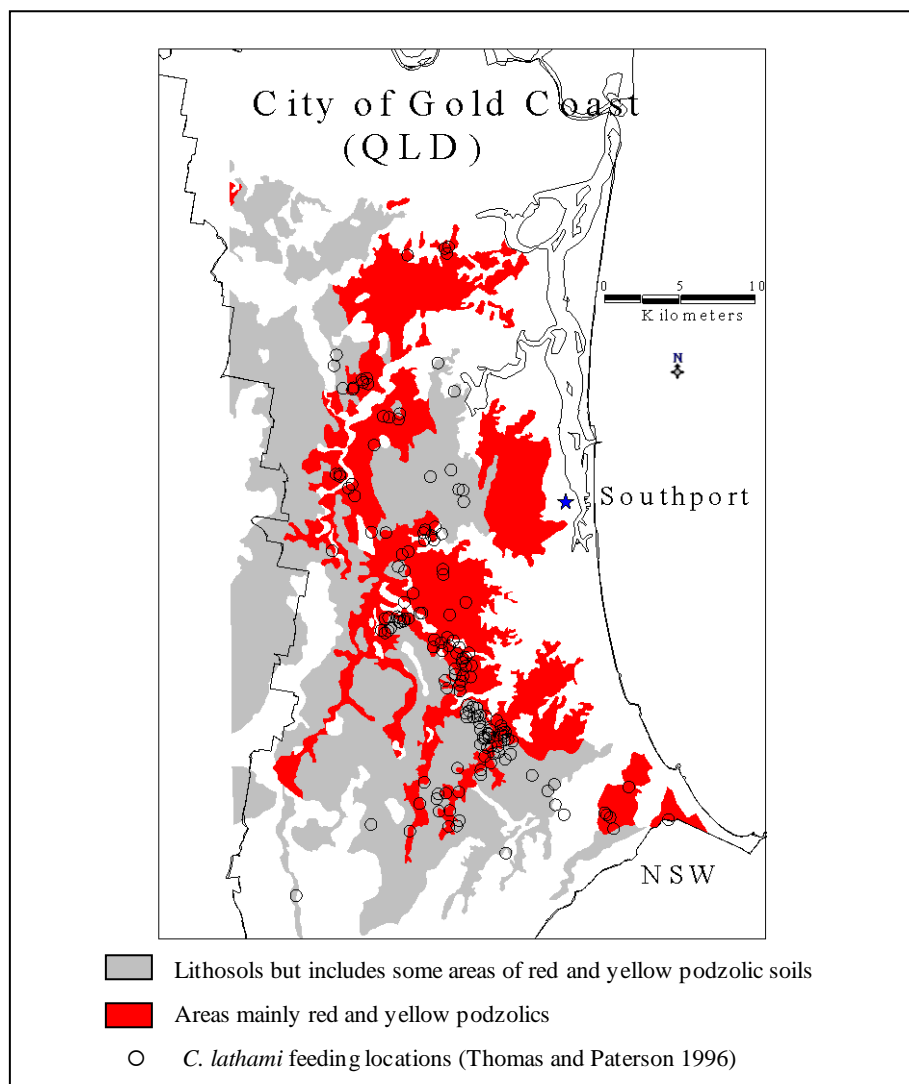


Figure 4. Podzolics and lithosols on the Gold Coast, with *C. lathami* feeding locations (from Thomas and Paterson 1997)

1.3.1 Feed Trees of *C. lathami* in Southeast Queensland

1.3.1.1 *Allocasuarina littoralis*

Allocasuarina littoralis is commonly found in low to medium height (10 – 14 m) open-forest and medium height woodland areas (Crowley 1986, Cronin 1988), growing on low nutrient soils (Barlow 1983, Melville 1995). It occurs on various soil types along the east coast of Australia, extending inland approximately 100 km (Doran and Hall 1981).

In southeast Queensland, *A. littoralis* occurs mainly on or near the coastal plain, especially in open forest on sandy or stony soils (Crowley 1986, Costermans 1996). *Allocasuarina littoralis* is anemophilous and dioecious (Barlow 1983), although some male-dominant dimorphic individuals

have been observed (personal observations of male plant with few female cones). The deep red male flowers are borne in catkin-like spikes and female inflorescences develop into woody cylindrical infructescences or cones (1.5–2.5 cm × 1.1–1.5 cm (Crowley 1986), on a peduncle 1–2 cm long (Figure 5). *Allocasuarina littoralis* has jointed, photosynthetic branchlets (cladodes), 0.3–0.5 mm thick (Stanley and Ross 1983), with each joint bearing a ring of six to seven leaves reduced to brown tooth-like sheaths (Costermans 1996). The bark is grey, rough and fissured.

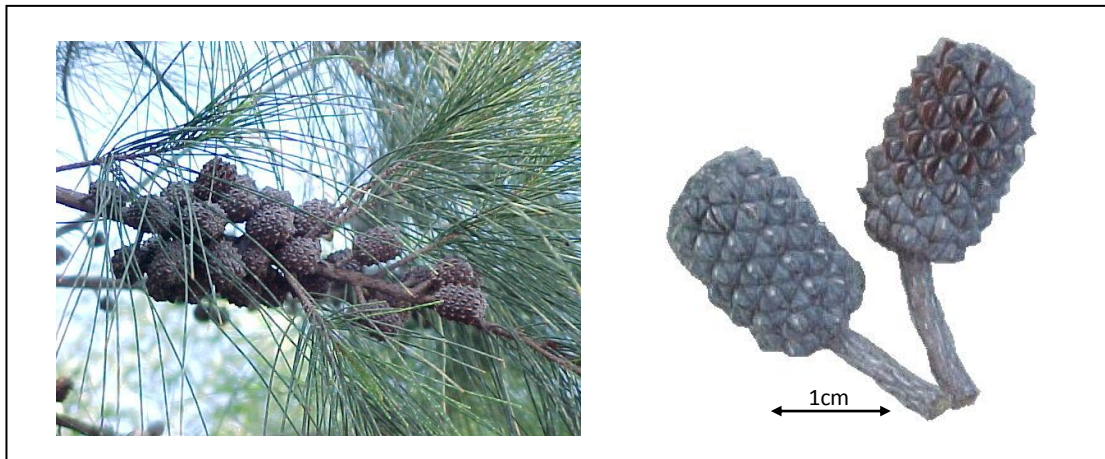


Figure 5. Female cones of *Allocasuarina littoralis*

The seeds of *A. littoralis* are enclosed in a samara (a dry indehiscent one-seeded fruit with part of the wall extended to form a wing — Clarke and Lee 1987), the seed colour deep reddish brown (matching Munsell 7.5YR to 10YR) (observed, Crowley 1986). Seed-fall occurs throughout the year upon desiccation of the cone, but is highest in March to July (Crowley 1986). Restricted dispersal appears characteristic in *A. littoralis* due to a tendency for cones to be shed before seed release (Crowley 1986). The cones usually fall within 3 m of the female tree, but seeds from cones that dehisce whilst still upon the trees are dispersed by wind, therefore the higher on the tree the cones are, the better the chance the seed has of being dispersed further away from the parent tree, preventing being over-shadowed or competitive with the parent tree (Crowley 1986).

Cones on trees may be of different ages. Cones less than a year old are russet-coloured and older cones are grey and harder (Clout 1989), with *C. lathami* appearing to prefer younger cones (Cameron and Cunningham 2006). The persistent cones mean that year-round, there are cones on the tree, although if it is hot and dry, old cones may shed their seeds (Clout 1989).

Very little undergrowth is found under the shade of the foliage of Casuarinas. Using powdered foliage, Crowley (1986) found that *A. littoralis* delayed seed germination in some species (*Eucalyptus* spp. and other *Allocasuarina* spp.), but found no indication that residues of inhibitory substances actually occur in the soil. This suggests that the lack of growth under the canopy

perimeter of Casuarinas may be due to shade intolerance or the dense matting of fallen persistent cladodes acting as a barrier against seedling growth, rather than any allelopathic effect where chemical emissions from one species of plant have a detrimental effect on the germination, growth and development of another species (Rice 1984).

1.3.1.2 *Allocasuarina torulosa*

In addition to *A. littoralis*, *C. l. lathami* also consumes seeds of the forest oak, *A. torulosa* (Figure 6; Clout 1989, Garnett 1997). *Allocasuarina torulosa* is a much taller tree than *A. littoralis*, growing up to 20 m (Stanley and Ross 1983) and is also dioecious (Cronin 1988). The two most characteristic features distinguishing between *A. littoralis* and *A. torulosa* are bark type and cone shape: *A. torulosa* has yellow-brown corky bark and globular-shaped cones (1–2 cm × 1–1.5 cm), whereas *A. littoralis* has fissured bark and cylindrical cones. Branchlets are 0.4–0.5 mm thick (Stanley and Ross 1983), and definitively, *A. torulosa* also has only four leaves per whorl (Costermans 1996).



Figure 6. Female cones of *Allocasuarina torulosa*

A. torulosa is widespread in moist open forests (Cronin 1988) along the east coast of Queensland and New South Wales (Doran and Hall 1981), and may also occur as emergents in subtropical rainforest in the region, possibly as remnants of previous open forests.

1.3.2 Symbiotic Relationship between *Allocasuarina* and *Frankia* species

The capacity of *Allocasuarina* to prosper on highly impoverished soils is believed to be due to symbiosis with nitrogen-fixing actinomycetes of the genus *Frankia*, for sourcing nitrogen, and this collaboration may fix 41–58 kg N ha⁻¹ yr⁻¹ (Crowley *et al.* 1996). *Frankia* spp. are

filamentous bacteria, in the Order Actinomycetales (Becking), Family Frankiaceae (Cano and Colome 1986) but are often incorrectly classed as fungi (e.g. Rose and Barron 1983). All the actinomycetes that form nodules on the roots of non-leguminous dicotyledons are in the single genus *Frankia* (Richards 1987). The *Frankia* species which nodulate *Casuarina* species has/have not been described (He and Critchley 2008).

Actinomycetes are typically aerobic, uncommon in waterlogged soils, and largely intolerant of acidity (Harris 1988). In the nodule-forming symbiotic *Frankia* spp. from *Casuarinas*, the apex of each nodule lobe produces a negatively geotropic, but otherwise normal, root; the nodule being covered by upward growing roots (Lynch and Wood 1988).

Nitrogen production in *Casuarinas* by *Frankia* spp. depends on trace elements such as molybdenum and cobalt, otherwise the plant, although nodulated, will be nitrogen deficient (Crowley 1986). A study on *A. verticillata* found that activity of *Frankia* spp. was reduced by dry conditions (Hopmans *et al.* 1983, Crowley 1986), saline conditions (Hopmans *et al.* 1983) and extreme soil pH values (Crowley 1986). When nitrogen is not limiting, the optimum root growth of *Casuarina* species is in pH range of 4–6 (Crowley 1986).

This symbiotic relationship between *Frankia* and *Allocasuarinas* has enabled these trees to survive and have a competitive advantage over many other plant species in nutrient deficient soils (Torrey and Berg 1988, Melville 1995, Rouvier *et al.* 1996).

1.3.3 Pressures on Woodland Areas on the Gold Coast, Queensland

Several studies have determined that the main factor contributing to low *C. l. halmaturinus* and *C. l. lathami* population size in South Australia and New South Wales, respectively, is habitat loss (Cleland and Sims 1968, Joseph 1989, Clout 1989, Pepper 1996). The last author also found the Kangaroo Island population of *C. l. halmaturinus* to be vulnerable to local events such as wildfires, drought and disease. There are three processes thought to negatively affect woodland areas, and thus *C. l. lathami*, on the Gold Coast: (i) land clearing, (ii) hazard reduction burning/bushfires and (iii) drought.

1.3.3.1 Land Clearing for Development

Much of the Gold Coast was originally forested, but considerable land has been cleared: originally for agriculture and dairy farms (Monroe and Stevens 1977), but more recently, for residential development. The main areas of remaining woodlands that support *C. lathami* are

around Mudgeeraba, Bonogin, Gilston, Nerang and additional areas of the Hinterland. Unfortunately, much of the lowland areas have either been cleared recently, or there are planned developments for these areas. The Gold Coast is a high population-growth area (3.0% per annum, Gold Coast City Council 2006, personal communication), with corresponding expansion of residential areas. Fortunately, some *C. lathami* habitat is protected: Nerang State Forest, Numinbah State Forest, State Forests in Bonogin, Mudgeeraba State Forest, Austinville State Forest, Springbrook National Park, Lamington National Park (O'Reilly's and Binna Burra), although these are still at risk from wildfires and drought.

1.3.3.2 Bushfires and Hazard-Reduction Burns in Southeast Queensland

Calyptrorhynchus lathami lathami in southeast Queensland feed on *A. littoralis* and *A. torulosa*. Most of the known areas where feed trees occur are in *Eucalyptus* woodlands or forests, which are subject to either uncontrolled and often severe bushfires or frequent low-intensity hazard-reduction burns. It is unknown whether the frequency of fire and the total area of *Casuarina* being affected by fire on the Gold Coast and surrounding areas pose a problem for *C. lathami*.

According to Melville (1995) fire of moderate intensity will lead to the death of all but the largest *Casuarina* trees (girth at least 100 cm (Pepper *et al.* 1993)). Nevertheless, regardless of intensity, fire stimulates *Casuarinas* to shed seed (Crowley 1986, Melville 1995). If fire should stimulate mass release of seed from feed trees, the shedding of seed is of no value to *C. lathami* as they extract the seeds from cones straight off the tree (Clout 1989, Pepper 1996), and there have been no reports of them taking seeds from the ground.

Melville (1995) also found that post-fire, in natural heathland and *Casuarina* thickets, heathland plants are more competitive than *Casuarinas* and will displace seedlings. He attributed this effect to the release of nutrients in the impoverished soils, by either release of bound nutrients from soil particles post-heating, or liberation of nutrients from the post-fire ash-bed. Such temporary soil enrichment might benefit competitive weed species more than the poor-soil specialist *Casuarinas*, as is apparent in Melville's heathland results.

The potential effect of fire on *C. lathami* is underscored by the report by Baird (1986) who suggested that the extinction of *C. lathami* on King Island (in Bass Strait between Victoria and Tasmania) was attributable to increased fire frequency or intensity.

In summary, it is probable that the *Casuarina* species in the study area have a response to fire that ensures their survival, and they may even depend on it for re-seeding; however fire may still be

prejudicial to the birds in its effect on the trees. In terms of *C. lathami* survival, there are three important issues:

1. in a severe fire, mature trees, including the feed trees in a given locality, may be killed,
2. in any case, a fire would cause Casuarinas in the area to shed their seeds, thereby removing the food crop from the local feed trees,
3. both the local feed species are known to have extremely low seedling survivorship post-fire in many areas (Melville 1995, Williams 2000), and given that young trees only very rarely serve as feed trees, it will take approximately 10 to 15 years for a new stand of Casuarina to develop to sustain a *C. lathami* population, if the stand is killed by a sufficiently severe fire. Casuarina seedlings, in favourable conditions, are able to produce cones as early as one year old, but feeding by *C. lathami* has only been observed on more mature trees. Pannell and Myerscough (1993) found, in two species of *Allocasuarina*, that seeds of young trees had low viability, suggesting that the avoidance of young trees may be attributable to the poor quality of their seed (and not just poor foraging efficiency due to low cone abundance). During this time, the birds will need to have access to other stands including feed trees.

Furthermore, fire has the potential to destroy hollow-bearing trees, thus reducing the availability of suitable nesting for *C. lathami*. Thus both uncontrolled bushfires and hazard-reduction burning in southeast Queensland have an impact on the survival, renewal and productivity of feed trees in Casuarina stands, potentially resulting in severe shortages of *C. lathami* food sources in localized areas.

1.3.3.3 Drought in Southeast Queensland

Southeast Queensland has a distinct dry season, but at some times, the region may also suffer from drought in the wet season (summer and autumn). The year 2002 was very dry (about 40% of 'normal' annual fall), when many Casuarinas suffered from severe water stress, resulting in low levels of reproduction, brown cladodes and in many cases death of trees (Figure 7). *Allocasuarinas* are known to be poor nutrient specialists (Yadav 1983, Cameron 2004) but the thriftiness of these trees may be dependent on adequate available moisture during the dry season (Yadav 1983). When moisture was limiting during droughts, high mortality or stunted growth occurred in *C. equisetifolia* (Yadav 1983) and significant declines in cone production and foliage density (branch death) occurred in *A. diminuta* and *A. gymnanthera* (Cameron 2004). Chapman (2005) observed similar declines in cone production, but not foliage density, on *A. verticillata* (on Kangaroo Island) as a result of drought. After a year of critically low rainfall, poor quality cones (discoloured, with lowered seed and cone weight) were produced, which were completely ignored by *C. lathami* (Chapman 2005). After several years of low rainfall and subsequent low cone

production, *C. lathami* fed upon older, less nutritious cones. *C. lathami* also failed to breed and were observed feeding on *C. cristata*, which previously had not been observed (Cameron 2004).



Figure 7. Drought consequences in *A. littoralis* on steep slopes near Springbrook (southeast Queensland). Most of these trees were dead with few cones: seeds in existing cones had dehisced.

It would seem that Casuarinas in drier conditions may not receive sufficient resources to replenish cones (Cameron 2004). It is not known if a similar restriction occurs in southeast Queensland.

Casuarinas have reduced leaves (cladodes), which is a strategy used by plants to minimise water loss (Crawley 1997). Casuarinas may use additional strategies to further cope with the effects of drought conditions by, for instance, altering the allotment of resources (Ramakrishnan *et al.* 1997) such as decreasing flower and fruit production, and this may lead to local food shortages for *C. lathami*. While there are a number of strategies that might be adopted by plants to tolerate or overcome drought conditions (Ramakrishnan *et al.* 1997), these will not be addressed in detail here. However, it is important to determine if climatic conditions may place pressures on plants, including Casuarinas, in southeast Queensland, that may ultimately have an effect on the abundance, distribution and viability of the *C. lathami* population.

1.3.3.4 Summary

To ensure the persistence of *C. lathami*, the distribution of Casuarinas needs to be widespread, so that localized events, such as fire, do not appreciably deplete the total food availability at any one time. Furthermore, the total abundance of Casuarina cones available to *C. lathami* needs to exceed their requirements, so that despite temporary losses of food in some areas, alternative places to feed are available whilst the food resources are being renewed in affected areas.

1.4 STUDY SPECIES: BIOLOGY OF *C. LATHAMI*

Three important factors are essential requirements for *C. lathami*: (1) feed trees (*Allocasuarina* species), (2) suitable drinking sites, and (3) nesting trees (hollow-bearing *Eucalyptus* trees). The abundance, quality, and suitability of these factors for *C. lathami*, and their relative distance from each other, will likely determine the abundance, movement and distribution of *C. lathami*.

1.4.1 Feeding Requirements

Calyptorhynchus lathami only feed on the extracted seeds from fresh cones of *Allocasuarina* species (Joseph 1982, Clout 1989), often returning to preferred trees on successive days until trees are almost stripped of cones (Marchant and Higgins 1990, Pepper *et al.* 2000). Pepper (1997) found that 77% of areas containing Casuarinas examined for feeding (43 of 56 localities, total ~1477 ha) had *C. lathami* foraging evidence (chewed cones on the ground under trees, known as “chewings”), with a mean of 12% of female Casuarina trees having chewings. Clout (1989) found that 24% of 1672 cone-bearing trees examined had feeding evidence, with the majority of feeding on trees with over 200 cones (25×0.175 ha plots in *A. littoralis* stands in Eden NSW).

Clout (1989, referring to *A. littoralis*) and Pepper (1996, *A. verticillata*) found preferred feed trees to be mature, low foliage density and between 2 and 10 m tall. In southeast Queensland the height of feed *A. littoralis* and *A. torulosa* observed by Wild *et al.* (2002) was 5-15 m (average 10 m) and 6-16 m (average 11 m), respectively, but this differed little from nearby non-feed trees.

1.4.1.1 Previous Work on Selective Feeding by *C. lathami*

On Kangaroo Island non-breeding *C. lathami* (*C. l. halmaturinus*) feeds on approximately 100 cones of *Allocasuarina verticillata* per day, whilst breeding *C. lathami* feed upon approximately 200 cones per day (Crowley *et al.* 1996). *Calyptorhynchus lathami* do not eat the entire seed: they dissect the seed and extract the kernel. On Kangaroo Island seed-fill (percentage of seeds containing kernels) varies between 0 and 95% (Crowley *et al.* 1996) and the birds have not been recorded taking cones from trees with less than 51% seed-fill. Crowley *et al.* (1996) observed breeding male birds spent approximately 80% of daylight hours obtaining food (when feeding on trees with high seed-fill rates of ~ 80%) therefore a decrease in the seed-fill rates of cones handled would increase the time required for feeding (Crowley *et al.* 1996). Wild *et al.* (2002) studied percentage of germination in seeds of *A. littoralis* and *A. torulosa* on the Gold Coast (percentage of germination determines the percentage of viable kernels, an easier and more

accurate method than dissection of seed). No difference was observed between the percentage germination in feed and non-feed trees, but seeds of feed trees did germinate quicker ($p = 0.024$).

Pepper (1996) reported that protein levels may be inadequate in the cockatoo's diet during nesting on Kangaroo Island, as a result of the additional protein required for incubation and feeding the nestling², combined with the reduction in feeding time by the female. Whether such limitations restrict where *C. lathami* can successfully breed in southeast Queensland needs to be determined.

Other factors that Clout (1989) and Crowley *et al.* (1996) found to increase the likelihood of a Casuarina being a feed tree for *C. lathami* are cone crop size and size of cones: factors which would affect search and handling time. Many studies have found that feed trees permit higher energy intake, and have higher seed-fill rates, Clout's index (seed weight as a fraction of cone weight), higher nutritional quality, more lipids, protein and less fibre, than non-feed trees, in *A. verticillata* and *A. littoralis* (Clout 1989, Crowley *et al.* 1996, Pepper 1996, Cameron and Cunningham 2006).

Studies on Kangaroo Island have also demonstrated that *C. l. halmaturinus* feeds almost entirely on seeds of *A. verticillata* (Garnett *et al.* 1997). The cockatoos' choice of feed trees, based on seed quality (i.e. seed-fill), may have a correlation with soil and geology (Garnett *et al.* 1997). Studies so far have indicated that Casuarina growth is best in acidic soils, specifically podzolics and lithosols (Crowley *et al.* 1996), and on certain rock types and slopes (Crowley *et al.* 1998). Highest levels of seed-fill in *A. verticillata* on Kangaroo Island are associated with topsoils which are slightly acidic, low in calcium and often high in aluminium. Crowley *et al.* (1996) found a positive relationship between seed-fill and the concentration of aluminium in the topsoil on Kangaroo Island. *A. littoralis* is known to reach seed-fills greater than 80% in riparian areas on acidic podzolic soils with pH ~4.5 (Crowley *et al.* 1996), therefore, it is expected that these areas would be able to support a large *C. lathami* population.

Within a small stand of Casuarinas, little variation in soil type and quality is to be expected, but in larger stands and between different stands greater variation is likely to occur. This variation in the soil may reflect a similar variation in the food value of Casuarina seeds of different trees. A tree's characteristics, in terms of growth and reproduction, will be dictated by genetics, but their full potential will still be limited by nutrient availability in the soil. Both soil and genetics will affect cone and tree characteristics, such as cone size and colour, palatability, and tree dimensions etc.

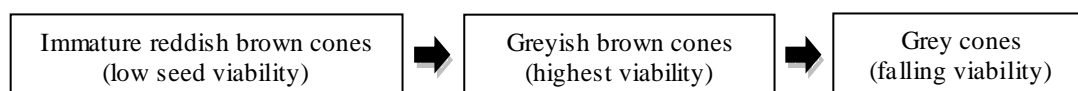
² *C. lathami* is an altricial species, meaning chicks are born dependent on the parent for an extended period: altricism occurs in birds where there is difficulty obtaining extra nourishment needed for egg formation, therefore smaller eggs are produced i.e. a more developed chick would require more energy put into the egg (O'Connor 1984).

Wild *et al.* (2002) investigated a complex suite of characteristics that may affect the dichotomous feeding status (feed or non-feed) of *Allocausarinas* in southeast Queensland. This study explored whether the seed quality of *A. littoralis* and *A. torulosa* differed between feed and non-feed trees, and if any differences were related to soil quality (soil type and a suite of nutrients was investigated), tree or habitat characteristics. That research indicated that individual seed weight, time taken for 50% of viable seeds to germinate and to a weak degree, number of cones, are determinants of feeding status for *A. littoralis* (i.e. if the tree is a feed or non-feed tree), and trunk circumference and ground slope are determinants for *A. torulosa*. No great difference in cone abundance between feed and non-feed trees was observed, but this estimate did not take into account cone loss from *C. lathami* feeding. Prior to feeding, the cone abundance is anticipated to have been significantly higher in feed than non-feed trees: *C. lathami* feeding had resulted in similar cone abundance.

There was some evidence to suggest that the differences for both species were influenced by soil quality, specifically nitrogen levels were higher in soil under feed trees. Similarly to *A. verticillata* on Kangaroo Island, *C. lathami* feed trees (*A. littoralis* and *A. torulosa*) on the Gold Coast typically grow on impoverished podzolics (red and yellow) and lithosols.

Both Wild *et al.* (2002) and Chapman (2005) found nitrogen levels to be higher in soil under feed trees than non-feed trees, and Chapman (2005) found that the addition of fertiliser significantly increased cone set. Further work investigating selective feeding of cockatoos on the Gold Coast is reported and expanded upon in Chapter 3.

As previously stated, Casuarinas usually have 3 distinguishable aged cones on a tree:



The seeds of greyish brown cones have higher protein (27% protein crude content, Kjeldahl digestion) than those of older grey cones and immature reddish brown cones (14% protein) (Clout 1989, Crowley and Garnett 2001). Long-term field studies have observed *C. lathami* have a preference for feeding on greyish brown cones of *A. littoralis*, only feeding on the older grey cones and immature reddish brown cones when there is an apparent shortage of greyish brown cones (Cameron 2004, Chapman 2005). Further, Pannell and Myerscough (1993) suggested that viability of seeds of Casuarina changes dramatically with tree age. On this basis, we would expect that young trees are ‘non-feed’ trees with low seed viability; at maturity they become apparently suitable trees with highest viability and with age possibly revert to non-feed trees, as found in *A. distyla* and *A. nana* (Pannell and Myerscough 1993). Juvenile trees would allocate more

resources to growth than reproduction, whereas mature trees would be able to allocate more to reproduction.

Although much of the literature (e.g. Cleland and Sims 1968, Forshaw and Cooper 1981) commonly states that *C. lathami* normally feed only on Casuarina seeds, there is speculation that they also subsidize their intake with other plant species or insects, as do most granivorous birds (Joseph 1986). Diaz (1996) found that insectivory by some granivorous birds might be attributable to seasonal shortages of their preferred food species (e.g. flowering and availability of seeds), rather than additional nutrient requirements, but both Clout (1989) and Pepper (1996) have reported that *C. lathami* do not actively search for insects. The persistent cones of *Allocasuarina* species (including *A. littoralis* and *A. torulosa*) may be retained on the tree, possibly several years after they have matured, allowing *C. lathami* a year-round supply of seeds, except after fire or drought. The only further requirement for the birds would be water, in light of the extremely low water content of most seeds (Diaz 1996): typically 5-15% of the total seed weight (Joseph 1986, Grace 1997).

The feeding ecology of *C. lathami* indicates that they actively search for high quality Casuarina seeds for food. Given observations that *C. lathami* do return to profitable trees annually without further exploratory sampling, there is support for the hypothesis that factors determining feeding status may be visual (observed, Anonymous 2002).

Since differences between feed and non-feed trees were observed on Kangaroo Island (Crowley *et al.* 1996, Garnett *et al.* 1997), *C. l. halmaturinus* probably have the ability to reduce their foraging time (search, manipulation and ingestion) by feeding on trees that have seeds that have high nutrient quality and cones that are easily manipulated. This is discussed in detail by Crowley and Garnett (2001).

Such a clear distinction between feed and non-feed trees is not observed in southeast Queensland (Wild *et al.* 2002), but the abundance and quality of *A. littoralis* and *A. torulosa* in this area needs to be investigated further. If it is discovered that *C. lathami* are in fact attracted to a specific characteristic, or a suite of characteristics, of Casuarinas or the surrounding localised habit, this trait can be taken into account in conservation and revegetation plans.

1.4.2 Drinking

Casuarina seeds provide very little water, which means that *C. lathami* must always have access to a suitable water source to drink daily. These birds usually drink at dusk, before moving to their

nests or roosts: they have been observed drinking at dawn only during particularly hot summer weather (Pepper 1996). Therefore, the ability of an area to maintain water throughout the dry period of the year is an important contributor to the suitability of an area to support a *C. lathami* population.

It seems that *C. lathami* prefer small creeks to rivers and dams, although during the wet season they are often seen drinking from puddles and during drought conditions, when many of the creeks are completely dry, they have been observed drinking from dams (Anonymous 2002).

According to Higgins (1990), *C. lathami* flock only to drink. In the study area, *C. lathami* have been observed drinking in pairs and in flock sizes ranging from 5 to 14 (Anonymous 2002). They are strongly arboreal and only come to the ground to drink (Forshaw and Cooper 1981, Marchant and Higgins 1990), but not all birds in the flock drink at once.

Usually only two or three birds will drink at any one time, while the remaining birds stay perched in surrounding trees (Pepper 1996), most likely for safety reasons. Predation has been suggested as a cause of flocking in parrots, where larger group sizes provide additional protection for individuals, thereby reducing an individual's predation risk (Pepper 1996).

With the conversion of much *C. lathami* habitat to residential areas, it seems likely that the presence of domestic animals (such as cats and dogs) and many anthropogenic factors (for example, noisy machinery and traffic etc.) may now prevent *C. lathami* from using previously acceptable drinking sites. On several occasions, the author observed *C. lathami* taking flight after being frightened by dogs barking close-by.

1.4.3 Nesting

Female *C. lathami* on Kangaroo Island usually first breed at two years of age (Garnett *et al.* 1997, Marchant and Higgins 1990), whereas males are usually older when they start breeding. *C. lathami* are obligate hollow nesters and have been observed nesting in hollows of living or dead tall eucalyptus trees (Marchant and Higgins 1990). Coffey (1996) found that most nests on the northeast coast of New South Wales were in blackbutt trees (*E. pilularis* Smith), and sometimes pink bloodwood (*Corymbia intermedia* Baker). Cameron (2006) observed nests in narrow-leaved ironbark (*E. creba*), blue-leaved ironbark (*E. nubila*) and Blakely's red gum (*E. blakelyi*) in central New South Wales (Goonoo State Forest). The subspecies of *C. lathami* on Kangaroo Island nests and roosts in sugar gum (*Eucalyptus cladocalyx* F. Muell.) or South Australian blue gum (*E. leucoxylon* F. Muell.) (Pepper 1996). However, it is thought that in

Queensland *C. lathami* may nest in any *Eucalyptus* or *Angophora* species that fulfill the necessary hollow requirements (Paterson 1997), but there are no studies confirming this.

In areas subject to logging and/or fire, a shortage of tree hollows for nesting sites affects nesting rates of many bird species (Ford 1985, Kavanagh *et al.* 1985, Smith 1985). In Western Australia, Saunders *et al.* (1985) studied the effects on cockatoos of land clearing for agriculture, as they are obligate hole-nesters but are not able to excavate hollows themselves³, and are never recorded nesting in anything other than hollows. The distributions of many species of cockatoos changed after land clearing, the degree of change dependent on the specificity of their nesting and feeding requirements.

For example, the Major Mitchell's Cockatoo (*Cacatua leadbeateri*) population declined after land clearing, with territoriality during nesting limiting the number of usable nests. Joseph *et al.* (1991) also found a lack of hollows in dead trees (dead trees have deeper hollows than live trees) to be a limiting factor for Red-tailed Black-Cockatoos (*Calyptorhynchus banksii graptogyne*) in southwestern Victoria. The number of suitable hollows for *C. lathami* may similarly be limited due to their particular requirements.

Garnett *et al.* (1999) found that most *C. lathami* nests on Kangaroo Island were in large (20–40 m height), living *E. cladocalyx* (39 of 45 trees were living *E. cladocalyx* and 5 of 45 trees were standing dead trees ('snags'): the availability of unused snags was not reported), whereas Cameron (2006) reported that 50 % of nests (~15) observed in Goonoo State Forest (central NSW) were in snags, despite their rarity (32 of 101 potential nest trees).

Snags usually have fewer hollows (resulting from partial loss of the crown), but tend to have larger hollows (age and exposure to hollow-forming elements (Cameron 2006)). Such hollows have less thermoregulatory capacity than hollows in living trees (Gibbons and Lindenmayer 2002).

Pepper (1996), Garnett *et al.* (1999) and Cameron (2006) all observed a clustering of active *C. lathami* nests, with nests typically occurring within 1 km from another nest. Pepper (1996) and Garnett *et al.* (1999) also observed trees containing more than one active *C. lathami* nest, although antagonism between females was observed. *C. l. halmaturinus* has been observed using the same nests in consecutive years, but not necessarily by the same pair (Joseph 1982, Pepper 1996, Garnett *et al.* 1997).

³ No tree-hollow nesting birds in Australia are known to excavate their own hollows (Ford 1985).

Forshaw and Cooper (1981), Pepper (1996) and Healey (1997) suggest 10 m as the minimum distance from the ground for nesting and shelter, with the branch preferably at an angle to prevent rain from entering the nest (Paterson 1997): many nest failures can be attributable to the nest flooding (Joseph 1982, Crowley *et al.* 1996) where chicks either drown or where survival is compromised due to reduced thermoregulatory capacity (Radford and Du Plessis 2003). Since females will re-lay if the first nest fails, the second clutch may be in winter, when it is too cold and too wet on Kangaroo Island for a nestling to survive (Joseph 1982), emphasising the importance of suitable hollows.

It has been observed that a shortage of suitable nest hollows, arising from loss of habitat and subsequent competition for nest hollows, may prevent nesting of *C. lathami* on Kangaroo Island. This problem is long-term as it takes up to 100 years for *Eucalyptus* spp. to form hollows suitable for *C. lathami* (Crowley *et al.* 1996, Chapman 2000). Species of trees that do commonly form hollows need to have been exposed to ‘hollow-forming’ agents, such as termites and fire, and it is usually older trees that have developed large hollows. Therefore many trees in eucalypt forests do not have hollows (Abbott 1998, Cameron 2006), and in many of the trees that do have hollows, they are relatively small, preventing large birds such as *C. lathami* from nesting in them (Garnett *et al.* 1997). The ideal hollow for *C. lathami* would need to be large enough to accommodate an adult cockatoo (45-50 cm, head to tail, Morcombe 2000) as well as the chick. Nest boxes that have been accepted by wild *C. l. halmaturinus* were 30 cm (d) x 30 cm (w) x 60 cm (h) (Garnett *et al.* 1997).

In addition to a possible shortage of suitable nest hollows, *C. lathami* also has to contend with competition for these nests and nest predation. Many birds from the family Cacatuidae, including Galahs (*Cacatua roseicapillus* Vieillot), Little Corellas (*Cacatua sanguinea* Gould), Sulphur-crested Cockatoos (*Cacatua galerita* Latham), and Yellow-tailed Black-Cockatoos (*Calyptorhynchus funereus* Shaw) compete for these nest hollows and some, being more aggressive, tend to drive *C. lathami* away (Crowley *et al.* 1996, Garnett *et al.* 1997, observed).

Furthermore, a high level of predation on eggs and young *C. lathami* by common brush-tailed possums (*Trichosurus vulpecula* Kerr (Phalangeridae)) is known to occur on Kangaroo Island resulting in a chick survival of only about 10% (Garnett *et al.* 1997, Garnett *et al.* 1999), and is expected elsewhere. A combination of these negative factors (i.e. competition for nests and high nest predation) is likely to contribute to a low breeding success in *C. lathami* (Crowley *et al.* 1996, Garnett *et al.* 1997).

Other factors possibly contributing to a low recruitment rate on Kangaroo Island are:

Chapter 1— Introduction

- male-biased populations (1.4 males : 1 female), which means there are low numbers of breeding pairs (possible high female mortality) (Schodde *et al.* 1993, Pepper 1996), and
- lack of suitable feed trees (i.e. limited nutritional resources to successfully raise a nestling).

Calyptrorhynchus lathami only lay one egg (Crowley *et al.* 1996, Garnett *et al.* 1997), thought to be due to a tight energy budget (Pepper 1996). The majority of *C. l. halmaturinus* observed by Garnett *et al.* (1997) have been observed laying their eggs between February and July, similar to Courtney (1986), but Connors and Connors (1988) found it to be as late as October. Females have been known to re-lay if the first egg fails (Courtney 1986), and eggs observed late in the season are expected to be second-laying eggs. Nesting incubation takes approximately 30 days (variously reported as 28–33 days — Courtney 1986, Connors and Connors 1988, Garnett *et al.* 1999, Chapman 2000).

Some studies suggest chicks fledge at 60 – 70 days (Forshaw and Cooper 1981), but Connors and Connors (1988) and Garnett *et al.* (1999), have found chicks to fledge on average at 90 days (min 85, max 106 (Connors and Connors 1988), whilst Courtney (1986) found it to take 100 days. Fledging mainly coincides with maximum food abundance (July/August), with the added advantage that new cones are easier to open than older cones, an important factor for naïve juveniles (Clout 1989, Pepper 1996). *C. lathami* only occupies a nest from egg laying to when the chick fledges, approximately 120 days on average.

In Eden (NSW) *C. lathami* breed in winter and probably fledge their single young in August (Clout 1989), while breeding is from late summer through to winter on Kangaroo Island (February to July) (Garnett *et al.* 1997). That author reported that, on the basis of breeding behaviour, nesting activity and sightings of juveniles, *C. lathami* on the Gold Coast probably have the same nesting season as those on Kangaroo Island.

During the breeding season the male collects food, and regurgitates it for the nesting female, who will in turn feed the nestling (Garnett *et al.* 1997, Chapman 2000). This means that for up to 100 days, usually only the male will be observed feeding. The female may join the male to feed for 1–2 hours per day and to drink in the evenings (observed, Garnett *et al.* 1997).

Juveniles usually stay with their parents for at least six months, possibly up to one year (Pepper 1996). Essentially, juveniles may stay with their parents until the onset of the next breeding season (Pepper 1996, Garnett *et al.* 1997), although birds older than twelve months have been observed still begging for food, sometimes being fed by unpaired mature males (observed, KIGBCRT 1996). Perennial monogamy has enabled this extended parental care beyond the breeding season (Pepper 1996).

It is not known whether similar nesting patterns occur on the Gold Coast and whether there is a similar low recruitment rate as seen on Kangaroo Island. *C. lathami* is believed to be long-lived (Garnett 1993), as is typical in parrots (Pepper 1996). Captive parrots of various species have lived for over 80 years (Hill 1954, Forshaw and Cooper 1981). This long life-span, coupled with a low reproductive potential, means *C. lathami* populations may be very slow to indicate any changes in circumstances that may ultimately be disastrous for the population (Pepper 1996).

1.4.3.1 Roosting

When *C. lathami* are not breeding, they may be found roosting, mainly in the canopy of live, leafy trees: preferably *Eucalyptus* species (Marchant and Higgins 1990). There have been reports of *C. lathami* roosting in *Pinus* species (Marchant and Higgins 1990) and Hoop Pine (*Araucaria cunninghamii* (Ait.) D. Don, Araucariaceae). O'Connor (1984), Pepper (1996) and Garnett *et al.* (1997) suggest that these choices may reflect maintenance behaviour, for example, providing the opportunity to chew loose bark off eucalypts etc, to maintain bills.

Pepper (1996) reported that groups of *C. l. halmaturinus* roosted year round in the same small (~0.25 ha) stand of sugar gums (*E. cladocalyx*). It has in fact been reported on the Gold Coast that *C. lathami* are seen in the same areas at various times of the year, and in consecutive years (Anonymous 2002). It is not known whether it is the same groups of birds returning, however.

1.4.4 Habitat Requirements of *C. lathami*

Calyptorhynchus lathami inhabit eucalyptus forests and woodlands, often being found in coastal or sub-coastal areas, including foreshores and offshore islands (Marchant and Higgins 1990). A loss of feeding habitat, and thus a change in *C. lathami* distribution (Pepper 1996), has occurred as a result of clearing of woodlands, altered fire regimes (Baird 1986) and grazing (suppressing regeneration) (Crowley *et al.* 1996).

Clout (1989) determined that during the breeding season (winter) breeding male *C. lathami* observed at Eden, New South Wales, spent 88% of their time foraging (compared to as little as 40% for non-breeders), 8% resting and preening and 4% involved in other activities (flying, drinking, socializing). Pepper (1996) found that on Kangaroo Island 60% of time was spent foraging and 34% perching. More recently Chapman and Paton (2005) suggest that *C. lathami* do not have foraging-intensive activity budgets, but they did also report greater foraging effort amongst breeding birds than non-breeding birds. These studies indicate that *C. lathami* spend a considerable amount of the day feeding, and spend little time flying between trees and sites. This

may of course be closely linked to forage availability across the landscape. If the food quantity required by breeding *C. lathami* was not available within 12 km of their nesting and drinking site, nests would be abandoned due to food shortages (Crowley *et al.* 1998, Garnett *et al.* 1999).

Crowley *et al.* (1996) reported that a successful breeding pair on Kangaroo Island was found to theoretically need 1 ha of *A. verticillata*, if they were all feed trees. Since less than 25% of Casuarina trees (viable trees) have been observed to be feed trees (Clout 1989, Pepper 1997) and many species in their habitat are not Casuarinas, Crowley *et al.* (1998) determined that a breeding pair required access to at least 400 ha (average 743 ± 320 ha) of *A. verticillata*. Such demanding requirements for breeding severely limit the number of areas where they can successfully breed.

1.4.5 Movements

The movement of breeding *C. lathami* is restricted to relatively short distances, but the extent of non-breeding *C. lathami* movement is little known. The South Australian subspecies *C. l. halmaturinus* is a relic of a larger population that once extended to the Mt Lofty Ranges, South Australia, and is thought to have traveled widely throughout their range (Joseph 1989, Schodde *et al.* 1993). Due to habitat loss and consequent food shortage, they are now restricted to Kangaroo Island. The literature suggests that *C. lathami* is capable of flying great distances during the non-breeding season (one pair flew over 60 km away from their nesting area in the non-breeding season (Garnett 1993), but may only relocate if necessary i.e. in response to depleted food sources (Pepper 1993). Studies have found several Rosella species (*Platycercus* spp. Cacatuidae: Ford 1985) and the Yellow-faced Honeyeater (*Lichenostomus chrysops* Meliphagidae: Farmer 2001) have both sedentary and mobile members of the population, reflecting the abundance of resources.

Calyptorhynchus lathami, unlike many parrots and cockatoos, do not form large flocks to feed. Lack of flocking in bird species has been observed when their food sources are limited, whereby flocking would quickly deplete resources, forcing birds to relocate, thus increasing their search time and expending extra energy to fly further distances to find adequate food sources (Pepper 1996). Joseph (1982) and Pepper (1996) found an increase in flock sizes in *C. lathami* in winter, after nestlings had fledged, coinciding with the greatest abundance of food supply.

Pepper (1996) also found a hierarchy exists in *C. lathami*, with paired birds being higher in the hierarchy than unpaired birds, giving them access to more, and higher quality, resources. Pepper (1996) observed male pairs on several occasions, this type of alliance placing them higher in the hierarchy than non-paired birds, but lower than breeding pairs. Hierarchical alliances, feeding

selectivity and lack of flocking are all indicative of resource competition and thus a shortage of resources (either in quantity or quality). It is unknown whether such limitation of resources occurs on the Gold Coast, influencing the movement of *C. lathami*.

1.5 REFERENCES

- Abbott, I. 1998. Conservation of the forest red-tailed black cockatoo, a hollow dependent species, in the eucalypt forest of Western Australia. *Forest Ecology and Management*. **109**: 175-185.
- Anderies, J.M., Katti, M. and Shochat, E. 2007. Living in the city: Resource availability, predation, and bird population dynamics in urban areas. *Journal of Theoretical Biology*. **247**: 36-49.
- Andrieu, E., Dornier, A., Rouifed, S., Schatz, B. and Cheptou, P-O. 2009. The town Crepis and the country Crepis: How does fragmentation affect a plant-pollinator interaction? *Acta Oecologica*. **35**: 1-7.
- Anonymous 2002. *Sightings and Records*. Unpublished report of the Wildlife Preservation Society of Queensland, Glossy Black-cockatoo Branch Inc. Gold Coast.
- Baird, R.F. 1986. Historical records of the glossy Black-Cockatoo *Calyptorhynchus lathami* and red-tailed Black-Cockatoo *C. magnificus* in south-eastern Australia. *South Australian Ornithologist*. **30**: 38-45.
- Ball, S.J., Ramsey, D., Nugent, G., Warburton, B. and Efford, M. 2005. A method for estimating wildlife detection probabilities in relation to home-range use: insights from a field study on the common brushtail possum (*Trichosurus vulpecula*). *Wildlife Research*. **32**: 217-227.
- Barlow, B.A. 1983. *Casuarina* - a taxonomic and biogeographical review. pp. 10-18 in Midgley, S.J., Turnbull, J.W. and Johnston, R.D. (eds) *Casuarina Ecology, Management and Utilization: Proceedings of an International Workshop*. CSIRO Melbourne. ISBN 0643034633.
- Baum, K.A. and Grant, W.E. 2001. Hummingbird foraging behaviour in different patch types: simulation of alternative strategies. *Ecological Modelling*. **137**: 201-209.
- Bennetts, R.E. and Kitchens, W.M. 2000. Factors influencing movement probabilities of a nomadic food specialist: proximate foraging benefits or ultimate gains from exploration? *Oikos*. **91**: 459-467.
- Block, W.M. and Brennan, L.A. 1993. The habitat concept in ornithology: Theory and applications. *Current Ornithology*. **11**: 35-91.
- Brook, B.W., Traill, L.W. and Bradshaw, C.J.A. 2006. Minimum viable population sizes and global extinction risk are unrelated. *Ecology Letters*. **9**: 375-382.
- Brown, G.S. and Gass, C.L. 1993. Spatial association learning by hummingbirds. *Animal Behaviour*. **46**: 487-497.
- Brown, G.W. and Triggs, B. 1989. Diets of wild canids and foxes in East Gippsland 1983-1987, using predator scat analysis. *Australian Mammalogy*. **13**: 209-13.
- Cameron, M. 2004. *Ecology of the Glossy Black-cockatoo (Calyptorhynchus lathami) in central New South Wales*. PhD thesis. University of New England, Armidale. 168pp.
- Cameron, M. 2006. Nesting habitat of the glossy black-cockatoo in central New South Wales. *Biological Conservation* **127**: 402-410.
- Cameron, M. 2007. *Cockatoos*. Australian Natural History Series, CSIRO Publishing, Collingwood Victoria. 230pp. ISBN 0643092327.
- Cameron, M. and Cunningham, R.B. 2006. Habitat selection at multiple spatial scales by foraging Glossy Black-cockatoos. *Austral Ecology*. **31**: 597-607.

- Campbell, S.P., Witham, J.W. and Hunter, M.L. Jr. 2010. Stochasticity as an alternative to deterministic explanations for patterns of habitat use by birds. *Ecological Monographs*. **80**(2): 287-302.
- Caneris, A. 2006. *Glossy Black-Cockatoo Conservancy*. Brisbane. Pers. comm.
- Cano, R.J. and Colome, J.S. 1986. *Microbiology*. West Publishing Company, St Paul Minnesota. 888pp. ISBN 0314852239.
- Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology*. **63**: 215-244.
- Champlin, T.B., Kilgo, J.C. and Moorman, C.E. 2009. Food abundance does not determine bird use of early-successional habitat. *Ecology*. **90**(6): 1586-1594.
- Chapman, T. 2000. Fussy Black-Cockatoo. *Nature Australia*. **26**(7): 49-55.
- Chapman, T.F. 2005. *Cone production by the Drooping Sheoak *Allocasuarina verticillata* and the feeding ecology of the Glossy Black-cockatoo *Calyptorhynchus lathami halmaturinus* on Kangaroo Island*. PhD thesis. University of Adelaide, Adelaide. 124pp.
- Chapman, T.F. and Paton, D.C. 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.
- Chapman, T.F. and Paton, D.C. 2006. Aspects of Drooping Sheoaks (*Allocasuarina verticillata*) that influence Glossy Black Cockatoo (*Calyptorhynchus lathami halmaturinus*) foraging on Kangaroo Island. *Emu*. **106**:1-6.
- Charnov, E.L. 1976. Optimal foraging, the marginal value theorem. *Theoretical Population Biology*. **9**(2): 129-136.
- Chittka, L. and Menzel, R. 1992. The evolutionary adaptation of flower colours and the insect pollinators' colour vision. *Journal of Comparative Physiology*. **A**: 171-181.
- Clarke, I. and Lee, H. 1987. *Name that Flower*. Melbourne University Press, Melbourne. 260pp. ISBN 0522843352.
- Cleland, J.B. and Sims, E.B. 1968. Food of the Glossy black-cockatoo. *South Australian Ornithologist*. **25**: 47-52.
- Clout, M. 1989. Foraging behavior of Glossy Black-Cockatoos. *Australian Wildlife Research*. **16**: 467-473.
- Coffey, T. 1996. *Habitat status of the glossy black-cockatoo (*Calyptorhynchus lathami*) in Cudgen Nature reserve, northern New South Wales*. Unpublished report, Southern Cross University, Lismore, NSW. 52pp.
- Connors, N. and Connors, E. 1988. The glossy black cockatoo *Calyptorhynchus lathami*. *Australian Aviculture*. (May 1988 edn): 116-119.
- Costermans, L. 1996. *Native Trees and Shrubs of south-eastern Australia*. Lansdowne Press, Sydney. 424pp. ISBN 0947116767.
- Courtney, J. 1986. Plumage development and breeding biology of the Glossy black-cockatoo. *Australian Bird Watcher*. **11**: 261-273.
- Crampton, L.H, Longland, W.S., Murphy, D.D. and Sedinger, J.S. 2011. Food abundance determines distribution and density of a frugivorous bird across seasons. *Oikos*. **120**: 65076.
- Crawley, M.J. 1997. *Plant Ecology*. Blackwell Science, Australia. 717pp. ISBN 0632036394.

Chapter 1— Introduction

- Cronin, L. 1988. *Key Guide to Australian Trees*. Reed Books, Victoria. 112pp. ISBN 1876334833.
- Crowley, G., Garnett, S., Meakins, W. and Heinich, A. 1998. *Protection and re-establishment of glossy black-cockatoo habitat in South Australia: Evaluation and recommendations, Kangaroo Island*. Report prepared for the Glossy black-cockatoo Rescue Fund, South Australian National Parks Foundation. 45pp.
- Crowley, G.M. 1986. *Ecology of Allocasuarina littoralis (Salisb) L. Johnson and A. torulosa (Ait.) L. Johnson in North Queensland*. PhD thesis, Botany Department. James Cook University, North Queensland. 301pp.
- Crowley, G.M. and Garnett, S.T. 2001. Food value and tree selection by glossy black-cockatoos *Calyptorhynchus lathami*. *Austral Ecology*. **26**: 116-126.
- Crowley, G.M., Garnett, S.T. and Pedler, L. 1996. *Assessment of the role of captive breeding and translocation in the recovery of the South Australian subspecies of the Glossy black-cockatoo Calyptorhynchus lathami halmaturinus. Kangaroo Island, South Australia*, Report prepared for the South Australian Glossy black-cockatoo Recovery Team. 40pp.
- Cruz-Angón, A., Sillett, T.S. and Greenberg, R. 2008. An experimental study of habitat selection by birds on a coffee plantation. *Ecology*. **89**(4): 921-927.
- Diaz, M. 1996. Food choice by seed-eating birds in relation to seed chemistry. *Comparative Biochemistry and Physiology*. **113A**(3): 239-246.
- Doran, J.C. and Hall, N. 1981. Notes on fifteen Australian *Casuarina* species. In Midgley, S.J., Turnbull, J.W. and Johnston, R.D. (eds), *Casuarina Ecology, Management and Utilization: Proceedings of an International Workshop*. CSIRO, Melbourne. ISBN 0643034633.
- Farmer, D. 2001. *Patterns of use of lowland eucalypt forests in southeast Queensland, by winter migrating forest birds*. Faculty of Environmental Sciences, Griffith University, Brisbane. 124pp.
- Ford, H.A. 1985. A synthesis of the foraging ecology and behavior of birds in Eucalypt forests and woodlands. Ch. 21, pp 249-254 in *Birds of Eucalypt forests and woodlands. Ecology, conservation and management*. Keast, A., Recher, H., Ford, H. and Saunders, D. (eds). Surrey Beatty and Sons. Chipping Norton NSW. 384pp. ISBN 0949324061.
- Forshaw, J. and Cooper, W. 1981. *Australian Parrots*, 2e. Lansdowne Press, Melbourne. 312pp. ISBN 0701810351.
- Franklin, I.R. 1980. Evolutionary change in small populations. pp 135-149 in M.E. Soulé and B.A. Wilcox *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland. 380pp. ISBN 0878938001.
- Fretwell, S.D. and Lucas, Jr. H.L. 1969. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical Development. *Acta Biotheoretica*. **19**: 16-36.
- Garnett, S. 1993 (ed.). *Threatened and extinct birds of Australia*. Royal Australian Ornithologists Union, Victoria. 212pp. ISBN 0008158012
- Garnett, S. 1997. *Conservation plan for the Gold Coast population of Glossy black-cockatoos (Calyptorhynchus lathami)*. *Gold Coast*. unpublished report. 6pp.
- Garnett, S.T. and Crowley, G.M. 2000. *The Action Plan for Australian Birds*. Environment Australia, Canberra. 673pp. ISBN 0642546835.

- Garnett, S.T., Crowley, G.M., Dennis, T.E. and Chapman, T.F. 1997. *Recovery Plan for the South Australian subspecies of the Glossy black-cockatoo (Calyptorhynchus lathami halmaturinus). Kangaroo Island, South Australia.* Unpublished report to the Threatened Species and Communities Section, Environment Australia. 16pp.
- Garnett, S.T., Pedler, L.P. and Crowley, G.M. 1999. The breeding biology of the glossy black-cockatoo *Calyptorhynchus lathami* on Kangaroo Island, South Australia. *Emu* **99**(4): 262-279.
- Gibbons, P. and Lindenmayer, D.B. 2002. *Tree Hollows and Wildlife Conservation in Australia.* CSIRO Publishing, Victoria. 240pp. ISBN 0643067059.
- Gibbons, P., Lindenmayer, D.B., Barry, S.C. and Tanton, M.T. 2002. Hollow selection by vertebrate fauna in forests of southeastern Australia and implications for forest management. *Biological Conservation.* **103**: 1-12.
- Grace, J. 1997. Plant water relations. pp. 28-50 in Crawley, M. J. *Plant Ecology.* Blackwell Science, London. 736pp. ISBN 0632036394.
- Harrington, L.A., Harrington, A.L., Hughes, J. and MacDonald, D.W. 2008a. Estimating the relative abundance of American mink *Mustela vison* on lowland rivers: evaluation and comparison of two techniques. *European Journal of Wildlife Research.* **54**: 79-87.
- Harrington, L.A., Harrington, A.L., Hughes, J. and MacDonald, D.W. 2008b. Distinguishing tracks of mink *Mustela vison* and polecat *M. putorius*. *European Journal of Wildlife Research.* **54**:367-371.
- Harrington, L.A., Harrington, A.L., Hughes, J., Stirling, D. and MacDonald, D.W. 2010. The accuracy of scat identification in distribution surveys: American mink, *Neovison vison*, in the northern highlands of Scotland. *European Journal of Wildlife Research.* **56**: 377-384.
- Harris, P.J. 1988. The microbial population of the soil. pp. 449-471 in Wild, A. *Russell's Soil Conditions and Plant Growth* (11e). Long man Scientific and Technical, Harlow UK. 991pp. ISBN 0470207965.
- Hass, C.C. 2009. Competition and coexistence in sympatric bobcats and pumas. *Journal of Zoology.* **278**: 174-180.
- He, X.H. and Critchley, C. 2008. *Frankia* nodulation, mycorrhization and interactions between *Frankia* and mycorrhizal fungi in Casuarina plants. Pp. 767-781 in Varma, A. (ed.), *Mycorrhiza - State of the Art, Genetics and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics* 3e. Springer-Verlag GmbH. Germany. 797pp. ISBN 978-3540788249.
- Healey, J.E. (ed) 1997. *Encyclopaedia of Australian Wildlife.* Reader's Digest, Sydney. 624pp. ISBN 0864491182.
- Hill, W.C.O. 1954. Longevity in psittacine birds. *Avicultural Magazine.* **60**: 165.
- Hopmans, P., Douglas, L.A., Chalk, P.M. and Delbridge, S.G. 1983. Effects of soil moisture, mineral nitrogen and salinity on nitrogen fixation (acetylene reduction) in *Allocasuarina verticillata* (Lam.). *Australian Forestry Research.* **13**: 189-196.
- Hurly, A.T. and Oseen, M.D. 1999. Context-dependent, risk-sensitive foraging preferences in wild rufous hummingbirds. *Animal Behaviour.* **58**: 59-66.
- Inger, R., Ruxton, G.D., Newton, J., Colhoun, K., Robinson, J.A., Jackson, A.L. and Bearhop, S. 2006. Temporal and intrapopulation variation in prey choice of wintering geese determined by stable isotope analysis. *Journal of Animal Ecology.* **75**: 1190-1200.

Chapter 1— Introduction

- Isbell, R.F. 1996. *The Australian Soil Classification*. CSIRO Publishing, Australia 144pp. ISBN 0-643-05813-3.
- Johnson, L.A.S. 1982. Notes on Casuarinaceae II. *Journal of the Adelaide Botanical Gardens*. **6**(1): 73-87.
- Jones, J. 2001. Habitat selection studies in avian ecology: a critical review. *The Auk*. **118**(2): 557-562.
- Joseph, L. 1982. The Glossy Black-Cockatoo on Kangaroo Island. *Emu*. **82**: 46-9.
- Joseph, L. 1986. Seed-eating Birds of Southern Australia. In *The Dynamic Partnership: Birds and Plants in South Australia*. Ford H. A. and Paton D. C. (eds) The Flora and Fauna of South Australia Handbook Committee. South Australia. 199pp. ISBN 0724346406.
- Joseph, L. 1989. The glossy Black-Cockatoo in the South Australian Mount Lofty Ranges. *South Australian Ornithologist*. **30**: 202-204.
- Joseph, L., Emison, W.B. and Bren, W.M. 1991. Critical assessment of the conservation requirements of red-tailed black cockatoos in south-eastern Australia with special reference to nesting requirements. *Emu*. **91**: 46-50.
- Kavanagh, R.P., Shields J.M., Recher, H.F. and Rohan-Jones, W.G., 1985. Bird populations of a logged and unlogged forest mosaic at Eden, New South Wales. pp. 273-281 in *Birds of Eucalypt forests and woodlands. Ecology, conservation and management*. Keast, A., Recher, H., Ford, H. and Saunders, D. (eds). Surrey Beatty and Sons. Chipping Norton, NSW. 384pp. ISBN 0949324061.
- KIGBCRT. 1996. *Chewings Newsletter No. 6*. Kangaroo Island Glossy Black Cockatoo recovery Team, South Australia. 2pp.
- Lunney, D., Law, B.A. and Rummery, C. 1996. Contrast between the Visible Abundance of the Brush-tailed Rock-wallaby, *Petrogale penicillata*, and its Rarity in Fox and Dog Scats in the Gorges East of Armidale, New South Wales. *Wildlife Research*. **23**: 373-80.
- Lynch, J.M. and Wood, M. 1988. Interactions between plant roots and micro-organisms. pp. 526-563 in Wild, A. *Russell's Soil Conditions and Plant Growth* (11e). Longman Scientific and Technical, Harlow UK. 991pp. ISBN 0470207965.
- MacArthur, R.H. 1958. Population ecology of some warblers of northeastern coniferous forests. *Ecology*. **39**: 599-619.
- MacArthur, R.H. and Pianka, E.R. 1966. On optimal use of a patchy environment. *American Naturalist*. **100**(916): 603-609.
- Marchant, S. and Higgins, P.J. (eds) 1990. *Handbook of Australian, New Zealand and Antarctic Birds vol. 1*. Royal Australasian Ornithologists' Union and Oxford University Press, Oxford. 1048pp. ISBN 0-19-553244-9.
- Melville, S. 1995. The effect of fire on Casuarina (*Allocasuarina littoralis*) regrowth communities: an urban bushland case study. *Proceedings of the Sixth Queensland Fire Research Workshop*, Brisbane. pp. 69-78.
- Meyer, C.G., Clark, T.B., Papastamatiou, Y.P., Whitney, N.M. and Holland, K.N. 2009. Long-term movement patterns of tiger sharks *Galeocerdo cuvier* in Hawaii. *Marine Ecology Progress Series*. **381**: 223-235.
- Miller, E. and Coll, M. 2010. Spatial distribution and deviations from the IFD when animals forage over large resource patches. *Behavioral Ecology*. **21**: 927-935.

- Monroe, R. and Stevens, N.C. (eds) 1977. *The Border Ranges. A Land Use Conflict in Regional Perspective*. Royal Society of Queensland, Brisbane. 81pp. ISBN 0959838228.
- Morcombe, M. 2000. *Field Guide to Australian Birds*. Steve Parish Publishing, Archerfield Queensland . 448pp. ISBN 1 876282 10X.
- Murray, K.G., Winnett-Murray, K., Cromie, E.A., Minor, M. and Meyers, E. 1993. The influence of seed packaging and fruit color on feeding preferences of American robins. *Vegetatio*. **217**: 26.
- O'Connor, R.J. 1984. *The Growth and Development of Birds*, John Wiley and Sons, New York. 315pp. ISBN 0471903450.
- Owens, I.P.F. and Bennett, P.M. 2000. Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences of the United States of America*. **97**(22): 12144-12148.
- Pannell, J.R. and Myerscough, P.J. 1993. Canopy stored seed banks of *Allocasuarina distyla* and *A. nana*. *Australian Journal of Botany*. **44**(1): 1-9.
- Paterson, R. 1997. *Gold Coast City Council Strategic Plan and Planning Scheme*. Wildlife Preservation Society of Queensland, Glossy Black-cockatoo Branch Inc., Gold Coast Queensland.
- Pedro, J. 1995. Frugivore-mediated selection on fruit and seed size: birds and St Lucie's cherry, *Prunus mahaleb*. *Ecology*. **76**: 2627-2639.
- Pepper, J.W. 1993. A new food source for the glossy black cockatoo. *South Australian Ornithologist*. **31**: 144-5.
- Pepper, J.W. 1996. *The behavioural ecology of the Glossy black-cockatoo* *Calyptorhynchus lathami halmaturinus*. PhD thesis, University of Michigan, Michigan. 307pp.
- Pepper, J.W. 1997. A survey of the South Australian glossy black cockatoo (*Calyptorhynchus lathami halmaturinus*) and its habitat. *Wildlife Research*. **24**: 209-223.
- Pepper, J.W., Male, T.D. and Roberts, G.E. 1993. *Report on a Follow-up Study of the Impact of the November 1991 Fire on the Glossy Black-Cockatoo in Flinders Chase National Park, South Australia*. Unpublished report for National Parks and Wildlife Services. 16pp.
- Pepper, J.W., Male T.D. and Roberts, G.E. 2000. Foraging ecology of the South Australian glossy black-cockatoo (*Calyptorhynchus lathami halmaturinus*). *Austral Ecology*. **25**: 16-24.
- Perry, G. and Pianka, E.R. 1997. Animal foraging: past, present and future. *Trends in Ecology and Evolution*. **12**(9): 360-364.
- Pierce, G.J. and Ollason, J.G. 1987. Eight reasons why optimal foraging theory is a complete waste of time. *Oikos*. **49**(1): 111-118.
- Price, M.V. and Correll, R.A. 2001. Depletion of seed patches by Merriam's kangaroo rats: are GUD assumptions met? *Ecology Letters*. **4**: 334-343.
- Purvis, A., Gittleman, J.L., Cowlishaw, G. and Mace, G.M. 2000. Predicting extinction risk in declining species. *Proceedings of the Royal Society of London Series B*. **267**: 1947-1952.
- Pyke, G.H. 1984. Optimal foraging theory: a critical review. *Annual Review of Ecology and Systematics*. **15**: 523-575.
- Radford, A.N. and Du Plessis, M.A. 2003. The importance of rainfall to a cavity-nesting species. *Ibis*. **145**(4): 692-694.

Chapter 1— Introduction

- Ramakrishnan, P.S., Saxena, A.K., Das, A.K. and Rao, K.S. 1997. Fire. pp. 493-518 in *Plant Ecophysiology*. Prasad, M.N.V. (ed). John Wiley and Sons Inc., USA. 542pp. ISBN 0-417-13157-1.
- Reed, D.H., O'Grady, J.J., Brook, B.W., Ballou, J.D. and Frankham, R. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation*. **113**: 23-34.
- Rice, E. (ed) 1984. *Allelopathy*. Academic Press, New York. 422pp. ISBN 0-12-587058-0.
- Richards, B.N. 1987. *The Microbiology of Terrestrial Ecosystems*. Longman Scientific and Technical Ltd, England. 399pp. ISBN 0-582-45022-5.
- Rose, N.R. and Barron, A.L. 1983. *Micobiology: basic principles and clinical applications*. Collier MacMillan London. 647pp. ISBN 02403620X.
- Rosenzweig, M.L. 1991. Habitat selection and population interactions: the search for mechanism. *American Naturalist*. **137**: S5-S28.
- Rouvier, C., Prin, Y., Reddell, P., Normand, P. and Simonet, P. 1996. Genetic diversity among *Frankia* strains nodulating members of the Family Casuarinaceae in Australia revealed by PCR and restriction fragment length polymorphism analysis with crushed root nodules. *Applied and Environmental Microbiology*. **62**(3): 979-985.
- Safi, K. and Kerth, G. 2004. A comparative analysis of specialization and extinction risk in temperate-zone bats. *Conservation Biology*. **18**(5): 1293-1303.
- Sallabanks, R. 1993. Hierarchical mechanisms of fruit selection by an avian frugivore. *Ecology*. **74**: 1326-36.
- Saunders, D.A., Rowley, I. and Smith, G.T. 1985. The effects of clearing for agriculture on the distribution of cockatoos in the southwest of Western Australia. pp. 307-321 in *Birds of Eucalypt forests and woodlands. Ecology, conservation and management*. Keast, A., Recher, H., Ford, H. and Saunders, D. (eds). Surrey Beatty and Sons. Chipping Norton, NSW. 384pp. ISBN 0949324061.
- Schodde, R., Mason I.J., Wood, J.T. 1993. Geographic differentiation in the Glossy Black-Cockatoo. *Emu*. **93**: 156-166.
- Schoener, T.W. 1971. Theory of feeding strategies. *Annual Review of Ecology and Systematics*. **2**: 369-404.
- Shaffer, M.L. 1981. Minimum population sizes for species conservation. *Bioscience*. **31**: 131-134.
- Shiple, L. A., Forbey, J.S. and Moore, B.D. 2009. Revisiting the dietary niche: When is a mammalian herbivore a specialist? *Integrative and Comparative Biology*. **49**(3): 274-290.
- Shochat, E., Warren, P.S., Faeth, S.H., McIntyre, N.E. and Hope, D. 2006. From patterns to emerging processes in mechanistic urban ecology. *Trends in Ecology and Evolution*. **21**(4): 186-191.
- Smith, P. 1985. Woodchip logging and birds near Bega, New South Wales. pp. 257-271 in *Birds of Eucalypt forests and woodlands. Ecology, conservation and management*. Keast, A., Recher, H., Ford, H. and Saunders, D. (eds). Surrey Beatty and Sons. Chipping Norton, NSW. 384pp. ISBN 0949324061.
- Sorensen, A.E. 1984. Nutrition, energy and passage time: experiments with fruit preference in European blackbirds (*Turdus merula*). *Journal of Animal Ecology*. **53**: 545-557.
- Soulé, M.E. and Wilcox, B.A. 1980. *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland. 380pp. ISBN 0878938001.

- Stanley, T. D. and Ross, E. M. 1983. *Flora of south-east Queensland*. Queensland Department of Primary Industries, Brisbane. 3 vols 545pp., 632pp., 532pp. ISBN 0724221271.
- Stock, M.J. and Wild, C.H. 2005. Seasonal variation in Glossy Black-Cockatoo sightings on the Gold Coast. *Corella* **29**(4): 94-96.
- Terraube, J., Arroyo, B. E., Bragin, A., Bragin, E. and Mougeot, F. 2012. Ecological factors influencing the breeding distribution and success of a nomadic, specialist predator. *Biodiversity and Conservation*. **21**: 1835-1852.
- Thomas, E. and Paterson, R. 1996. *Soils and the Planning of a City*. Gold Coast, Gold Coast City Council and Wildlife Preservation Society of Queensland. 1p. (A1).
- Torrey, J.G. and Berg, R.H. 1988. Some morphological features for generic characterization among the Casuarinaceae. *American Journal of Botany*. **75**(6): 864-874.
- Traill, L.W., Brook, B.W., Frankham, R.R. and Bradshaw, C.J.A. 2010. Pragmatic population viability targets in a rapidly changing world. *Biological Conservation*. **143**: 28-34.
- Westcott, D.A. 1999. Counting cassowaries: what does cassowary sign reveal about their abundance? *Wildlife Research*. **26**: 61-67.
- Whisson, D.A., Engeman, R.M. and Collins, K. 2005. Developing relative abundance techniques (RATs) for monitoring rodent populations. *Wildlife Research*. **32**: 239-244.
- Wild, A. 1988. *Russell's Soil Conditions and Plant Growth* (11e), Longman Scientific and Technical, Harlow UK. 991pp. ISBN 0470207965.
- Wild, C.H., Stock, M. and Thomas, E. 2002. *Factors influencing choice of feed trees by the Glossy Black-Cockatoo in south-east Queensland*. Gold Coast, Unpublished report. Griffith University, Gold Coast City Council and WPSQ Glossy Black-Cockatoo Branch. 91pp.
- Williams, P.R. 2000. Fire-stimulated rainforest seedling recruitment and vegetative regeneration in a densely grassed wet sclerophyll forest of north-eastern Australia. *Australian Journal of Botany*. **48**: 651-658.
- Witmer, G.W. 2005. Wildlife population monitoring: some practical considerations. *Wildlife Research*. **32**: 259-263.
- Yadav, J.S.P. 1983. Soil limitations for successful establishment and growth of Casuarina plantations. pp. 138-157 in Midgley, S.J., Turnbull, J.W. and Johnston, R.D. (eds), *Casuarina Ecology, Management and Utilization: Proceedings of an International Workshop*. CSIRO, Melbourne. ISBN 0643034633.

2 DETERMINANTS AND STABILITY OF THE FEEDING STATUS OF CASUARINA TREES FOR *C. LATHAMI*

Calyptorhynchus lathami has a highly specialised diet, demonstrating distinct preferences for certain feed trees over other potential feed trees. Numerous authors have found consistent differences between feed and non-feed trees of *A. littoralis* (in Eden, Dubbo, NSW) and *A. verticillata* (on Kangaroo Island, South Australia), suggesting that habitat quality appears to be influential in selecting for foraging habitats (Clout 1989, Pepper *et al.* 2000, Crowley and Garnett 2001, Cameron and Cunningham 2006). Furthermore, Cameron and Cunningham (2006) also reported variable forage quality (Clout's index; the ratio of kernel weight to total cone weight) among different *Allocasuarina* species, with some species delivering greater returns than others. Given the fine-scale variability in forage quality varying amongst cones, trees and species it is possible that individual *C. lathami* adopt foraging strategies that maximise their returns (nutrient intake) on investment (search and handling time, predation risk, competition, missed opportunity costs) (Brown 1988). This hypothesis is akin to the marginal value theorem proposed by Charnov (1976), where an individual with an optimal foraging strategy will have greater fitness. For *C. lathami* it would therefore be advantageous if individuals were able to discern which trees do actually provide a higher nutritional value and/or require less effort (search and handling time), than other trees. The low unit return and high handling time of Casuarina cones (Clout 1989, Pepper *et al.* 2000, Crowley and Garnett 2001), suggests that *C. lathami* may experience considerable foraging costs. Previous studies report that *C. lathami* spend considerable amounts of their daily activity budget foraging (Clout 1989, Crowley *et al.* 1996), where the actual handling of cones comprises much of this effort (Pepper *et al.* 2000). While Cameron (2005) confirmed that *C. lathami* forage extensively throughout the day, Chapman and Paton (2005) show that this effort may be a reflection of food availability more broadly, with foraging effort dropping to as low as 25% of daily activity budgets in habitats with abundant food supply. This suggests that *C. lathami* have indeed maximized their foraging efficiencies through a combination of habitat selection (Clout 1989, Crowley and Garnett 2001), and behavioural mechanisms (Cameron 2005), as opposed to the random selection of trees. As a result, the presence and distribution of *C. lathami* within a region is closely linked to the distribution and quality of food trees (Pepper *et al.* 2000).

Despite extensive research investigating foraging habitats of *C. lathami* on Kangaroo Island and localised areas in NSW (Clout 1989, Pepper *et al.* 2000, Crowley and Garnett 2001, Cameron and Cunningham 2006), comparatively little work has assessed regional differences in habitat-associated forage quality in the southeast Queensland region. Consequently, further research to

increase our knowledge of the distribution and quality of foraging resources in the southeast Queensland region is required as this may have implications for the future conservation of the Glossy Black-Cockatoo. The dominant food species available to *C. lathamii* in southeast Queensland are *A. littoralis* and *A. torulosa*, and these species are widely distributed throughout sclerophyll forests in the region. Previous research by Wild *et al.* (2002) on these species found some differences in soil quality and tree characteristics between feed and non-feed trees in southeast Queensland. Specifically, *A. littoralis* feed trees had marginally more cones, heavier seeds, and took less time for 50% of viable seeds to germinate, than non-feed trees. For *A. torulosa*, feed trees had larger girths and grew on a gentler slope than non-feed trees. Overall though, these differences provided only very weak prediction of the feeding status of any given tree, and were only weakly correlated with environmental variables such as soil chemistry or landscape character. Despite the inclusion of 80 sites in that study, the work had limited ability to draw general conclusions about food tree patterns. A possible design failing of that study was that sites had to contain a *current* feed tree with a non-feed tree *of similar stature* ultimately restricting the number of available sites due to the difficulties in finding feed trees currently being used by *C. lathamii* (Wild *et al.* 2002).

Furthermore, by restricting their comparison of known current feed trees with nearby similar trees which were non-feed trees at the time of the study, Wild *et al.* (2002) may have shifted attention away from areas of potentially suitable habitat but where no Casuarina trees are known to have feed tree status. There are considerable areas of the Gold Coast where *A. littoralis* is recorded but no feed trees have been reported. While it is likely that, in most locations, this is the result of an absence of feed-tree observers (i.e. no detection of feeding activity), these areas may alternatively be lacking other essential requirements, i.e. conveniently located nesting and drinking sites, or suitable trees in terms of foraging rewards.

Given the regional uncertainties in the availability of high quality foraging habitats for *C. lathamii* in southeast Queensland, this chapter reviews edaphic and other environmental variables to determining if there is a consistent difference between areas where feed-status trees do and do not occur, and between feed and non-feed trees within foraging areas. To easily distinguish between *trees* and *sites*, they will be referred to as **feed and non-feed TREES** and **foraged and non-forages SITES**. The majority of this work is focused on *A. littoralis*, with some minor work on *A. torulosa*. The stability through time of the feeding status was also investigated to determine whether individual Casuarinas in southeast Queensland are similar to those in other regions within Australia in that they are likely to provide a year-to-year food supply due to their serotinous nature (Clout 1989, Pepper *et al.* 2000). If *C. lathamii* are loyal to certain trees, this will have a

major influence on management plans for *C. lathami* on the Gold Coast, as well as elsewhere in the region.

2.1 METHODS - DETERMINANTS OF FEEDING STATUS IN *A. LITTORALIS*

The vegetation types occurring on the Gold Coast containing *A. littoralis* (Table 1) were mapped using the Gold Coast City Council Strategic Vegetation maps and MapInfo® software. Due to the relatively coarse resolution of the vegetation mapping, Casuarinas growing in some residential parts of the city were excluded from this study. Land clearing and urbanisation removes and fragments existing habitats. Remaining residential blocks usually only support a few trees and are unlikely representative of complex community structures. Furthermore, these areas have been studied previously and provided very little discrimination (Wild *et al.* 2002). Confirmatory surveys of various locations across different vegetation types were undertaken to determine if they did in fact contain *A. littoralis*, and thus were suitable for this study. Only five vegetation types contained *A. littoralis* while a sixth vegetation type containing viable *C. lathami* habitat was dominated by *A. torulosa*. These vegetation communities were used for the abundance and distribution study in Chapter 3.

Table 1. List of vegetation types on the Gold Coast containing *A. littoralis*

Vegetation Type	Approximate Area (km ²)
Bluegum – grey ironbark and/or pink bloodwood/open forest	57.5
White mahogany – grey gum – Qld white stringybark – broad leaved white mahogany – woodland/open forest	243.3
Spotted gum and ironbark open forest complex	87.2
Brush box – moist eucalypt open forest complex (often with rainforest understorey)	108.5
Regrowth – Swamp oak/broad leaved paper bark open forest	6.2
Approximate Total Area	502.7

A 500m × 500m grid was placed over all *A. littoralis* vegetation communities, and each grid cell was uniquely numbered, totaling an area of approximately 503 km² of potentially suitable vegetation types. Subsequently, 200 study sites were randomly allocated across the five vegetation types containing *A. littoralis* by using the randbetween() function in Excel. The majority of the randomly chosen grid cells consisted of a single vegetation type, but some grid cells did include two vegetation types. Some sites also clearly had strong anthropogenic effects,

including, it turned out, high weed abundance. Where grid cells did comprise two vegetation types, the dominant community was usually consistent with the vegetation type observed in the actual study quadrats. Three such quadrats were selected within each grid cell, and were each classified as the vegetation type observed with the study quadrat — the three quadrats constitute the **site**, as the term is used hereafter.

An estimation of the quantity of *C. lathami* feeding evidence was determined using a nested sub-sampling method whereby three 20 m × 20 m quadrats were located within each of the 200 selected grid cells. Each quadrat was placed 40 m from the centre of the grid cell. The first quadrat was chosen using a randomly selected direction, and quadrats 2 and 3 were placed so that each was 120° away from the others, resulting in quadrats being approximately 70 m apart (Figure 8).

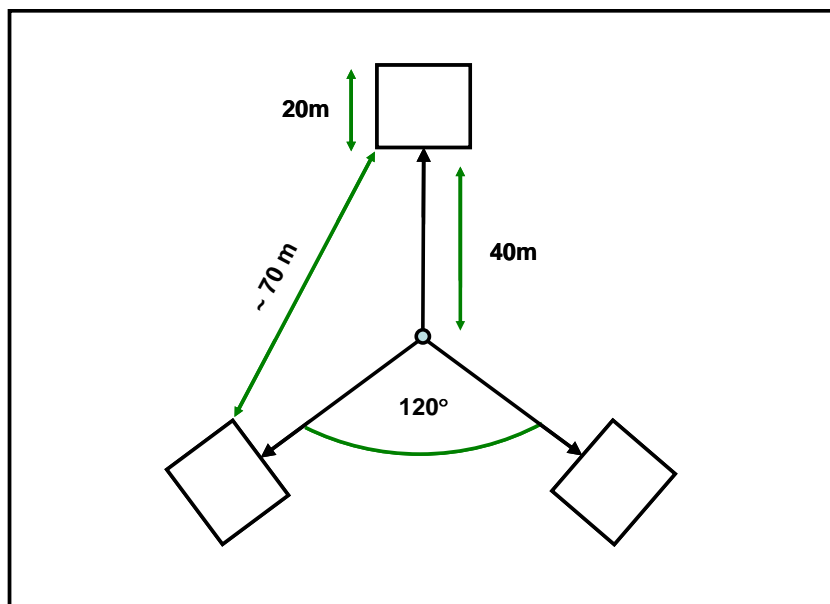


Figure 8. Arrangement of three 20 × 20 m sampling quadrats within 500 × 500 m grid cells

As highlighted previously, the lack of any known discriminating differences between feed and non-feed trees in southeast Queensland¹ (Wild *et al.* 2002) could be ascribed to a true absence of difference between feed and non-feed trees, or limitations imposed by the experimental design. The design used by Wild *et al.* (2002) compared a feed tree with a nearby non-feed tree of similar stature within each field site, with the result that local environmental and edaphic factors were controlled and probably matched, thereby masking any differences between feed trees and other nearby trees not of similar stature. Sites without known feed trees were not included. Quantifying

¹ Wild *et al.* (2002) did find statistically significant discriminating variables, but they had very low discriminating power, and some of the variables, such as seed weight and especially time to germinate, are unlikely to be evident to a bird when choosing which tree to feed upon.

the differences between feed and non-feed trees therefore remains an important research question, and is the focus of this chapter.

The goal of this study therefore seeks to elucidate how feed trees differ from non-feed trees, beyond the obvious fact that the birds have fed in the former and not in the latter. It is postulated that, if there is any real difference between the trees, they will be caused by one or more of (1) the genetic makeup of the tree, (2) the contrast with the plants amongst which it is growing, or (3) environmental factors such as soil conditions. The paired design in the previous study (Wild *et al.* 2002) may have masked some of these effects (or possibly controlled for these effects). Hence, two fundamental improvements to this design was (a) to estimate the number of chewings, thereby determining the number of available cones *prior* to *C. lathami* feeding, and (b) to compare foraged sites with non-foraged sites. In order to overcome possible deficiencies, and to make more inclusive comparisons, this study specifically compared (1) any feed trees with all other nearby non-feed trees within quadrats, and (2) foraged sites with other non-foraged sites. It was therefore important to have clear definitions of feed and non-feed tree types, and foraged and non-foraged sites, and the following section outlines the classifications used to define this terminology.

2.1.1 Classification of Trees

Trees of the feed species may belong to one of four categories:

1. feed trees which are identifiable as such due to the evidence of actual feeding, or to “chewings” scattered under the tree — here called “feed trees”,
2. trees that appear, and in some intrinsic way are, suitable for feeding but are not identifiable as actual feed trees since no evidence of feeding is currently observable — called “apparently suitable trees”,
3. trees that appear to be suitable for feeding, but are not acceptable to the birds, possibly due to poor seed quality, poor location making the tree inaccessible or lack of other trees making the site too inefficient in terms of an optimal foraging strategy etc. — called “actual non-feed trees”, and
4. trees which are unsuitable for feeding (e.g. lacking cones, immature, etc.) — here called “unsuitable trees”.

The first three types of trees *appear* to be suitable as feed trees, but only the first two actually are, and only the first can be seen to be so. On field inspection it is easily determined that a tree is an actual feed tree or an unsuitable tree, but apparently suitable trees and actual non-feed trees are indistinguishable (to the researcher if not the birds) and will be here jointly referred to as

“apparently suitable trees”. When discussing categories 2-4, they will be collectively referred to as “non-feed” trees (i.e. all trees with no current feeding).

The unavoidable confusion between apparently suitable trees and actual non-feed trees makes any comparison of feed trees and actual non-feed trees difficult, for there will be an unknown number or proportion of apparently suitable trees amongst any group that are classified as non-feed trees.

Judging from the minimum conditions of the feed trees studied here, a tree has little to no chance of being a feed tree (i.e. it will be ignored by the birds) if it has less than 50 cones on it. Previous studies have shown that cone abundance does influence feed tree choice by *C. lathami* (Pepper *et al.* 2000), Although *C. lathami* have sometimes been observed feeding in trees with less than 50 cones, in such cases only a few cones have been foraged (i.e. less than five). These foraging attempts may also demonstrate exploratory behaviour where the birds may be testing novel environments in times of general resource abundance (Bennetts and Kitchens 2000, Pepper *et al.* 2000). Despite this potential exploratory behaviour, essentially any tree with less than 50 cones simply does not have enough cones to be considered an *important* feed tree. Important feed trees are those that are repeatedly visited and fed upon until almost stripped of cones, leaving hundreds to thousands of chewings behind. Therefore, for the purposes of this study, to be classified as feed trees and apparently suitable trees, a tree needs to have over 50 cones, with feed trees being distinguished from others by the presence of at least 5 chewings under the tree (usually many times this number), as summarised in Table 2.

Table 2. Definitions of tree categories for Casuarinas on the Gold Coast as used in this study.

Tree Category	Total number of cones on trees	Total number of chewings under trees
(1) feed trees	≥ 50	≥ 5
(2) apparently suitable trees	≥ 50	< 5
(3) actual non-feed trees	≥ 50	< 5
(4) unsuitable trees	< 50	< 5

The main issue here is that trees with all the qualities of a feed tree (category 2) may well be classified in the non-feed trees group, and thus the difference between the two groups is reduced due to misclassification. A feed tree is a known feed tree because either *C. lathami* has been seen feeding in it or there are chewings on the ground indicating past feeding, but it is harder to identify whether a tree really is, intrinsically, a non-feed tree. It is not possible to know with any certainty whether a tree has either been a feed tree in the past or will be one in the future. While there is anecdotal evidence to suggest that *C. lathami* faithfully return to certain trees whilst

consistently ignoring others (Pepper *et al.* 2000, Anonymous 2002), this study will provide empirical evidence that can either support or refute such claims.

There are three reasons why what appears to be a category 2 non-feed tree might really be an actual non-feed tree:

1. palatability: the birds have tested cones on the tree and have rejected the tree based on poor taste (therefore, cone abundance etc. is unimportant, because the birds won't eat there anyway).
2. feeding reward: the tree does not bear enough cones (technically an unsuitable tree, but the number of cones separating unsuitable and potential feed trees has been arbitrarily set, although previous research has shown feed trees to bear as little as 50 cones, but as stated above, these trees simply cannot be important feed trees in terms of the number of birds they can support) — such trees may well develop into feed trees over time (years), however.
3. sparseness of area: the tree is the only tree, or the only tree bearing cones (i.e. unsuitable), therefore the site has too high an effort for return (i.e. it is too inefficient for them to fly there for the cones on a single tree or a sparse stand).

Further, there are two reasons why a category 2 non-feed tree might have all the qualities of a feed tree yet for the moment be an actual non-feed tree:

1. high density of potential feed trees: an excess of suitable trees may mean it is a matter of chance which trees are fed upon and which ones are ignored (ignored now, but may be fed upon in the near or distant future)
2. location of the site: the birds have not found the site, possibly since the site is too distant from another foraged site, and/or drinking and nesting site. Even though the site appears to be a suitable foraging site (i.e. contains multiple trees, each bearing over 50 cones), the trees are actually suitable trees, but location has restricted any feeding potential.

All of these reasons could be temporary, in that over time, these could change. Change in nutrient input may change palatability, unless the cause is genetic and therefore the tree will never be considered a suitable tree. A tree's membership of categories 2-4 are likely to change based on seasonal and yearly changes in the trees' reproductive outputs. Where this study finds that the differences between presently category 1 feed trees and category 2 and 3 non-feed trees are small, it may be due to the variable being unimportant to the classification, or it may be that there are too many category 2 trees in the non-feed tree group.

2.1.2 Classification of Sites

Soil type may possibly influence the development of feed trees amongst a stand of the feed species, particularly where soil type may be relatively inhomogeneous across a single study site. It is also desirable to compare trees at a site where foraging has occurred (either birds observed feeding or chewings present), with a site without feeding (no chewings or birds present), but where the feed species is present. Sites were chosen at random from across the habitat types in which the feed species was likely to occur, and comparisons were made between sites found to be *foraged* sites, and those found to be *non-foraged* sites. Just as tree classification contains some ambiguities, so too does site classification.

Sites may belong to one of four categories:

1. foraged sites where clear evidence of feeding was present (i.e. actual feed trees were present as evidenced by the presence of chewings on the ground),
2. non-foraged sites where no actual feed trees are present although apparently suitable trees are available, but no chewings, or only a very few chewings (i.e. less than 5), indicating a ‘test and reject’ history (Garnett *et al.* 1999, Pepper *et al.* 2000),
3. unsuitable Casuarina sites where only unsuitable trees are present, and
4. unsuitable sites where no feed species trees occurred at all - Although the feed tree species does occur in the specified vegetation type, the species was either not growing in the area of was growing in such low numbers as not to be observed using the sampling technique.

Our interest is limited to only the foraged and non-foraged sites, although most of the sites examined at random were unsuitable as defined in site categories 3 and 4.

The purpose of defining a site as ‘foraged or ‘non-foraged’ was to permit contrast between conditions, especially soil, at sites which had produced actual feed trees with conditions at other sites that had not. The simple absence of feed trees at a site does not guarantee that it is a non-foraged site. Feed trees may be relatively uncommon amongst apparently suitable trees, and random sampling errors could well lead to a sampling quadrat lacking feed trees when there were such trees nearby. This would lead to an erroneous classification of such a site as non-foraged. Such an error is more likely if a site has relatively few apparently suitable trees in it.

The problem here is determining detection probability, specifically the probability of detecting all feed trees. Similar detection problems have been addressed elsewhere, specifically, MacKenzie and Kendall (2002), Alpizar-Jara and Nichols (2004) and Ball *et al.* (2005). Where species are particularly elusive (i.e. are particularly small, their colourations make them camouflaged, or they have quiet behaviour etc.), this may mean that some individuals within the field remain

undetected. Counts will provide a relative abundance for the given survey area, but to provide an unbiased estimate of abundance, some measure of detection probability needs to be included (MacKenzie and Kendall 2002), especially for species that are highly elusive. While many of these studies consider detection of mobile species, these issues may also arise for flora where phenological stages affect the detectability of particular life history stages (e.g. fruiting).

In this research, experience suggests that, where feed trees occur, there are always apparently suitable (but presently non-feed) trees present. Typically, at feed sites, about 20% of the apparently suitable trees were actual feed trees (Wild *et al.* 2002, and current research). Clearly, if the researcher went to a site within a region where actual feed trees were present in this proportion, but there are only two apparently suitable trees in the quadrats, there is little chance that either tree would be a feed tree, and the researcher would mis-classify the site as non-feed. It is therefore desirable to evaluate the number of apparently suitable trees that need be examined before we have reasonable confidence that feed trees are absent from the area. The modeling for this is shown in Appendix 1, with the result that a minimum of 60 trees need to be examined. Fieldwork showed, however, that not many sites actually contained 60 non-feed trees. Some vegetation types contain Casuarina but in low densities, or they grew in small stands of high density, or due to land clearing (i.e. for houses, fencing, roads etc.), large proportions of many sites had no Casuarina. Ultimately, all Casuarina trees within all investigated sites were examined, reducing this problem as far as possible.

Some of the randomly chosen sites were not accessible, because permission could not be obtained from owners, or the site was considered too dangerous (i.e. not physically accessible or the site was on restricted-access land etc.). When a site was not accessible, a location was chosen nearby in an area of the same vegetation type. Where areas were not suitable for this study despite the mapping effort to locate nearby sites in suitable vegetation types, a new random number was used.

2.1.3 Statistical Analysis

The aim of this study is to determine what characteristic/s make an area suitable for *C. lathamii* feeding, and within an area, what determines which trees will be fed upon. Data from feed and non-feed trees were collected from foraged and non-foraged sites.

For most sites, not all three quadrats yielded results i.e. area had been cleared, presence of roads or houses etc. Of the thirteen quadrats analysed statistically (~112 sites were visited, but most sites were not considered currently viable i.e. no cones produced or Casuarina trees dead from fire

or drought), three quadrats were from one site, two of the quadrats from a second site, with the remaining eight quadrats from eight different sites. Quadrats within a single site were treated as independent samples as there is a distance of 70 m between quadrats neighbouring quadrats (Figure 8).

Two broad sets of analyses were completed: (1) comparing foraged and non-foraged sites' tree and soil attributes between sites, and (2) comparing female trees, between feed and non-feed trees, within foraged sites:

1. Foraged compared with non-foraged sites
Differences in tree, soil and anthropogenic factors
2. Female Trees
 - a. *Foraged Sites* - two comparisons were made at foraged sites:
 - i feed trees compared with non-feed trees, and
 - ii feed trees compared with apparently suitable trees, thereby ignoring female trees with little to no current cone production (i.e. unsuitable trees), and hence negligible current feeding potential.
 - b. *Foraged and Non-foraged Sites* - two comparisons were made between foraged and non-foraged sites:
 - i all female trees in foraged sites compared with all female trees in non-foraged sites
 - ii Apparently suitable trees (including feed trees in foraged sites) compared between foraged and non-foraged sites

Some of the data was transformed (mainly $\log(y+1)$ and square root(y)), to reduce skewness and kurtosis, allowing parametric analyses using the t -tests. Where the data were not suitable for parametric analysis, either Fisher's Exact Probability, Chi-square analysis, CLUMP bootstrapping with 1000 iterations (Sham and Curtis 1995), or Kolmogorov-Smirnov tests (Siegel and Castellan 1988) were used. The Statistic and any transformations performed on variables are outlined in the results section (Tables 8-16).

2.1.4 General Environmental Variables

Within each of the three quadrats at each site, data were collected from all Casuarina within the quadrats, as well as seed and cone data on selected *A. littoralis*. Habitat variables that may influence whether *C. lathami* feed in an area were measured for each quadrat. Many of the variables studied will affect tree attributes and therefore the foraging efficiency of *C. lathami*: an

important factor since these birds have been shown to be restricted by foraging efficiency. The following is an outline of the data collected from the quadrats. Each variable is explained in detail in the next section.

For each quadrat the following data were collected:

- Presence and distance from the quadrat to anthropogenic factors and their description
- Understorey and/or groundcover
- Presence/absence of fire scarring on Casuarina trees
- Soil pH, type, colour (Horizons A and B)
- Data on all *A. littoralis* within the quadrat
 - Number, DBH, height and reproductive output
 - Cone Crop Size (i.e. number of cones on tree)
 - Chewings – Quantity and Age (i.e. number of cones foraged)
 - Presence of monoecious or dioecious *A. littoralis*
- Sampled *A. littoralis*
 - Seed and cone weight
 - Cone softness

Variables such as soil chemistry will affect tree health, and subsequently cone quantity and quality. Cone size and nutrition will subsequently affect *C. lathamii*'s search, handling and ingesting time, thereby affecting the acceptability of a tree being an actual feed tree.

Other factors may also deter *C. lathamii* from an apparently suitable area. Factors causing frequent disturbances to the birds may cause them to stop feeding, and possibly leaving the area. Both of these would reduce their feeding time, and abandonment of an area would also increase their search time. If *C. lathamii* are disturbed within an area on more than one occasion, to optimise their foraging strategy, it may be advantageous for them to completely abandon the area as a food source, regardless of the feeding potential.

2.1.4.1 Presence and Distance to Anthropogenic Factors

Any anthropogenic factor in the area that may potentially affect birds while feeding in the area was recorded. The distance between any such factors to the centre of the quadrat was measured using a measuring tape if nearby, otherwise the distance was paced out and estimated in metres. The anthropogenic source was categorised to reflect the degree of expected disturbance, as

outlined below. Anthropogenic sources recorded were those determined during the course of completing the field work at each site (normally only took 2-3 hours depending on the abundance of trees to measure).

Although not all anthropogenic noises might be heard during that time, a quick review of the surrounding area was done to find out what might be heard but wasn't heard during the sampling. For example, for residential sites, irregular and loud noises would be factored into it, taking into account activities such as mowing. The terms used to describe anthropogenic factors are as follows:

- Low frequency – irregular disturbance
- High frequency – regular or constant disturbance
- Low level – background noise
- High level – loud noise

Constant loud noise such as that produced from a busy road would be considered a frequent and high level of disturbance. A low number for the level of disturbance denotes a low level and/or low incidence disturbance caused by the anthropogenic factor (Table 3).

Table 3. Categories for levels of anthropogenic disturbances

Level of disturbance	Anthropogenic factor	Examples
0	No anthropogenic factors observed	Off track, bushland
1	Infrequent, low level	Walking tracks
2	Infrequent, high level	Occasional car on nearby minor road
3	Frequent, low level	Traffic on minor road
4	Frequent, high level	Traffic on a major road

2.1.4.2 Understorey and/or Groundcover

The plants of the understorey found in each quadrat were classified into ecological growth forms and a visual estimation of percentage groundcover was made. The classes used were ferns, grasses, shrubs and exotics. All sites studied had entirely grassy understoreys (100% grass cover) with little structural complexity in the understorey. In hindsight, it would have been valuable to measure additional variables such as canopy height, vegetation density and composition to assess the structural physiognomy of each site. Data limitations and limited variability amongst sites precluded any rigorous analysis of this variable.

2.1.4.3 Presence or Absence of Fire

Evidence of fire was recorded, including recent evidence such as burnt or charred areas around the trunk and/or branches and any post-fire re-sprouting. No estimate was made to determine the time since fire, nor the intensity of the fire. However, uniformity of age of plants in the area, possible indication of a large disturbance (high intensity fire) resulting in stand renewal, was noted where observed. Some sites were obviously recently affected by fire, but for the most part, sites that were considered ‘affected by fire’, were large areas of new growth (i.e. dense young Casuarinas), with two or three older trees that were obviously not killed by the fire, but still showed charring on lower parts of the tree. For statistical analysis, this variable was treated as dichotomous (i.e. ‘yes’ or ‘no’).

2.1.4.4 Soil pH, Type and Colour

Using a jarret auger (each increment 5cm depth), three holes (sub-samples) were dug within each quadrat (Figure 9). Soil pH, type and colour were determined in the field for horizon A and horizon B. Soil pH was determined using a Manutec soil pH test kit. Soil type was determined by the degree to which a moist bolus adhered together, determining if the soil is predominantly sand, loam or clay (Isbell 1996). The approximate clay content for the different soil types (Isbell 1996) was used for statistical comparisons between foraged and non-foraged sites (Table 4). Some soil types have the same approximate clay content but differing loam or sand content, therefore a soil rank was used to differentiate between these soil types (Table 4). Soil colour was determined with a Munsell Colour Chart using the moist bolus.

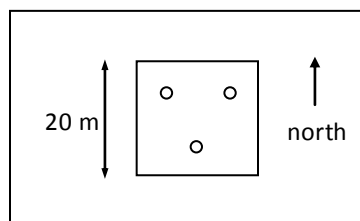


Figure 9. Arrangement of soil samples taken with a hand augur within each quadrat.

Table 4. Clay types (from Isbell 1996)

Soil type	Average % clay	Clay rank
Loamy sand	5	1
Sandy loam	15	2
Fine sandy loam	15	3
Loam	25	4
Silty loam	25	5
Fine sandy clay loam	32.5	6
Clay loam	32.5	7
Silty clay loam	32.5	8
Light clay	37.5	9
Medium clay	47.5	10
Heavy clay	50+	11

2.1.5 Measurements of all *A. littoralis* within each Quadrat

The total number of *Casuarina* within the quadrat were counted, their diameter at breast height (DBH, 130cm) measured, and tree heights estimated visually to the nearest metre (several trees were measured using an inclinometer to check accuracy, but due to the density of trees, an inclinometer was not practical to use in all instances). An estimate of the cone abundance and flowers (male and female) was made for each mature *Casuarina*.

2.1.5.1 Flowers Abundance

The number of flowers on each tree was estimated by counting the number of flowers on three typical branches, providing an average number of cones per branch and multiplying by the number of branches.

2.1.5.2 Cone Abundance

The number of cones on each tree was estimated by counting the number of cones on three typical branches, providing an average number of cones per branch and multiplying by the number of branches. Since *C. lathami* have been known to completely strip trees of cones (Pepper *et al.* 2000), it is expected that the *pre*-feeding number of cones may better reveal any differences between feed and non-feed trees. The number of *pre*-feeding cones was calculated by:

$$\text{Pre-feeding number of cones} = \# \text{ cones currently on tree} + \frac{\# \text{chewin}}{X}$$

Where x is the number of chewings derived from one cone. In Section 3.1, examining *C. lathami* feeding, it is determined that *C. lathami* feeding breaks *A. littoralis* cones into 3.4 chewings on average and *A. torulosa* 3.7.

2.1.5.3 Chewings – Quantity and Age

The quantity and age of chewings was determined and recorded where feeding evidence existed (using methods determined and discussed in Chapter 3).

Cone Colour and Softness

Cones were to be sampled to determine cone softness, but due to lack of cones in the study sites, a second small experiment was devised. The first five cone-bearing trees were sampled along a transect through *A. littoralis* stands within the randomly chosen field sites. Due to the sparseness of cone-bearing trees, transect length differed for all sites. Tree height, DBH, cone crop abundance and the number of chewings were recorded. Ten cones were randomly collected from each tree and the cone softness and cone colour were measured on the day of collection.

Calyptorhynchus lathami is known to exhibit a preference for certain cones over others (Clout 1989, Pepper *et al.* 2000). Taking into account the importance of handling and feeding efficiency required by *C. lathami*, three characteristics of cones that would be expected to influence feeding efficiency are (1) cone colour (age), (2) seed viability, and (3) cone softness.

Cone Colour

The cone colour was determined using a Munsell Colour Chart and an approximated greyness scale (Table 5). Since the colour of the cones is not uniform across the entire cone, the Munsell Colour Chart was used to give the hue and chroma of the redness of the brown colour in the cones (body of cone, not locule lip), with the greyness scale indicating how much of the cone has turned grey with age.

Table 5. Grey scale used to categorize cone colour.

Cone Colour	Grey Scale
Pale red-brown with green	-1
All red-brown	0
More than 50 % red-brown, with less than 50 % of the cone grey	1
Approximately 50 % red-brown and 50 % grey	2
More than 50 % grey, with less than 50% of the cone red-brown	3
All grey	4

Seed Viability

Wild *et al.* (2002) found no significant differences in the viability (germinability) of seeds from cones taken from feed and non-feed *A. littoralis* of similar stature. The viability of seeds, important to *C. lathami* due to its probable association with nutritional content, is expected to change with tree age and cone age.

The birds on Kangaroo Island are thought to feed only on russet brown (e.g. Munsel Colour 5yr31 to 7.5yr32) to grey-brown cones (e.g. 10yr21) and not grey cones (Joseph 1982, Clout 1989, Crowley *et al.* 1996). Pepper *et al.* (2000) found cones to change colour (red-brown (young) to grey (old)) slowly on trees, allowing annual cohorts to be distinguished. Ideally, to maximise handling and feeding efficiency of Casuarina cones, *C. lathami* would feed on mature trees with a high proportion of greyish-brown cones. Lack of cone production during the study period, due to prevailing drought conditions, meant any experiment on seed nutrients was not possible.

Cone Softness

Here, the difference in cone softness between feed and non-feed trees within a foraged site; and between foraged and non-foraged sites was assessed.

Cone softness was determined using a device that roughly simulates the pressures presumed to apply at the beak of a cockatoo when opening a cone. The actual forces applied have been determined by trial crushing of actual cones, so that a typical cone is crushed to a realistic degree. The “cone crusher” (Figure 10) is constructed of two long pieces of sturdy hardwood ~400 mm long. They are hinged at one end and a known weight (w) is applied at the other. A groove in the base plate supports the cone while a metal cutter is forced into the cone, with the cutter oriented perpendicular to the length of the cone (as if to cut the cone in half across its axis, if the crusher was overloaded).

Given the known weight (w) on the end of the cutter arm of the device, the ratio of the distance of action of the weight-force (d), and the cutter leverage (l), and the cross-section of the end of the cutter, the force and pressure on the end of the cutter in contact with the cone can be calculated. Dimensions of the device are given in Figure 10, which illustrates the device diagrammatically.

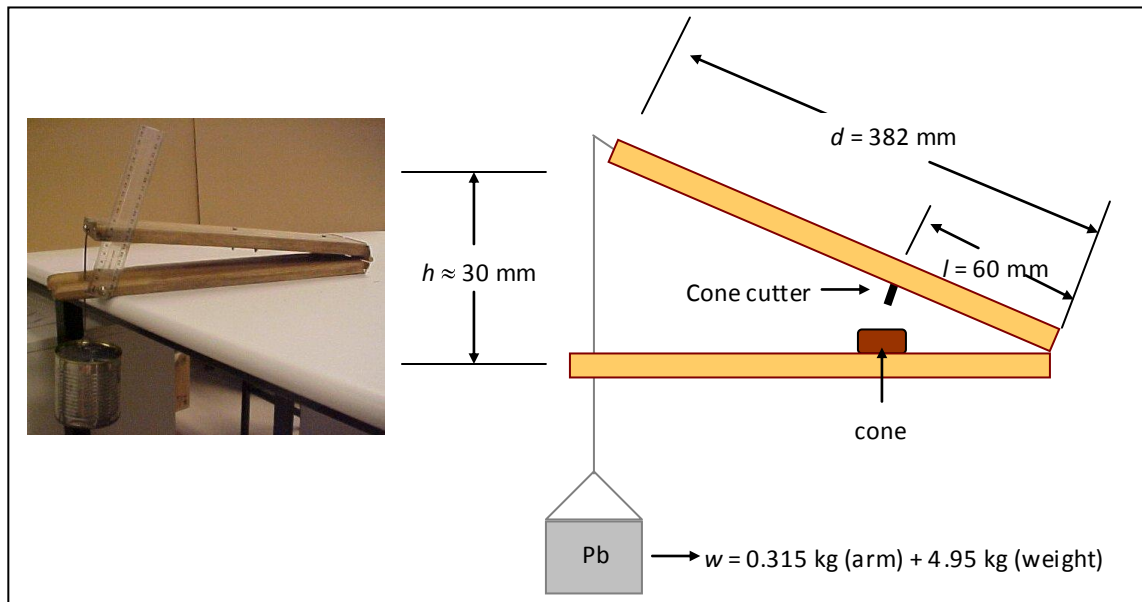


Figure 10. Cone Crusher: device for measuring cone softness

Strictly, the force at the end of the upper arm will depend on the angle of that arm above horizontal, with reduced force at higher angles, given that h is the height at which the upper arm is raised at the start of the crushing process. Typically h starts at about 60 mm, at which level the reduction in force at the attachment point is less than 1.3% and at the final crushed height ($h \sim 30$ mm) the reduction in force is less than 0.32%. These effects can be neglected for the purpose of calculating force or pressure on the cone.

Given a weight-force at the end of the upper arm of 5.275 kg and a leverage of $\times 6.37 (= 382/60)$ the force on the cone cutter is 33.6 kg. The end of the cutter is $2.95 \text{ mm} \times 1.04 \text{ mm} = 3.08 \text{ mm}^2$ so the pressure at the point of contact is 10.9 kg mm^{-2} .

When this force/pressure is applied to the cone, the cutter penetrates the cone to a certain depth. Softer cones will allow greater penetration. Penetration was reported in the reduction of the height (Δh) from first placing of the cutter on the cone (the arm without the lead weight is 0.315 kg) to the final height after application of the 4.95 kg weight. The height is measured at the end of the upper arm, and has a magnification of $\times 6.29$ from the cutter to the measuring point. Typical (Δh) values are ~ 25 mm, and given the magnification of the movement at the cutter to the end of the upper arm, this indicates typical cutter penetration depths of ~ 4 mm. Hard cones show smaller values of (Δh). The weight was selected to achieve cutting depths of this magnitude.

2.1.6 *Allocasuarina torulosa* data

While this study was mainly focused on *A. littoralis* as the preferred forage tree on the Gold Coast, additional data were collected on *A. torulosa* as *C. lathamii* are known to feed on this species as well, particularly in areas where *A. littoralis* density is sparse (e.g. higher altitude, wetter sclerophyll forests). The data collected at each site for *A. torulosa* is summarised below:

1. Number of juveniles (< 4m) without cones
2. Number of juveniles (< 4m) with cones
3. Number of adults (> 4m) without cones
4. Number of adults (> 4m) with cones
 - a. Tree height (m)
 - b. Number of cones
 - c. Quantity and age of any chewing (e.g. time since feeding)

As with the *A. littoralis* data, multiple analyses were performed to determine tree differences within foraged sites, and between foraged and non-foraged sites. Two broad sets of analyses were completed: (1) comparing all trees and cone abundance between foraged and non-foraged sites, and (2) comparing female trees within foraged sites, and between foraged and non-foraged sites:

1. Foraged compared with non-foraged sites
Differences in tree and cone numbers
2. Female Trees
 - a. *Foraged Sites* - two comparisons were made at foraged sites:
 - i feed trees compared with non-feed trees, and
 - ii feed trees compared with apparently suitable trees, thereby ignoring female trees with little to no current cone production (i.e. unsuitable trees), and hence negligible current feeding potential.
 - b. *Foraged and Non-foraged Sites* - two comparisons were made between foraged and non-foraged sites:
 - i all female trees in foraged sites compared with all female trees in non-foraged sites, and
 - ii apparently suitable trees (including feed trees in foraged sites) compared between foraged and non-foraged sites.

2.1.7 Stability of the Feeding Status of *A. littoralis*

All of the field sites (65 sites) studied on the Gold Coast in 2000 by Wild *et al.* (2002) with *A. littoralis* were reassessed in 2002 and 2004 to determine the stability of the feed tree status. Tree health was also noted. Using the chewings data collected as dichotomous (yes/no to the presence/absence of feeding evidence), the data were analysed using either Chi-square or Fisher's Exact probability test for 2×2 contingency tables, to determine the likelihood of a tree having the same feeding status in 2002 and 2004, as in 2000.

2.2 RESULTS

Considerable effort went into traveling to randomly located sites in suitable vegetation types across the Gold Coast, endeavoring to find suitable Casuarina stands for this study. For many sites the terrain was too dangerous or difficult to traverse, and therefore some areas of the Gold Coast (56 sites), mainly southwest sections of the hinterland and Clagiraba Land Warfare reserve, were not accessible, and therefore not sampled (some sites were deemed not possible from reading topographical maps, visits to others were attempted but difficulties prohibited access). At 24 of the sites visited, the quantities of Casuarinas were very small, and no Casuarinas grew within the randomly placed quadrats. At a further 75 sites, although a vegetation type that contains Casuarina was present, these particular sites did not support *A. littoralis* or *A. torulosa*. These sites sometimes contained *Casuarina cunninghamiana* but no *C. lathami* feeding was evident. Several sites ($n = 8$) were in suitable Casuarina areas, but had recently been cleared.

Ultimately, a total of 112 sites were visited that contained *A. littoralis* or *A. torulosa*: 15 foraged sites (6 *A. littoralis* and 9 *A. torulosa*), 37 non-foraged sites and 60 unsuitable sites. Figure 11 shows the distribution of foraged and non-foraged sites, as well as unsuitable sites.

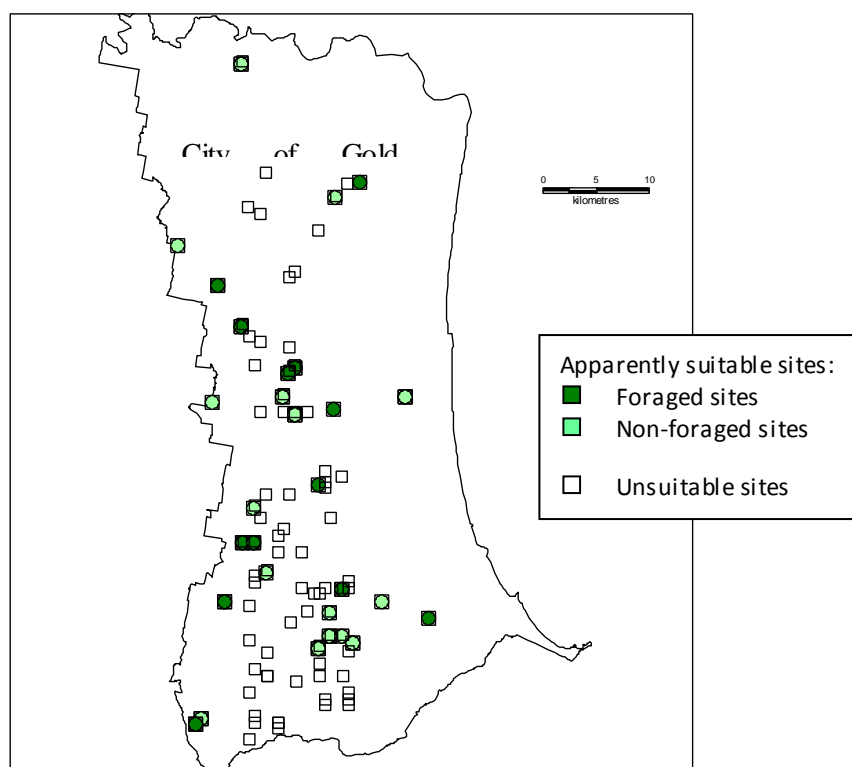


Figure 11. Foraged, non-foraged and unsuitable field sites on the Gold Coast during 2003 sampling.
Source: Gold Coast City Council: Gold Coast region

Given that many sites were distant from roads or other easy access, and some were in very difficult terrain, the time taken to visit and appraise these sites was considerable. Although a large number of sites were visited, only a small percentage of these were suitable, and thus low levels of replication is available for the analysis.

By the definitions used for foraged and non-foraged sites, the presence of 5 or more chewings distinguished these site categories. Two *A. littoralis* foraged sites had very small quantities of chewings (7 and 10), whilst other sites had thousands of chewings. The sites were therefore partitioned into three groups: feed (> 11 chewings), non-feed (0-5 chewings) and “other” (6-10 chewings, observed at only 2 of the 5 sites); in order to determine if the “other” group should be categorised as foraged or non-foraged. Analysis of site and tree characteristics by ANOVA (i.e. all tree data for all sites were incorporated into the analysis) showed that the “other” group was significantly different to both foraged and non-foraged sites. To prevent further complications of the results, the 2 ambiguous sites were removed from the analysis. The foraged site group for *A. littoralis* then had only 3 cases (i.e. 3 of the 5 sites); therefore an additional 3 known foraged sites were examined, to increase replication (totalling 6 feed sites - 3 original and 3 new sites). The random foraged sites were compared to the chosen foraged sites (all tree height, DBH, cone and flower abundance and site characteristics were analysed using ANOVA), to determine if there was a significant bias from choosing sites. No characteristics examined varied significantly

between the random and chosen sites. The analysis of anthropogenic level among sites revealed a weak relationship ($p = 0.049$), but one or more weak spurious significances might occur as a result of testing a large number of variables with few replicates. A Bonferroni adjustment of α for a 10 variable analysis would yield an adjusted α much lower than this p value and this result would therefore be non-significant. When comparing female trees (rather than sites) between the trees at previously known and randomly chosen sites, the number of flowers and chewings differed significantly ($p = 0.001$ and ~ 0 , respectively). The selected foraged sites were assessed at a different time of year, when different flowering might be expected. For this reason, the number of flowers has not been analysed. Table 6 shows the number of sites for each category, with only the foraged and non-foraged sites being analysed.

Table 6. Foraging status of sites of *A. littoralis* and *A. torulosa* on the Gold Coast (including the 3 additional chosen *A. littoralis* foraged sites)

Foraging Status	<i>A. littoralis</i>	<i>A. torulosa</i>	Total (% of sites)
Foraged site	6	9	15 (13%)
Non-foraged site	11	26	37 (33%)
Unsuitable Casuarina site	9	51	60 (54%)
Total	25	86	112

Although many sites across the Gold Coast were studied, few areas contained Casuarinas. Only 25% of sites contained *A. littoralis*, with the majority being *A. torulosa*. Previous reports of *C. lathamii* feeding suggested that *A. littoralis* was the more important feed tree, but this study indicates that this is limited to the lowlands (mainly residential/park living areas), and in the more pristine hinterland, *A. torulosa* was present at considerably more foraging sites than *A. littoralis*. Nevertheless, only 40% (14 of 36) of the feed trees were *A. torulosa*. On average *A. torulosa* is a larger tree bearing more cones, but the quadrats studied indicate that *A. torulosa* are less dense than *A. littoralis* (average 0.012 apparently suitable *A. littoralis*/m² and 0.005 apparently suitable *A. torulosa*/m²).

Although *A. littoralis* yielded less foraged sites, they had significantly more feeding than *A. torulosa* (47 900 vs 17 600 chewings). The distribution of chewings for *A. littoralis* and *A. torulosa* sites is shown in Figure 12. There was a marginally significantly greater number of chewings at *A. littoralis* sites ($p = 0.048$ by randomization test), but no significant difference in the number of feed trees ($p = 0.11$ by randomization test), nor in the proportion of sites at which feeding evidence was found ($p = 1.0$ by Fisher's Exact Probability Test) (Table 7).

Table 7. Quantity of chewings at *A. littoralis* and *A. torulosa* *C. lathami* foraged sites

	A. littoralis		A. torulosa	
	# Feed trees	Total chewings at each feed site	# Feed trees	Total chewings at each feed site
	1	66	1	6
	1	2134	1	73
	3	3610	1	326
	3	5042	1	501
	12	13825	1	719
	2	23223	2	1337
			2	2892
			3	4138
			2	7632
Total	22	47901	14	17624
Average	3.7	7983	1.6	1958
# Non-feed sites		11		26

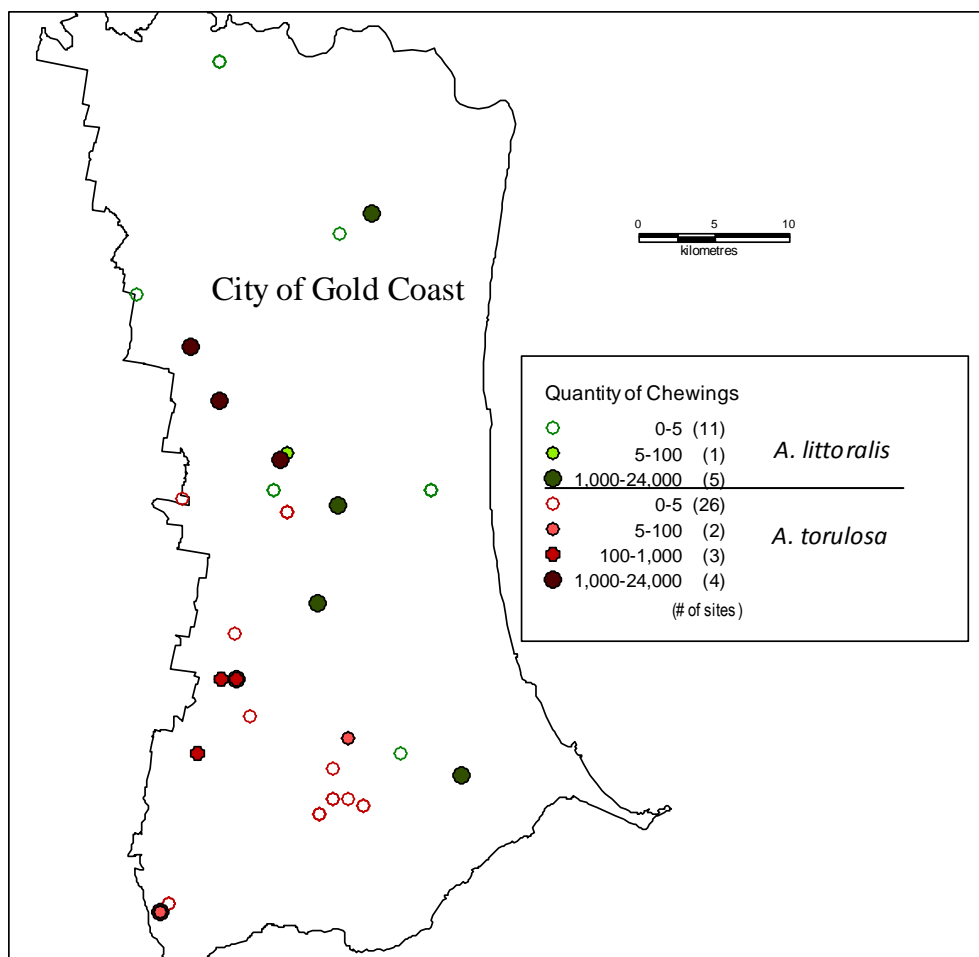


Figure 12. Location and quantity of chewings at field sites on the Gold Coast

Source: Gold Coast City Council: Gold Coast region

2.2.1 Vegetation Types

Allocasuarina littoralis and *A. torulosa* were found in six different vegetation types on the Gold Coast (Figure 13). Several other vegetation types were investigated, but eliminated from this study when confirmed that they do not contain *A. littoralis* or *A. torulosa*. Some sites contained *C. cunninghamiana*, but no feeding was observed.

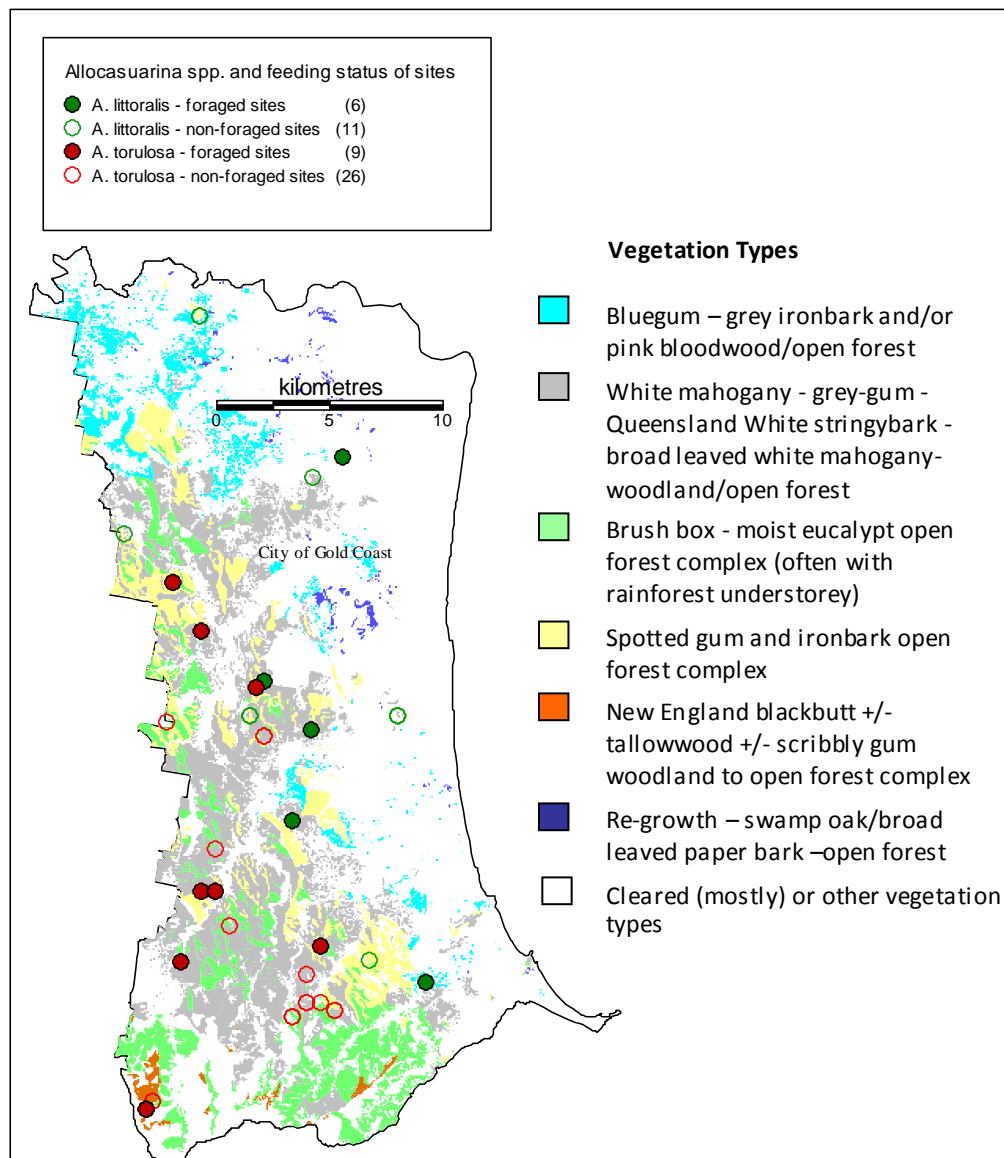


Figure 13. Field sites in different vegetation types on the Gold coast

Source: Gold Coast City Council: Nature Conservation Strategy – Remnant Vegetation (Ecograph), Gold Coast region

Most foraged sites were found in white mahogany woodland/open forest, the dominant vegetation type on the Gold Coast (approximately 48% of area containing *A. littoralis* and *A. torulosa* on the Gold Coast). Five other vegetation types contain *A. littoralis* and *A. torulosa*, but at the time of

the study, contained few foraged sites. Only one field site was in broad leaved paper bark open forest (regrowth), and this site had the most feeding (Table 19).

Table 8. Number of feed and non-feed potential *C. lathami* feeding sites in different vegetation types

Vegetation Type	# Field Sites			
	<i>A. littoralis</i>		<i>A. torulosa</i>	
	Foraged (# chewings)	Non- foraged	Foraged (# chewings)	Non- foraged
Bluegum – grey ironbark and/or pink bloodwood/open forest	1 (3610)	–	–	–
White mahogany – grey gum – Qld white stringybark – broad leaved white mahogany – woodland/open forest	3 (16025)	6	6 (9257)	13
Brush box – moist eucalypt open forest complex (often with rainforest understorey)	1 (5042)	0	1 (2892)	7
Spotted gum and ironbark open forest complex	0	5	2 (5475)	4
New England blackbutt +/- tallowwood +/- scribbly gum woodland to open forest complex	–	–	0	2
Regrowth – Swamp Oak/Broad leaved paper bark open forest	1 (23223)	0	–	–

2.2.2 Comparison of Foraged and Non-Foraged Sites

Analysis of the numerical data indicated that only a few variables are significantly different between foraged and non-foraged *sites*: there were significantly more pre-feeding cones and male flowers, and less clay in the A horizon at foraged sites, than in non-foraged sites (Table 9). These variables are investigated in more detail below.

Table 9. Statistical analysis (t-tests) of *A. littoralis* site data. Significant results are in bold typeface

Variables	Trans-formation	Difference**	t	df	p(difference)	Foraged Mean	Non-foraged Mean	Direct'n***
Site								
# Apparently suitable trees	log (y+1)	0.193	1.35	15	0.20	4.8	2.7	
# Total Casuarinas	log (y+1)	0.301	1.14	15	0.27	42.3	20.6	
Anthropogenic distance	log (y+1)	0.321	0.72	15	0.48	55.8	26.1	
Ppn Females	raw	-0.129	1.17	15	0.26	0.31	0.44	
Ppn Juveniles	log (y+1)	0.058	1.25	15	0.23	0.38	0.21	
Ppn Males	4th root (y)	-0.042	0.28	15	0.78	0.001	0.003	
Ppn Adults (un-sexed)	raw	-0.062	0.76	15	0.46	0.2	0.26	
Total cones at site	log (y+1)	0.351	1.97	15	0.068	1127	501	
Understory % cover	raw	-13.53	0.72	15	0.48	42.8	56.4	
# Pre-feeding cones	log (y+1)	0.788	4.17	15	0.00082	3082	501	+
Soil								
Horizon A								
% Clay	raw	-10.03	4.04	52	0.00018	18.8	28.9	-
Clay rank	raw	-2.65	3.94	52	0.00025	4.4	7	-
Value	raw	-0.221	0.98	52	0.33	2.9	3.2	
Chroma	log (y)	-0.076	1.58	52	0.12	1.7	2.1	
pH	raw	0.060	0.69	52	0.49	4.8	4.8	
Horizon B								
Depth	log (y)	-0.857	0.39	48	0.70	25.3	25.9	
% Clay	sq root (y)	-0.600	1.30	48	0.20	29.3	36.2	
Clay rank	raw	-0.695	0.71	48	0.48	8.3	9.0	
Value	raw	-0.110	0.42	48	0.68	3.9	4.0	
Chroma	sq root (y)	0.056	0.54	48	0.59	2.5	2.7	
pH	raw	-0.064	0.82	48	0.42	4.9	5.0	
Male <i>A. littoralis</i>								
Height*	raw	0.297	0.42	23.2	0.68	8.5	8.2	
DBH (cm)	log (y+1)	-0.016	0.19	42	0.85	7.9	7.5	
# Male flowers	log (y+1)	0.515	3.10	42	0.0034	436.0	134.1	+
* Where the two groups were not homoscedastic, an unequal variance test was applied. Where this applies, a decimal number for degrees of freedom occurs								
** Feed minus non-feed mean in transformed scale where relevant								
*** Where a positive direction means "means at foraged sites were greater than at non-foraged sites". Direction only shown for significant variables								

2.2.2.1 Number of Cones Prior to *C. lathami* Feeding

Whilst the number of cones at the time of study did not differ significantly ($p = 0.068$) between foraged and non-foraged sites, the number of cones at foraged sites when adjusted for feeding losses was greater (~1100) than at non-foraged sites (~500). The estimated number of cones prior to *C. lathami* feeding e.g. the number of cones when *C. lathami* had a choice of trees to feed upon (pre-feeding cones), did differ significantly ($p = 0.001$), with feed trees bearing a larger quantity of cones (Figure 14).

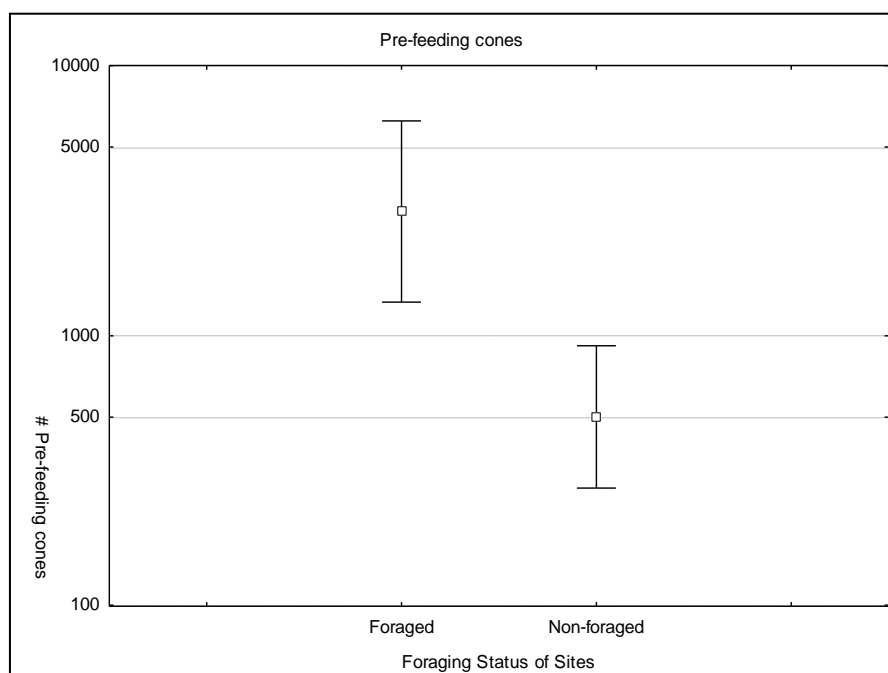


Figure 14. Comparison of the number of cones on *A. littoralis* trees prior to *C. lathami* feeding, in foraged and non-foraged sites ($p = 0.001$, means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

2.2.2.2 Clay Content of Horizon A

Horizon A has more sand and less clay than Horizon B at both foraged and non-foraged sites. In this instance, the clay content of Horizon B did not differ between foraged and non-foraged sites, but did in Horizon A: foraged sites have significantly less clay (i.e. more sand) than non-foraged sites (see Table 10).

Table 10. Soil type and clay content in Horizon A supporting *A. littoralis*

Soil Type	% Clay (Average approx.)	# Sites*		% Sites*	
		Foraged	Non-foraged	Foraged	Non-foraged
Loamy sand	5	3	0	17.6%	0.0%
Sandy loam	15	5	5	29.4%	15.6%
Fine sandy loam	15	1	1	5.9%	3.1%
Loam	25	3	0	17.6%	0.0%
Silty loam	25	3	1	17.6%	3.1%
Fine sandy clay loam	32.5	0	9	0.0%	28.1%
Clay loam	32.5	2	6	11.8%	18.8%
Silty clay loam	32.5	0	4	0.0%	12.5%
Light clay	37.5	0	6	0.0%	18.8%

* Three soil samples were taken in each quadrat, but since not all three samples had the same soil type, each has been included separately, hence total sites equals 49 (3 samples could not be obtained at some sites) and not 17.

When sites were categorized by Horizon A clay content (Table 10), it was evident that sites were rather more likely to be a feed tree if the Horizon A had less than 30% clay (Table 11).

Table 11. Probability of foraging status in high and low clay soils

% Clay	# Foraged Sites	# Non-foraged Sites
< 30 %	15	7
> 30 %	2	25
	χ^2_1	30.3
	p	~0

2.2.2.3 Male Flowers

Male flowers were found to be significantly more abundant in foraged sites than non-foraged sites ($p = 0.003$), but ecologically, this is not apparent. Only two of the six foraged sites had any male trees but these were not significantly different from non-foraged sites ($p = 0.78$, Table 8), with one foraged site having exceptionally high numbers of flowers (estimated 7000 flowers), resulting in a possibly spurious conclusion that foraged sites have significantly more flowers. Four of the foraged sites had no male trees within the quadrats, implying that the density of male *A. littoralis* may be sparse.

2.2.2.4 Other Variables

The remaining variables were analysed using non-parametric analysis. None of these differences between foraged and non-foraged sites was statistically significant (Table 12).

Table 12. Statistical results of non-parametric *A. littoralis* site data.

Variable	Foraged	Non-foraged	Statistic and sign.
Site			
(# of sites)			
Anthropogenic Factor			CLUMP: p = 0.21
House	1	0	
Roads	1	7	
Walking tracks	2	3	
Other	2	1	
Anthropogenic Factor - Roads			Fisher's Exact Probability: p = 0.081
Roads	1	7	
Other	5	4	
Anthropogenic Level			CLUMP: p = 0.90
0	2	1	
1	2	5	
2	0	1	
3	2	3	
4	0	1	
Fire			Fisher's Exact Probability: p = 0.32
Yes	5	4	
No	1	3	
<i>A. torulosa</i> presence			Fisher's Exact Probability: p = 0.24
Absent	4	6	
Present	2	1	
# Sites with Male <i>A. littoralis</i>			Fisher's Exact Probability: p = 0.36
Present	2	5	
Absent	4	2	
Soil			
Horizon A - Hue (red)			Fisher's Exact Probability, p = 0.65
0	0	1	
1	17	25	
Horizon A - Hue #			CLUMP, p = 0.080
2.5	0	1	
7.5	0	7	
10	17	24	
Horizon B - Hue (red)			Fisher's Exact Probability, p = 0.14
0	1	6	
1	14	18	
Horizon B - Hue #			CLUMP, p = 0.28
2.5	1	7	
7.5	0	1	
10	14	22	
Hue #: 7.5YR = reddish brown; 10YR = yellowish brown ; 2.5Y = olive brown			

2.2.2.5 Comparisons of Female *A. littoralis*

Comparison of Trees within Foraged Sites

There are two broad choices that *C. lathami* make when searching for food resources: (1) site – where to feed, and (2) within a site, which tree. Feed trees were contrasted with all other *Casuarinas* within a quadrat (20m × 20m). Feed trees were significantly taller, have a larger DBH and have more cones (Table 13, Figure 15).

Table 13. Summary table of *t*-tests on feed and non-feed trees within foraged sites

Variable	Transformations	Difference	t	df	p	Feed trees Mean	Non-feed trees Mean	Direction
Height (m)*	raw	3.947	7.92	62.7	~ 0	11.7	7.8	+
DBH (cm)	square root (y)	1.601	7.90	147	~ 0	14.3	4.7	+
# Cones	log (y+1)	0.885	6.12	147	~ 0	72	9	+
# Pre-feeding cones	log (y+1)	1.582	11.20	147	~ 0	363	9	+

* unequal variance *t*-test used

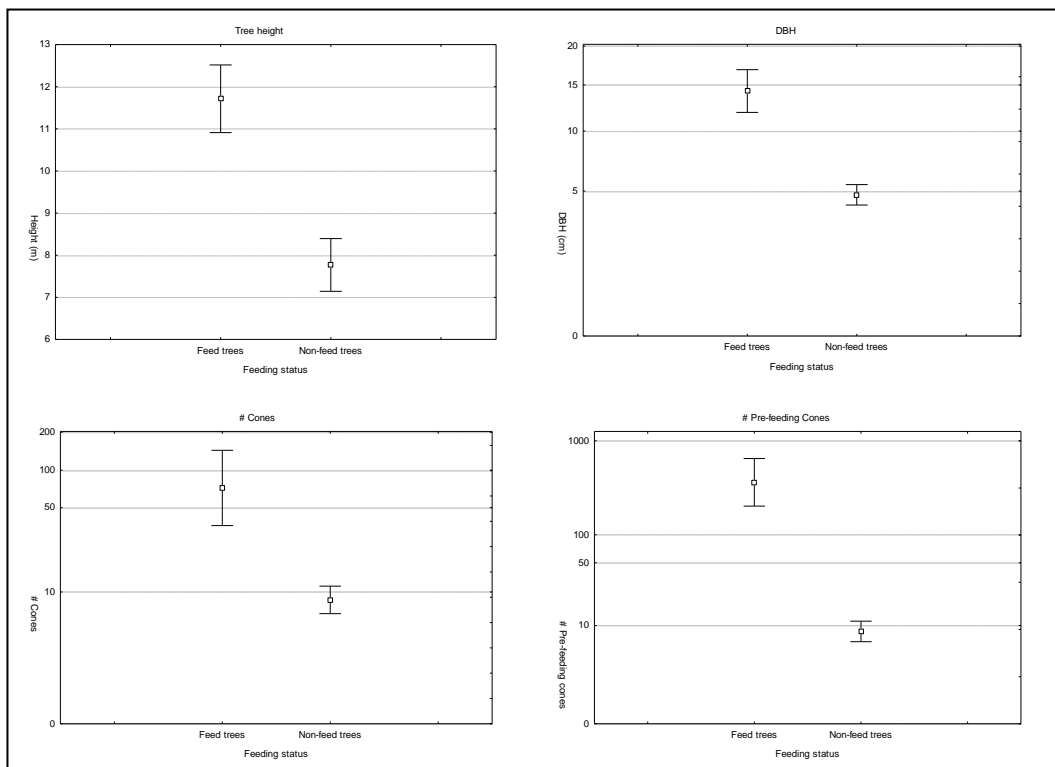


Figure 15. Tree height, DBH and number of cones on feed and non-feed trees in *A. littoralis* foraged sites (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled on some charts).

Comparing the means of the feed and non-feed trees indicates that the latter group may include many juvenile trees, lowering the average height and DBH, as well as having small quantities of cones (i.e. being unsuitable trees). The average number of cones for non-feed trees was only 9, below the definition of an apparently suitable tree.

A second set of analyses compared feed trees with apparently suitable trees (i.e. not including trees with less than 50 pre-feeding cones), to determine if *C. lathami* had randomly picked a feed tree among various apparently suitable trees (i.e. in a foraged site), or if there is a difference between the trees and *C. lathami* have selected a particular tree. These comparisons indicate that *C. lathami* were ‘choosing’ their feed trees, as these trees, although of similar stature to apparently suitable trees, had significantly more pre-feeding cones (Table 14, Figure 16). Evidently, when *C. lathami* have a choice within a site, they will feed on the trees with more cones.

Table 14. Summary table of *t*-tests on the feed trees and apparently suitable trees in foraged sites

Variable	Transformation	Difference	t	df	P	Feed trees Mean	Apparently suitable trees Mean	Direction
Height (m)*	raw	0.023	0.030	18.5	0.98	11.7	11.7	
DBH (cm)	Square root	3.67	2.02	39.0	0.05	14.3	10.4	
# Cones *	4th root (y)	0.32	1.04	20.2	0.31	88	130	
# Pre-feeding cones *	log (y)	0.47	3.29	20.1	0.0037	362	121	+

*unequal variance *t*-test used

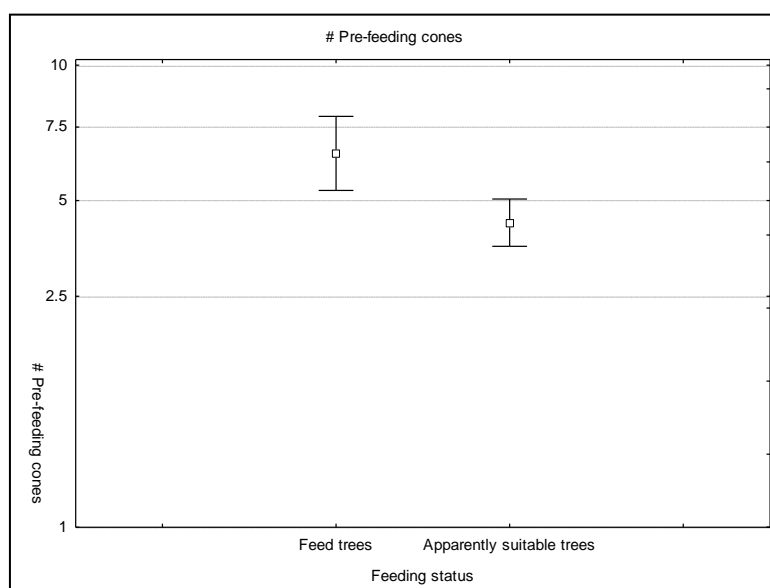


Figure 16. Abundance of pre-feeding cones on feed and apparently suitable trees in *A. littoralis* foraged sites (mean in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

Comparison of Trees between Foraged and Non-foraged Sites

To determine if there is a difference in the trees between foraged and non-foraged *sites*, a comparison was made between all female trees in foraged and non-foraged sites. It was found that Casuarinas in foraged sites have significantly *smaller* girths (DBH) than those found in non-foraged sites (Table 15, Figure 17, $p = 0$).

Table 15. Summary table of *t*-tests on all trees in foraged and non-foraged sites

Variable	Transformation	Difference	t	df	p	Foraged site Mean	Non-foraged site Mean	Direction
Height (m)	raw	- 0.380	0.87	269	0.39	8.3	8.7	
DBH (cm)	4 th root (y)	- 0.180	4.16	270	~ 0.000	5.3	8.3	-
# Cones	log (y+1)	- 0.160	1.86	270	0.064	12	18	
# Pre-feeding cones	log (y+1)	0.057	0.60	270	0.55	15	18	

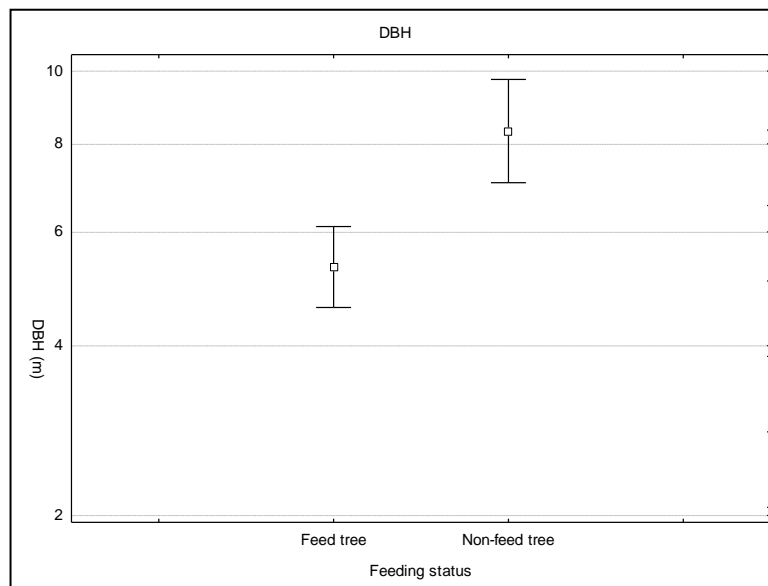


Figure 17. DBH of all trees in *A. littoralis* foraged and non-foraged sites (mean in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

The comparison of apparently suitable trees, including feed trees, between foraged and non-foraged sites showed no significant differences, but trees at foraged sites did tend to have smaller girths and more pre-feeding cones (Table 16).

Table 16. Summary table of *t*-tests on apparently suitable trees (including feed trees) in foraged and non-foraged sites

Variable	Trans-formation	Difference	t	df	p	Apparently suitable trees (incl. feed trees)	
						Foraged sites Mean	Non-foraged sites Mean
Height	raw	0.157	0.30	75	0.76	11.7	11.6
DBH (cm)	4th root (y)	-0.408	1.95	76	0.060	12.1	15.0
# Cones *	4th root (y)	-0.292	1.52	38.7	0.14	106	150
# Pre-feeding cones*	log (y+1)	0.191	1.95	38.8	0.058	219	141

* unequal variance *t*-test used

It seems that the main factor affecting foraging status is the number of pre-feeding cones. No difference was observed between apparently suitable trees (including feed trees) at foraged and non-foraged sites (Table 15). Analysing just apparently suitable trees (i.e. excluding feed trees), there is no significant difference ($p = 0.50$). Ignoring site, a significant difference is observed between feed trees and all apparently suitable trees ($p = 0.003$). To summarise, both within a site and between sites, *C. lathami* are feeding on the trees with more cones.

2.2.2.6 Cone Colour and Softness

None of the variables for cone softness and colour (in terms of greyness and hue), differed *significantly* between feed and non-feed trees (Table 17); but there are some interesting differences, in the details, worth investigating between cone greyness and cone softness between feed and non-feed trees.

Table 17. Cone colour and softness from feed and non-feed trees.
(Additional data from cone softness study)

Variable	# Cones		Kolmogorov-Smirnov test		
	Feed trees	Non-feed trees	Test Value	Critical Value	p
Greyness			0.0958	< 0.1309	> 0.1
0	10	31			
1	9	51			
2	50	75			
3	17	57			
4	33	107			
Hue #			0.1184	< 0.1309	> 0.1
2.5	6	15			
5	27	36			
7.5	70	206			
10	16	64			
Value			0.0651	< 0.1309	> 0.1
2.5	0	2			
3	83	201			
4	36	115			
5	0	3			
Chroma			0.1094	< 0.1309	> 0.1
1	45	139			
2	21	65			
3	17	55			
4	36	61			
6	0	1			
Cone Softness*			0.1131	< 0.1330	> 0.1
15-19	1	4			
20-24	23	89			
25-29	63	164			
30-34	26	38			
35+	4	5			
			2 × 2 Contingency		
Hue redness			$\chi^2_1 = \sim 0$		p = 0.997
0	6	18			
1	113	303			

* compilation of individual cone values

Cone Colour

Although cone greyness was not found to be significantly different ($p = > 0.1$), Figure 18 shows a different trend in cone colour between feed and non-feed trees. In general, non-feed trees have a higher proportion of all cone colours than feed trees, except 50% red-grey cones, as highlighted in Figure 18 ($p = 0.00019$ by Chi-square ($\chi^2 = 16.67$, $df = 4$)). The cones on feed trees are predominantly 50% red-grey in colour (42% of cones), whereas the most abundant colour class on

non-feed trees are more than 50% grey; therefore non-feed trees have a higher proportion of older cones.

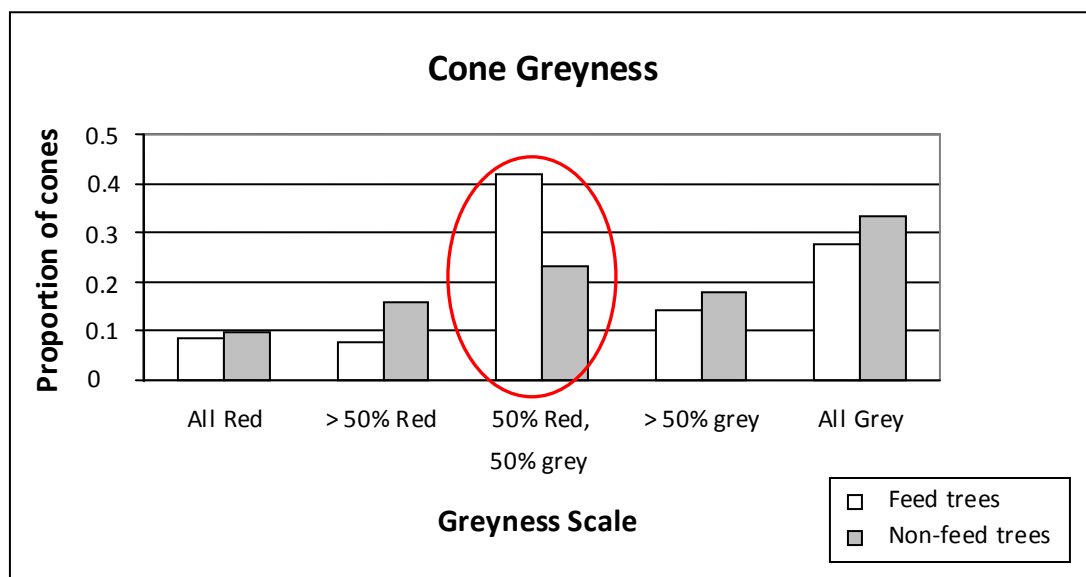


Figure 18. Greyness of cones of feed and non-feed *A. littoralis* trees

Examining skewness and kurtosis of greyness values of cones from feed and non-feed trees instead, the result is that cone greyness of feed trees is neither skewed nor kurtotic, but non-feed trees are negatively skewed (Table 18, $p = 0.008$, i.e. more older cones) and platykurtotic ($p = 0.0001$). Variance is not significantly greater ($p = 0.17$), and means do not differ significantly ($p = 0.79$).

Table 18. Skewness and kurtosis of feed and non-feed tree cone greyness data

Tree Status	Skewness	p (t-test)
Feed trees	-0.267	0.23
Non-feed trees	-0.364	0.0075
Kurtosis		
Feed trees	-0.624	0.16
Non-feed trees	-1.096	0.0001

Cone Softness

Superficially, it seems that the cones of feed and non-feed trees have similar average cone softness (Table 19), with the softest cones on feed trees: the average softness of cones measured 27.5 for feed trees and 26.4 for non-feed trees. However, although the difference between these values seems small (1.1), it may in fact reflect a great difference in cone handling efficiency by *C. lathami*, since the two trees with the most chewings (~ 10 800 and 25 500) had the softest

cones (tree average of 31.2 and 29.8 respectively). Furthermore, regression analysis reveals that the number of chewings increases with the average cone softness of a tree ($p_{\text{regression}} = 0.0021$) (Figure 19).

Table 19. Average cone softness of feed and non-feed trees

Statistic	Cone Softness	
	Feed trees	Non-feed trees
Minimum	24.8	23.4
Average	27.5	26.4
Maximum	31.2	29.3
N	11	30
Standard deviation	1.9	1.9

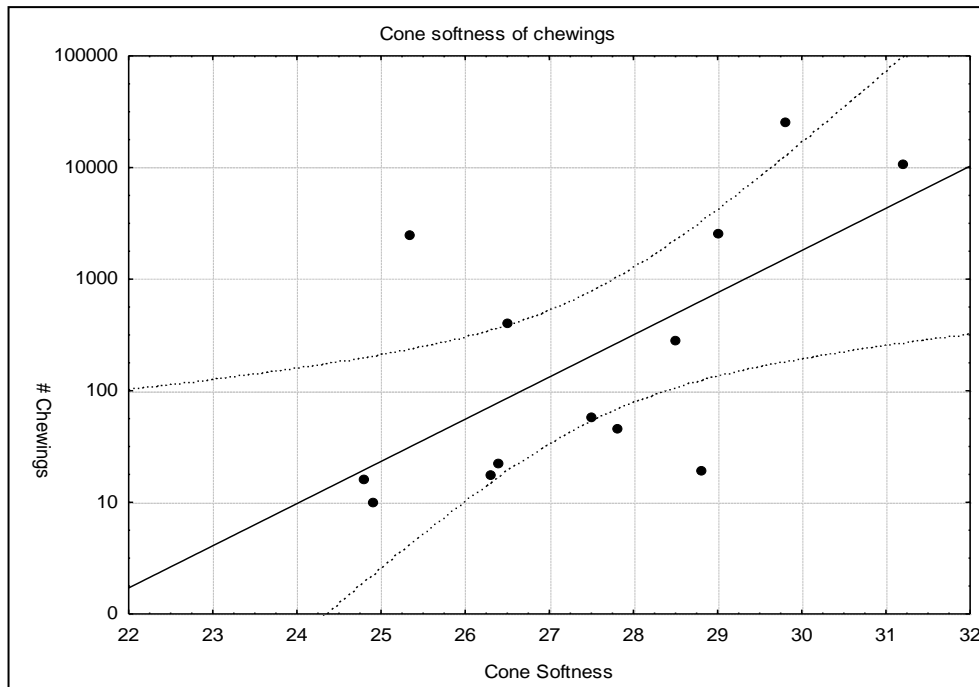


Figure 19. Quantity of chewings from feed trees with different cone softness values (averaged for tree) (regression: $\text{chewings} = 8.79 + 0.403 \times \log(x+1)$, $p = 0.0021$; 95% confidence bands on the regression — note that the y-axis is not linearly scaled)

2.2.3 *Allocasuarina torulosa* Data

As with *A. littoralis*, foraged sites were found to have significantly more pre-feeding cones than non-foraged sites (Table 20, Figure 20).

Table 20. Summary table of comparisons of foraged and non-foraged sites with *A. torulosa*

Variables	Transformation	Difference	t	df	p	Foraged Mean	Non-foraged Mean	Direct'n
# Juvenile (no cones)	log (y+1)	- 0.026	0.15	33	0.89	2.4	2.2	
# Adult (no cones)	raw	- 2.970	1.36	33	0.18	6.2	9.2	
# Adult (cones)	raw	0.948	1.16	33	0.26	4.3	3.4	
# Total cones	log (y+1)	0.267	1.53	33	0.14	747	404	
# Pre-feeding cones	log (y+1)	1.022	5.34	33	~ 0	4254	404	+
# Apparently suitable trees	log (y+1)	0.111	1.78	33	0.084	2.5	1.7	
Total # trees	log (y+1)	- 0.064	0.67	33	0.51	12.8	15.0	

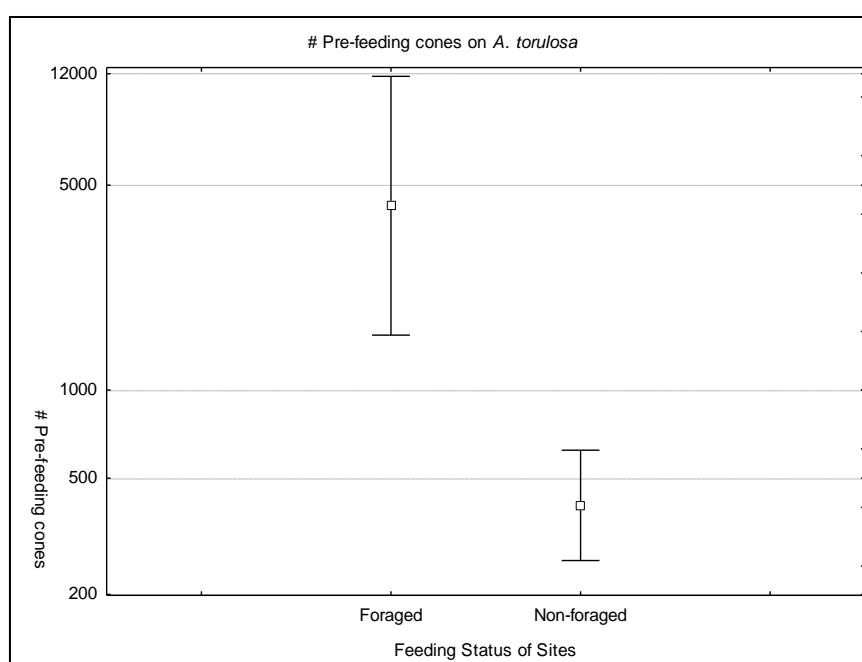


Figure 20. Total abundance of pre-feeding cones in foraged and non-foraged sites (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

2.2.3.1 Comparison of Trees within Foraged Sites

When comparing feed trees with non-feed trees within a foraged site, feed trees have significantly more cones (pre-and post-feeding) and are taller, than non-feed trees (Table 21, Figure 21).

Table 21. Summary table of comparisons on feed and non-feed *A. torulosa* trees in foraged sites

Variable	Transformation	Difference	t	df	p	Feed trees Mean	Non-feed trees Mean	Direction
# Cones	4th root	1.632	3.52	37	0.0011	312	44	+
Height (m)	4th root	0.138	3.47	37	0.0014	13.7	10.1	+
# Pre-feeding cones	log (y+1)	1.220	5.48	37	~ 0	542	32	+

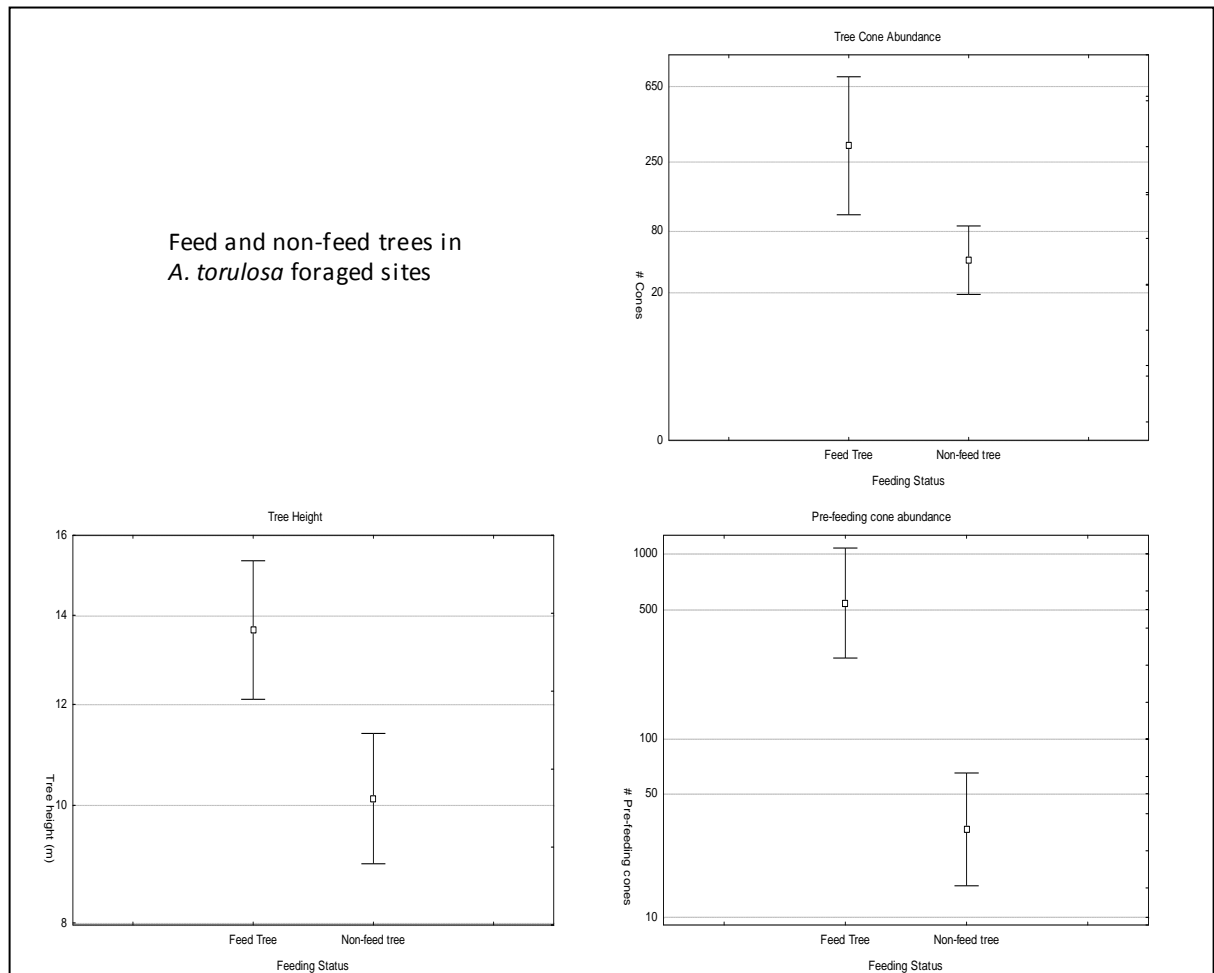


Figure 21. Height and cone abundance of feed and non-feed trees in *A. torulosa* foraged sites (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

When feed trees are contrasted with only apparently suitable trees (i.e. non-feed trees bearing more than 50 cones) in foraged sites, it is evident that feed trees had significantly more pre-feeding cones (Table 22, Figure 22).

Table 22. Summary table of comparisons on feed and apparently suitable *A. torulosa* trees in foraged sites

Variable	Transformation	Difference	t	df	p	Feed trees Mean	Apparently suitable trees Mean	Direction
# Cones	square root (y)	5.623	1.38	22	0.18	415	217	
Height (m)	raw	1.757	1.62	22	0.12	13.9	12.1	
# Pre-feeding cones	log (y+1)	0.480	2.48	22	0.021	542	179	+

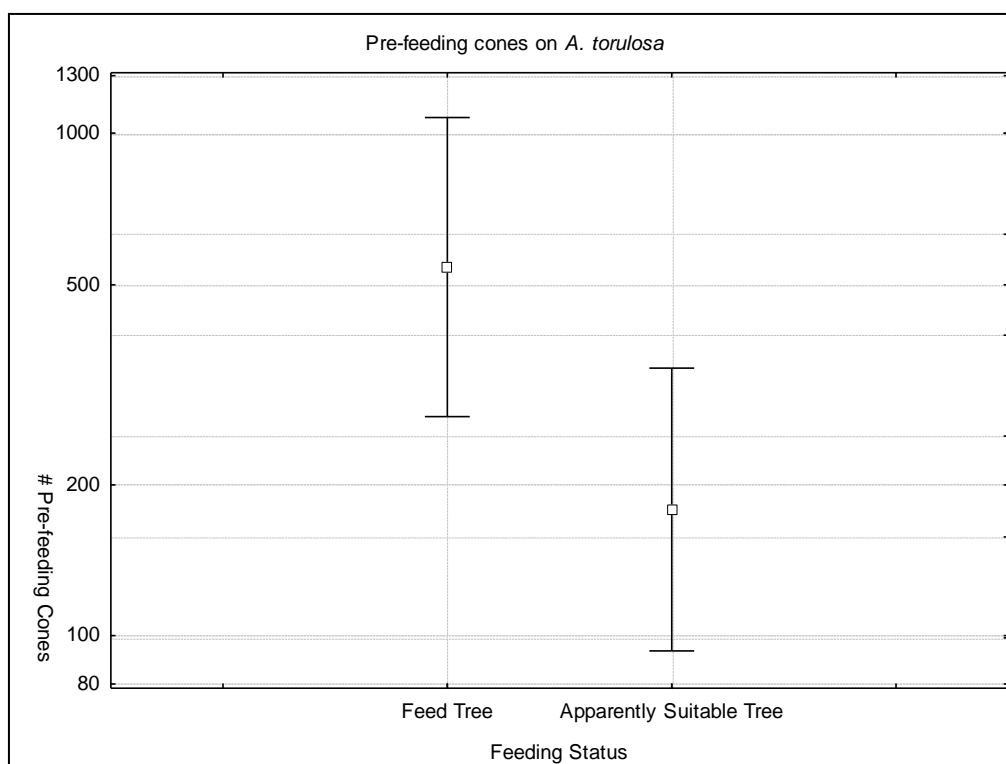


Figure 22. Abundance of cones pre-feeding on feed and non-feed trees in *A. torulosa* foraged sites (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

2.2.3.2 Comparison of Trees between Foraged and Non-foraged Sites

When comparing female trees between foraged and non-foraged sites, whether analysing all trees (Table 23) or only apparently suitable trees (Table 24), no differences between sites are revealed.

Table 23. Summary table of comparisons of all *A. torulosa* trees in foraged and non-foraged sites

Variable	Transformation	Difference	t	df	p	Foraged Mean	Non-foraged Mean
# Cones	log (y+1)	0.047	0.30	125	0.76	65	58
Height (m)	raw	0.269	0.36	125	0.72	11.7	11.4
# Pre-feeding cones	log (y+1)	0.181	1.17	125	0.25	89	58

Table 24. Summary table of comparisons of apparently suitable *A. torulosa* trees (including feed trees) in foraged and non-foraged sites

Variables	Transformation	Difference	t	df	p	Foraged Mean	Non-foraged Mean
# Cones	square root (y)	1.534	0.70	72	0.48	325	272
Height (m) *	raw	0.105	0.13	36.6	0.90	13.1	13.0
# Pre-feeding cones	log(y+1)	0.198	1.76	72	0.083	341	216

* Unequal variance t-test used

2.2.4 Stability of the Feeding Status of *A. littoralis*

The 65 *A. littoralis* trees studied on the Gold Coast in 2000-01 were re-examined for the presence of *C. lathami* feeding in 2002 and again in 2004. Sixty-three trees were examined in 2002 and 41 in 2004. Fifty-four percent of these trees (22/41) were either dead or had been removed by 2004 (they may have died then been removed). The dead trees were either old or had been showing signs of stress, possibly from the drought at the time, as suggested by their brown cladodes. A further three trees, although alive, showed similar signs of distress when examined in 2004. As the result of mortality and some sites not continuing to be accessible, the number of replicates for assessing actual feeding status decreased from 63 in 2000-01 to 19 in 2004.

The feeding status of trees was defined by the presence (feed) or absence (non-feed) of chewings. Given that chewings remain visible for an appreciable time (6-12 months (see Section 3.2.3) under a feed tree and property owners were reporting any feeding, it is unlikely that trees classified as non-feed in 2002 would have been feed trees in the previous year (2001).

Table 25. 2 × 2 Contingency table of feeding status of *A. littoralis* between 2000 and 2002 (number and percentage)

		2002		
		Feed tree	Non-feed tree	Total
2000	Feed tree	7 (29%)	17 (71%)	24
	Non-feed tree	7 (33%)	14 (67%)	21
	Total	14	31	45
		$\chi^2_1 = 0.00046$	P = 0.98	

Table 25 indicates that a feed tree in 2000 has a higher likelihood (although not significant) of being a non-feed tree in 2002 (71%) than has a non-feed tree in 2000 (67%). Similarly, a non-feed tree in 2000 has a higher likelihood of being a feed tree in 2002 (33%), than non-feed trees (29%). Correspondingly, a feed tree is more likely to change its status (0.53) than retain it (0.47). There was, overall, no evidence of any association between feed status in 2000 and in 2002 ($P_{(\text{random allocation})} = 0.98$).

Comparing the feeding status of trees in 2000 with 2004 shows that trees were likely to have the same feeding status (feed trees 70% and non-feed trees 67%) in 2004 as in 2000, although this is not statistically significant ($p = 0.11$, Table 26).

Table 26. 2 × 2 Contingency table of feeding status of *A. littoralis* between 2000 and 2004 (number and percentage)

		2004		
		Feed tree	Non-feed tree	Total
2000	Feed tree	7 (70%)	3 (30%)	10
	Non-feed tree	3 (33%)	6 (67%)	9
	Total	10	9	19
		Fisher's Exact Probability, $p = 0.11$		

It was observed that only 37% of trees (2 feed and 5 non-feed/19, Table 27) maintained the same feeding status throughout, meaning it is more likely that a tree will change its status over time (63%) than retain it.

Table 27. Feeding status of *A. littoralis* trees during a 5 year study

2000	2002	2004	# Sites	% Sites
Feed	Feed	Feed	2	10.5 %
Feed	Feed	Non-feed	0	0 %
Feed	Non-feed	Feed	5	26.3 %
Feed	Non-feed	Non-feed	3	15.8 %
Non-feed	Feed	Feed	2	10.5 %
Non-feed	Feed	Non-feed	1	5.3 %
Non-feed	Non-feed	Feed	1	5.3 %
Non-feed	Non-feed	Non-feed	5	26.3 %
			19	100 %

An important issue raised from this research, as mentioned above, is the loss of trees during the study. In 2002, 16 trees were dead, with another 6 dead in 2004, totaling 22 of the original 65 trees (34%). Feed and non-feed trees had suffered equal losses (i.e. 11 trees dead each). Other trees in the vicinity of trees observed to be non-feed trees in 2002 and/or 2004 that had previously been feed trees, were searched for chewings: only one non-feed tree had a feed tree nearby, thus implying the non-feed tree had been ignored in that year. None of the dead trees had feed trees nearby, but this was mainly due to lack of trees.

2.3 DISCUSSION – FEEDING DETERMINANTS AND STABILITY

2.3.1 Casuarina Health

As outlined in Section 2.2, a total of 112 sites contained Casuarina, with sixty (54%) of these categorized as ‘unsuitable’, meaning that trees at the site did not support more than a total of fifty cones. Some of these sites only had juvenile Casuarinas – some sites were sparse, but most were dense re-growth, suggesting sites were previously affected by fire or other processes resulting in total loss of vegetation and subsequent dense regrowth. Other sites contained mature Casuarina but still had very few cones. The number of cones produced may differ seasonally and between years, being dependent on tree age and nutrient availability.

The nutritional value of seeds is expected to be a good surrogate of tree health but this would be indicative of the period of cone production rather than the time of the study. Although the actual health of Casuarinas is not being studied, it is important to acknowledge that there were various environmental factors negatively affecting the trees on the Gold Coast during the period of study. Many study sites were in various stages post-fire, thus trees had no *closed* cones (refer to

Section 1.3), or the trees had allocated little, if any, resources into cone production after a period of severe drought.

New growth on *A. torulosa* (as evident by purplish cladodes), was observed on many trees, suggesting these trees were placing resources into growth rather than reproduction.

Many trees displayed characteristics indicative of poor health, including wilting cladodes and a high percentage of dead branches. Furthermore, many dead Casuarina trees were observed, some of which appear to have died from being blown over. Observations of these trees indicated shallow root systems growing in dry soils, suggesting inadequate anchorage.

These problems appear widespread and are possibly the result of water stress. Cameron (2004) and Chapman (2005) observed reduced cone production during years of low rainfall. High mortality and stunted growth of Casuarina during drought has been reported in Casuarina plantations in India (Yadav 1983). This type of stress can prevent and/or minimise reproductive growth and may account for the lack of cones observed on Casuarinas. It is more advantageous to allocate resources to growth than reproduction under poor environmental conditions (Chiariello and Gulmon 1991).

Since drought (there had been several consecutive years of below average rainfall), and fire occur frequently on the Gold Coast, it is expected that these factors are a recurrent problem negatively affecting the resources of *C. lathami*. These findings are consistent with the recent work by Cameron (2009) in NSW where interannual variability in rainfall and drought conditions influencing the breeding performance of *C. lathami*. Sightings of *C. lathami* recorded by a community group (Anonymous 2002) were analysed by Stock and Wild (2005), indicating that sightings of *C. lathami* may be influenced by water availability, and Cameron (2005) has found that *C. lathami* tend to occur in larger groups during drought periods. A large bushfire at Boonah (southeast Queensland) highlighted the effects of fire on *C. lathami* with a decline of bird observations in Boonah and a corresponding increase on the Gold Coast (approximately 70 km east of the fire) (Anonymous 2002).

Regardless of the reason for low cone numbers, 54% of Casuarina sites (60 of 112 sites) investigated across the Gold Coast had no *current potential* for *C. lathami* feeding. Therefore, in this region the availability of forage resources may be one of the factors limiting the distribution and abundance of *C. lathami*.

2.3.2 Significant Factors Affecting Forage Resources

Calyptorhynchus lathamii is reputed to have a declining population in southeast Queensland (Garnett 1997). One possible reason contributing to this decline is limitation of available food resources. An extensive study was conducted here comparing foraged and non-foraged sites on the Gold Coast. The results indicate that there is a difference, at foraged sites the soil has lower clay content, trees had higher cone abundance and smaller girth. Within a foraged site, it was observed that the trees fed upon simply had more cones (prior to feeding) than other trees within the area.

2.3.2.1 Soil – Clay Content

This study found that *C. lathamii* feed on *A. littoralis* growing in soils with a higher shallow sand content than those trees growing where feeding was not present. *C. lathamii* have a tight energy budget, forcing them to select cones with a high nutritional value, which may mean, since feed trees were growing in sandier soils, that this particular soil type enables the production of higher quality (or abundance of) cones, than on soils with more clay (there was insufficient data to test this speculation). Different soil types will affect the amount of water and nutrients available to plants (among other factors) (Wild 1988). Considering that Casuarinas were showing signs of severe water stress during the period of study, it would seem likely that factors affecting water availability might differ between foraged and non-foraged areas.

Allocasuarinas are known to be low nutrient specialists (Torrey and Racette 1989, Deim *et al.* 2000), but the robustness of Casuarinas may be dependent on adequate available moisture during the dry season (Yadav 1983). *A. littoralis* is a coastal species, typically growing in sandy soils. McLauren and Cameron (1996) found in selected New Zealand soils the availability to plants of water is higher in the A horizon of sandy or silt loams than of clays. The soil substrate can affect root depth, as root systems can more easily penetrate soils with many macropores and little structure (i.e. sandy soils), than soils with few macropores and many micropores (i.e. clay soils) (Singer and Munns 1996). For this reason, plants growing in sandy soils usually have a longer (deeper) tap-roots than those in clay, since macropores usually drain more rapidly than micropores (Singer and Munns 1996). Depending on the depth of the water table, it would be expected that plant species with a long tap root would be better adapted to cope during a drought, than those with a shorter tap root.

The quantity of water available to plants and root depth were not studied here, but it seems likely that the difference in soil substrates between foraged and non-foraged areas may be affecting their moisture and nutritional quality and merits further investigation.

2.3.2.2 *Allocasuarina littoralis* female trees

As might be expected, the number of pre-feeding cones was significantly greater on feed trees than non-feed trees. By restricting their feeding to trees with the most abundant cones, *C. lathami* would decrease their search and travel time, both within and between trees (Chapman and Paton 2005).

When comparing the apparently suitable trees (including feed trees) between foraged and non-foraged sites, it is observed that apparently suitable trees at foraged sites have noticeably more cones (pre-feeding, Table 15). The average number of pre-feeding cones on apparently suitable trees in foraged sites was 219 and 141 in non-foraged sites (difference not statistically significant, although $p = 0.058$). This lack of significance brings us back to the problem of ‘classification of trees’ (section 3.1.1) – are apparently suitable trees that have not been fed upon not actually *suitable*, or they are suitable, but have not yet been fed upon but may be sometime in the future?

Although not significant, a slightly smaller girth for the trees in foraged sites than non-foraged sites was observed. Pannell and Myerscough (1993) found that the viability of *A. nana* and *A. distyla* seed decreased with tree age: old trees may not have resources to produce high quality cones, and any cones, although abundant, may be old i.e. retained from previous seasons, and as suggested by Crowley (1986), seeds may have commenced degradation. In terms of *C. lathami*, this means that the cones of older trees may be of lower quality and are therefore not an optimal food source.

Cone colour and softness produced rather complicated results. The simple difference between feed and non-feed trees was not statistically significant, yet important trends were identified. The difficulty in understanding these findings is that the average cone greyness obtained for a feed tree is after *C. lathami* feeding, therefore it is not known what the proportion of cone of various greyness classes was prior to feeding. There are two possible scenarios resulting in a particular post-feeding cone greyness ratio i.e. the feed tree prior to feeding:

1. bore mainly red-grey cones, perhaps as a result of previous stripping of younger cones before they could age to grey cones, and after feeding mainly red-grey cones remain, or
2. had a broad distribution of cone ages and therefore colours, and post-feeding, the desirable red cones have been selectively removed, leaving a high proportion of red-grey cones.

Since *C. lathami* return to a feed tree with abundant cones on consecutive days, it is surmised that the tree would (at least initially) have a large supply of their favourite cone type i.e. younger red cones. Furthermore, it is expected that there would be a difference in the proportion of the various cone colours between feed and non-feed trees as a consequence of *C. lathami* feeding: a feed tree that has been a feed tree for some years, especially if they are being stripped of cones, would be expected to have few old cones and many very young cones. Results here show, however that, irrespective of feed status, the trees studied had a higher proportion of older cones than younger cones, which indicates that *C. lathami* on the Gold Coast may be preferentially feeding on young cones i.e. cones that are more than 50% red. This result was also observed by Clout (1989, in Eden NSW), Pepper (1996, on Kangaroo Island), Crowley and Garnett (2001, on Kangaroo Island), and Cameron and Cunningham (2006, Dubbo NSW), due to a higher nutritional value in younger cones. Younger cones are softer and therefore believed to be easier to handle. This does not, however, explain why the highest proportion of cones on feed trees are 50% red/grey. A study investigating cone colour needs to be done over years to gather ‘before’ and ‘after’ information to gain a better understanding of these dynamics.

One might postulate a similar question related to cone softness being; “Give that *C. lathami* prefer soft cones, do they choose trees with soft cones, so that feed trees generally have soft ones, or do they choose trees of diverse cone softness, eat the soft cones and leave predominantly hard cones behind on feed trees?”

Two of the trees studied here were found to have been fed upon after cone collection. These trees had fresh chewings and were visited repeatedly to collect data on chewing colour and age (section 3.2.2.2). Cones on these two trees were predominantly of the 50% red/grey and > 50% grey colour classes, with an average cone softness of approximately 30 to 31 (Figure 18). Tree ‘W1’ had at least 4 separate feeding bouts, even after cone collection. Since both of these trees had cones softer than other feed or non-feed trees, these observations suggest that the birds have a preference for softer cones, consistent with other studies (Clout 1989, Pepper 1996, Crowley and Garnett 2001).

Summary

Overall, it seems that apparently suitable trees in foraged and non-foraged sites may have the capacity to be feed trees, but not whilst substantially more cones exists on other trees (i.e. *current* feed trees). If these trees with more cones are stripped, it seems likely that some of the apparently suitable trees (once they have the most cones) would become feed trees, as found in Section 3.4.

2.3.3 *Allocasuarina torulosa*

The patterns observed in *A. torulosa* were similar to *A. littoralis*, where feed trees within a site have higher pre-feeding cone abundance than other trees, thus having the potential to permit reduced search and handling time for *C. lathami*. Although pre-feeding cones were more abundant in foraged sites than non-foraged sites, this was not statistically significant (Table 20).

As with *A. littoralis*, it seems that *C. lathami* feed intensively at a few sites, and ignore most other sites. This is consistent with previous studies that report that *C. lathami* regularly frequent the same site (Pepper *et al.* 2000, Wild *et al.* 2002). There were actually more apparently suitable trees observed in non-foraged sites than foraged sites (i.e. a higher number of ignored apparently suitable trees). *A. torulosa* growth in brush box-moist eucalypt open forest complex is quite sparse (compared to *A. littoralis* etc.) and lack of feeding may be indicative of distances between potential foraging opportunities.

Nevertheless, *A. torulosa* grows in sparser associations than *A. littoralis* on the Gold Coast (average 0.012 apparently suitable *A. littoralis*/m² and 0.005 apparently suitable *A. torulosa*/m² within sampled quadrats). Consequently, this species could be considered a less efficient choice for *C. lathami* feeding due to greater distances to relocate to another feed tree, although the larger cone crops on *A. torulosa* (average of 421 cones on *A. torulosa* and only 171 on *A. littoralis*), means that *C. lathami* would not need to relocate between trees as often.

This study found that a large proportion of randomly chosen field sites did not currently provide a food source for *C. lathami*. 59% of *A. torulosa* quadrats (and 33% for *A. littoralis*) were categorised as 'Unsuitable'. Some *A. littoralis* and *A. torulosa* sites had been affected by fire, resulting in an 'Unsuitable' status in many instances, while trees at many *A. torulosa* sites had failed to invest in reproduction, thought to be a result of drought conditions (cf. Cameron 2004).

2.3.4 Feeding Stability

Prior to this study, it was believed that *C. lathami* were faithful to feed trees, in that reports indicate that they return to the same feed tree year after year, consistently ignoring other available trees (Pepper *et al.* 2000, Anonymous 2002). This may be true in locations where there are few suitable trees, but this study has shown that the feeding status of Casuarina trees is not stable, with the feeding status of trees in previous years not able to predict the tree's status in the future. This finding is consistent with that of Cameron (2009) who also reported that forage resources fluctuated from year to year in response to rainfall variability.

Where possible, it would appear that *C. lathami* are faithful to trees if such trees are still the tree with the most cones within the stand. Potentially, foraging by *C. lathami* may actually aid in ensuring these trees continually have the most cones by stripping it of cones. Loss of reproductive structures may in fact stimulate more production, thus ensuring a large crop of fresh (red-brown, not old grey) cones. While *C. lathami* do prefer younger (red / brown) cones (Clout 1989, Pepper *et al.* 2000, Cameron and Cunningham 2006), this ‘farming’ hypothesis remains to be tested.

The study of foraged and non-foraged sites, as well as feed and non-feed trees, indicates that the feeding status is based on the number of cones on a tree, and therefore, future feeding status of a tree or an area cannot be predicted based on previous feeding status. However, it is possible to visit an area and predict if *C. lathami* will feed there, and on which trees. This research has demonstrated that *C. lathami* are most likely to feed on adult trees (mature, but not senescent), with the most cones, but influenced by the age as well as softness of these cones. Once again this is consistent with previous findings where cone abundance was a significant determinant of feed tree status (Clout 1989, Pepper *et al.* 2000). Indeed, cone abundance may be the driving factor contributing to tree selection, and then cone colour may drive individual cone selection within a tree to maximise seed kernel intake rates (Crowley and Garnett 2001, Cameron and Cunningham 2006).

Coffey (1996) studied the feeding of *C. lathami* over 10 days during August and September 1996, in the Cudgen Nature Reserve, north New South Wales coast. She was unable to find any evidence of *C. lathami* feeding from *A. littoralis*, *A. torulosa* or *C. glauca* (dense ground cover and rocky areas may have prevented finding any chewings present). Data from the present study (Section 3.3.2.1) suggests that the chewings of *A. littoralis* and *A. torulosa*, on the Gold Coast, take between 9 and 10 months to decay (i.e. decayed to such a point whereby the debris is no longer recognizable as chewings). The absence of such reasonably easily located feeding evidence suggests that *C. lathami* had not been in the Cudgen Nature Reserve for nearly a year, prior to Coffey’s study. The stability study here (Section 2.2.4), demonstrated that the feeding status of an area changes over time, therefore it is not possible to predict the future feeding status of an area much better than if it were randomly allocated. Indeed, Castley (2010) reported abundant feeding in the Cudgen area in 2009.

Pepper *et al.* (2000) reported that *C. lathami* would completely strip trees of their cones, which means trees would take a few years to replace a large cone crop. A lack of current *C. lathami* feeding evidence therefore does not mean the site is not suitable *C. lathami* habitat, it only means it is not *currently* suitable, but may have been an important foraging site in the past, and may be an important foraging site in the future.

The high number of dead trees observed during this study is of concern. This study was conducted mainly on private property in rural/residential areas where most sites only had a few Casuarina growing. Typically, there is poor recruitment of Casuarina in many of these sites due to mowing etc. preventing seedling growth (observed), which means many of the feed trees are not being replaced. In 2000, Wild *et al.* (2002) examined 80 sites containing either *A. littoralis* or *A. torulosa*. Sixty-five of these were on private property, with many of these sites showing evidence of intensive feeding. While these sites may not be considered optimal in terms of number of available trees (i.e. may require regular relocation compared to large stands of Casuarinas found in bushland), they are obviously making an important contribution to the total food source of *C. lathami* on the Gold Coast. This mortality and possible low recruitment is therefore expected to be negatively impacting the abundance and distribution of *C. lathami* on the Gold Coast.

2.3.5 Summary

The analysis indicates that *C. lathami* preferentially feed in trees and areas with more cones, optimizing their feeding efficiency by reducing flying and search time. Since it does in fact seem that it is the number of cones that is important, and this changes over time, with age and changes in environmental conditions, it is necessary to have an excess of feeding resources, widely distributed, to ensure adequate food availability, taking into account that temporary losses of food that may occur in some areas.

The key point shown from this study is that the sole reliable indicator of feed tree status is the number of cones. The reduction of cones from a major feeding tree will most likely render the tree a non-feed tree for some unknown time. This study has demonstrated that *C. lathami* feed in more optimal sites when they are available, but Wild *et al.* (2002) showed that they also utilize less optimal sites (i.e. where low number of trees may force them to relocate to new trees and new areas more frequently). Whether this is a response to limitations in availability of food resources is unknown at this time, but *C. lathami* preferentially feed in more optimal sites when possible.

It is evident from these results that *C. lathami* appears to be adopting an optimal foraging strategy (Charnov 1976, Perry and Pianka 1997), in an effort to maximize the intake of forage resources and hence enhance its own chances for survival. This optimisation also appears to be linked to forage availability and quality as previously reported by Crowley and Garnett (2001), as well as Cameron and Cunningham (2006). While it is possible to postulate on these optimal foraging behaviours at a local scale, there remain a number of questions about how *C. lathami* selects for such resources at a landscape level and this requires further investigation.

2.4 REFERENCES

- Alpizar-Jara, R. and Nichols, J.D. 2004. The relationship between species detection probability and local extinction probability. *Oecologia*. **141**: 652-660.
- Anonymous. 2002. Sightings and Records. Unpublished report of the Wildlife Preservation Society of Queensland, Glossy Black-cockatoo Branch Inc., Gold Coast.
- Ball, S.J., Ramsey, D., Nugent, G., Warburton, B. and Efford, M. 2005. A method for estimating wildlife detection probabilities in relation to home-range use: insights from a field study on the common bushtail possum (*Trichosurus vulpecula*). *Wildlife Research*. **32**: 217-227.
- Bennets, R.E. and Kitchens, W.M. 2000. Factors influencing movement probabilities of a nomadic food specialist: proximate foraging benefits or ultimate gains from exploration? *Oikos*. **91**: 459-467.
- Brown, J.S. 1988. Patch use as an indicator of habitat preference, predation risk, and competition. *Behavioral Ecology and Sociobiology*. **22**: 37-47.
- Cameron, M. 2004. Ecology of the Glossy Black-cockatoo (*Calyptorhynchus lathami*) in central New South Wales. PhD Thesis. University of New England. Armidale. 168 pp.
- Cameron, M. 2005. Group size and feeding rates of Glossy Black-Cockatoos in central New South Wales. *Emu*. **105**: 299-304.
- Cameron, M. 2009. The influence of climate on Glossy Black-cockatoo reproduction. *Pacific Conservation Biology*. **15**: 65-71.
- Cameron, M. and Cunningham, R.B. 2006. Habitat selection at multiple spatial scales by foraging Glossy Black-cockatoos. *Austral Ecology*. **31**: 597-607.
- Castley, G. 2010. Griffith University, Glossy Black-Cockatoo Conservancy. Brisbane. *Pers. comm.*
- Chapman, T.F. 2005. Cone production by the Drooping Sheoak *Allocasuarina verticillata* and the feeding ecology of the Glossy Black-cockatoo *Calyptorhynchus lathami halmaturinus* on Kangaroo Island. PhD Thesis. University of Adelaide. Adelaide. 124 pp.
- Chapman, T.F. and Paton, D.C. 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.
- Charnov, E.L. 1976. Optimal Foraging, the Marginal Value Theorem. *Theoretical Population Biology*. **9**(2): 129-136.
- Chiariello, N.R. and Gulmon, S.L. 1991. Stress Effects on Plant Reproduction. Pp 161-188 in Mooney, H.A., Winner, W.E. and Pell, E.J. (eds.). 1991. *Response on Plants to Multiple Stresses*. Academic Press, USA. 396pp. ISBN 0125053556.
- Clout, M. 1989. Foraging behaviour of Glossy black-cockatoos. *Australian Wildlife Research*. **16**: 467-473.
- Coffey, T. 1996. *Habitat status of the glossy black-cockatoo (Calyptorhynchus lathami) in Cudgen Nature reserve, northern New South Wales*. Unpublished report, Southern Cross University, Lismore, NSW. 52pp.
- Crowley, G.M., Garnett, S.T. and Pedler, L. 1996. *Assessment of the role of captive breeding and translocation in the recovery of the South Australian subspecies of the Glossy black-cockatoo*

Chapter 2 — Feed Status of Casuarina Trees

- Calyptorhynchus lathami halmaturinus. *Kangaroo Island, South Australia*, Report prepared for the South Australian Glossy black-cockatoo Recovery Team. 40pp.
- Crowley, G.M. 1986. Ecology of *Allocasuarina littoralis* (Salisb) L. Johnson and *A. torulosa* (Ait.) L. Johnson in North Queensland. PhD Thesis. Botany Department. James Cook University. North Queensland. 301 pp.
- Crowley, G.M. and Garnett, S.T. 2001. Food value and tree selection by glossy black-cockatoos *Calyptorhynchus lathami*. *Austral Ecology*. **26**: 116-126.
- Diem, H.G., Duhoux, E., Zaid, H. and Arahou, M. 2000. Cluster roots in Casuarinaceae: role and relationship to soil nutrient factors. *Annals of Botany* **85** (6) 929-936.
- Garnett, S. 1997. *Conservation plan for the Gold Coast population of Glossy black-cockatoos (Calyptorhynchus lathami)*. Unpublished Report, Gold Coast. 6pp.
- Garnett, S.T., Pedler, L.P. and Crowley, G.M. 1999. The breeding biology of the glossy black-cockatoo *Calyptorhynchus lathami* on Kangaroo Island, South Australia. *Emu* **99**(4): 262-279.
- Isbell, R.F. 1996. *The Australian Soil Classification*. CSIRO Publishing, Australia 144pp. ISBN 0-643-05813-3.
- Joseph, L. 1982. The glossy black cockatoo on Kangaroo Island. *Emu*. **82**: 46-9.
- MacKenzie, D. I. and Kendall, W. L. 2002. How should detection probability be incorporated into estimates of relative abundance? *Ecology*. **83** (9): 2387-2393.
- McLauren, R.G. and Cameron, K.C. 1996. *Soil Science. Sustainable Production and Environmental Protection*. Oxford University Press Auckland. 304 pp. ISBN 0195583450.
- Pannell, J.R. and Myerscough, P.J. 1993. Canopy stored seed banks of *Allocasuarina distyla* and *A. nana*. *Australian Journal of Botany*. **44**: 1-9.
- Pepper, J.W. 1996. *The behavioural ecology of the Glossy black-cockatoo Calyptorhynchus lathami halmaturinus*. PhD Thesis, University of Michigan, Michigan. 307 pp.
- Pepper, J.W., Male, T.D. and Roberts, G.E. 2000. Foraging ecology of the South Australian glossy black-cockatoo (*Calyptorhynchus lathami halmaturinus*). *Austral Ecology*. **25**: 16-24.
- Perry, G. and Pianka, E. R. 1997. Animal foraging: past, present and future. *Trends in Ecology and Evolution*. **12** (9): 360-364.
- Sham, P.C. and Curtis, D. 1995. Monte Carlo tests for associations between disease and alleles at highly polymorphic loci. *Annals of Human Genetics*. **59**: 97-105.
- Siegel, S. and Castellan, N.J. 1988. *Nonparametric Statistics for the Behavioural Sciences*. McGraw-Hill Inc. New York. 399pp. ISBN 0-07-100326-6.
- Singer, M. and Munns, D. 1996. *Soils. An Introduction*. Prentice Hall U.S.A. 480 pp. ISBN 0134491742.
- Stock, M.J. and Wild, C.H. 2005. Seasonal variation in Glossy Black-Cockatoo sightings on the Gold Coast. *Corella*. **29**: 94-96.
- Torrey, J.G. and Racetta, S. 1989. Specificity among the Casuarinaceae in root nodulation by *Frankia*. *Plant and Soil* **118** (1-2) 157-164.
- Wild, A. 1988. *Russell's Soil Conditions and Plant Growth* (11e), Longman Scientific and Technical, Harlow UK. 991pp. ISBN 0470207965.

- Wild, C.H., Stock, M. and Thomas, E. 2002. *Factors influencing choice of feed trees by the Glossy Black Cockatoo in south-east Queensland*. Unpublished Report. Griffith University, Gold Coast City Council and WPQS Glossy Black Cockatoo Branch, Gold Coast. 91 pp.
- Yadav, J.S.P. 1983. Soil limitations for successful establishment and growth of Casuarina plantations. pp. 138-157 in Midgley, S.J., Turnbull, J.W. and Johnston, R.D. (eds), *Casuarina Ecology, Management and Utilization: Proceedings of an International Workshop*. CSIRO, Melbourne. ISBN 0643034633.

3 ABUNDANCE AND DISTRIBUTION OF CALYPTORHYNCHUS LATHAMI ON THE GOLD COAST

According to Garnett (1997) the (then) Queensland Department of Environment commissioned estimates the entire Queensland population of *C. lathami* in 1993, and in the *Assessment of Conservation Status* reported a population estimate of 1000 and 2500 individuals, although this was not based on any empirical population study. Further, in 1997 Garnett reported this population to be declining as a result of habitat loss. As outlined in Chapter 1, the likelihood that populations of *C. lathami* are declining in the region, coupled with the uncertainty over the size of the population, limits the ability to implement effective conservation interventions. If the population is indeed declining as anticipated, then it is important that the mechanisms driving such decline are identified, but also that the population does not become at risk from inbreeding or stochastic events due to its small size (Lande 1993, Caughley 1994). This uncertainty over the distribution and abundance of *C. lathami* in southeast Queensland therefore requires further research. Unless stated otherwise, *C. lathami lathami* will be referred to as *C. lathami* in this chapter. When other subspecies are referred to, their origin or subspecies will be specified,

While the general distribution of *C. lathami* is generally well documented (see Chapter 1), their local movements are poorly known (Marchant and Higgins 1990). Forshaw and Cooper (1981) suggested that they are relatively sedentary, whilst others consider them as a permanent resident (Costello 1981), and others still, as nomadic (Roberts and Ingram 1976). Some members of the population (i.e. non-breeding birds, having less nutritional requirements than breeding birds), may be more mobile, thereby travelling further for resources during periods of high competition etc. (Ford 1985, Farmer 2001). *Calyptorhynchus lathami* are said to move locally in flocks, when preferred foraging areas are depleted of food (Pepper 1993); but flocks are rarely seen on the Gold Coast (Anonymous 2002, and personal observations). Flocking in *C. lathami* may also be associated with periods of reduced food availability when associations with conspecifics may actually improve foraging efficiencies (Cameron 2005).

Calyptorhynchus lathami are regularly reported feeding on the Gold Coast in Queensland (Garnett 1997), however, there are no baseline data on the size of the local population or their movements. This lack of data means the magnitude of an effect (e.g. expected decline) resulting from habitat loss and fragmentation cannot be calculated and may not even be noticed. If the birds are nomadic, then it is most likely that *C. lathami* are genetically “mixing”, but if they are relatively sedentary and have formed isolated populations, the small numbers of birds being observed in different locations may be inbreeding to an undesirable degree. Inbreeding reduces the variability

within the gene pool, reducing the population's likelihood of overcoming environmental changes (Krebs 2009). Franklin (1980) proposed that in order to reduce extinction risk in species with small populations a minimum effective population of 50 individuals would be required, with this figure increasing to 500 if genetic heterozygosity was to be preserved in the longer term. While others (Traill *et al.* 2010) argue that these figures may be an order of magnitude too small, it does highlight that small populations with fewer than 500 effective individuals may be at considerable risk. For *C. lathami* this suggests that the species may be at risk from both the factors contributing to a perceived decline as well as a potentially small number of individuals (Caughley 1994).

A rigorous study needs to be performed to gain more information on the *C. lathami* population on the Gold Coast. As highlighted by Garnett and Crowley (2000), we need to know how many birds are in the area, and identify and protect important feeding and nesting areas. These baseline data will enable the implementation of an effective conservation management plan.

As outlined in the introduction, the size, terrain and accessibility of the Gold Coast, required the development of a novel method to assess the population status of *C. lathami*. An indirect method of estimating the abundance of *C. lathami* was employed, using 'indicators', in this instance, feeding residue commonly called 'chewings' (Clout 1989). The use of signs left by animals is commonly used to determine the *relative* abundance of a variety of species across taxonomic groups including small mammals (Whisson *et al.* 2005), larger herbivores (Plumptre and Harris 1995, Barnes *et al.* 1997), and carnivores (Wilson and Delahey 2001, Harrington *et al.* 2008a, Jeffress *et al.* 2011, Lara-Romero *et al.* 2012), but is less commonly used as a means to assess bird populations, especially in absolute terms. The literature is replete with studies using visual or auditory methods to detect birds to estimate abundance (e.g. Haselmayer and Quinn 2000, Watson 2004, Gregory *et al.* 2004, Acevedo and Villanueva-Rivera 2006). Few papers, however, report on the use of signs of birds, with the exception of Westcott (1999), who suggested that the use of signs to assess the abundance of Cassowary, *Casuaris casuaris*, was of limited reliability. Two potential problems that arise from indirectly estimating abundance are:

1. Relying on anecdotal evidence about where the species does and does not occur, thereby incorrectly restricting the size of the study area (Lunney *et al.* 1996, Harrington *et al.* 2008a); and
2. Mis-identification of the scat or other evidence of the species presence (Brown and Triggs 1989, Lunney *et al.* 1996, Witmer 2005, Harrington *et al.* 2008a,b, Hass 2009, Harrington *et al.* 2010).

These issues are not considered problematic in this study. As discussed in Chapter 1 (section 1.1), other species do eat from the cones of *Allocasuarina* but not in the same manner as *C. lathami*

(due to their highly evolved beak). Therefore, chewings observed in the field can be identified as evidence of *C. lathami* feeding with a high degree of confidence. Secondly, the study area included all areas that contain suitable *Allocasuarina* on the Gold Coast (i.e. *A. littoralis* or *A. torulosa*). The results presented in Chapter 2 also provided an indication of the relative extent of forage habitat at a landscape scale providing field verification and analysis of relative habitat quality across the Gold Coast. Furthermore, by determining the study area based on *Allocasuarina* distribution using GIS mapping, this study was not limited by only using locations where *C. lathami* have previously been reported.

The aim of this Chapter is therefore, to develop and apply a novel method of estimating the abundance of *C. lathami* using signs of their feeding activity. Despite the extensive literature on *C. lathami* foraging patterns there are no studies that use such indirect signs as a means to estimate the abundance of the species. This research gap currently limits our ability to make informed management decisions related to the conservation of the species, particularly in rapidly urbanising regions such as southeast Queensland.

3.1 METHODS

As discussed in Chapter 1, *C. lathami* has a specialised feeding behaviour whereby they extract the kernels from cones of *Allocasuarina* spp. (Clout 1989, Crowley and Garnett 2001). This feeding behaviour results in the remnants of cones being discarded as ‘chewings’ beneath feed trees, providing an indication of *C. lathami* feeding across the landscape. To use chewings as an index of bird abundance and distribution, a greater understanding of *C. lathami* foraging, including cone and chewings dynamics is required. The present study estimates the total quantity of chewings (by sub-sampling) on the Gold Coast, and uses these data to estimate the number of birds that would produce this much feeding.

To enable the estimation of *C. lathami* numbers on the Gold Coast it is necessary to determine the specifics of their local feeding ecology, as well as the retention and detectability of evidence of such feeding behaviour. These two primary variables provide the basis for further analyses and are further subdivided as follows:

- *C. lathami* foraging ecology;
 - Time spent feeding per day (daily diel activity patterns to determine foraging behaviour),
 - Average time *C. lathami* drink prior to sunset (to correct for diel periods not spent feeding),

- Foraging efficiency (relates to the number of cones processed per unit time to derive a number processed each day),
- Average number of chewings produced from each cone processed.
- The abundance of feeding evidence on the Gold Coast;
 - Chewing abundance using a sub-sampling method,
 - Age of chewings (colour) to enable determination of average age (or life) of chewings observed in the field.

Data on the feeding ecology and abundance of chewings was gained through field sampling, direct observations and video-recordings, to support the estimate of the *C. lathamii* population on the Gold Coast. The specific methods for each variable are outlined in detail below.

3.1.1 *Calyptorhynchus lathamii* Foraging Ecology on the Gold Coast

Observations (in field and recorded for later analysis) of *C. lathamii* daily behavioural routines were made to assess the proportional contributions of a range of activities, including feeding, preening/resting and drinking. Data were recorded directly from the field, as well as by video-recordings. When more than a single bird was observed, video recordings of the birds enabled subsequent capture of activity data for all individuals. Feeding rates were recorded for all foraging birds observed. The duration of observations were dependent on bird activity, and varied from several minutes, to several hours. Birds observed were categorised into sex, age and breeding status categories to aid in the analysis of these data to detect any demographic patterns in feeding behaviour.

3.1.1.1 Number of Chewings Produced from Individual Cones and Handling Time

In order to determine how many *C. lathamii* have fed to produce a given number of chewings on a given day, we need to determine:

1. How many chewings are derived from one cone,
2. The mean handling time per cone, and
3. Feeding time per day.

The number of cones eaten and the number of resulting chewings for each cone was recorded. Using binoculars, chewings were counted as they were discarded — another approach would have been to place a large sheet etc. over the ground within the perimeter of the tree's canopy, and then

count all chewings, but difficulty is in predicting which tree the birds will feed from and placing the sheet down before they come, or put it down after they come and risk scaring them off. *C. lathamii* feed in a fairly predictable manner, and with the binoculars, it was easy to see the birds feeding and the chewings being discarded. The number of chewings derived from a single cone (# chewings per cone) and the number of cones consumed in one minute (mean handling time) were compared between gender and the presence/absence of a juvenile in the feeding group using ANOVA. The number of chewings per cone data were square-root transformed as required to reduce positive skewness prior to statistical analysis. Analyses also considered the individual values of *A. littoralis* and *A. torulosa* which were the primary feed trees in the study area. Due to the sparsity of *A. torulosa* feeding data for juveniles and adult females, all data for *A. torulosa* feeding rates were combined and analysed as a single group.

The data were not entirely suitable for application of this test since the number of chewings produced is not continuous - it is necessarily an integer but given the large data set (n = 578 cones) this failure of assumptions was judged acceptable.

3.1.1.2 Percentage Time Spent Feeding Per Day

The aim here was to determine the average amount of time *C. lathamii* spend feeding per day. We know that the birds are active between sunrise and some time prior to sunset (elsewhere up to one hour –Pepper 1996) and daily activities include feeding, flying, preening and perching (personal observation, Pepper *et al.* 2000, Cameron 2004, Chapman 2005, Chapman and Paton 2005). We need to know what percentage of their daylight hours are spent feeding, to determine their feeding effects.

On Kangaroo Island *C. l. halmaturinus* perch, preen, call and fly around the roosting site at sunrise, then disperse to feed for the day (Pepper 1996). Estimates of the amount of time spent foraging throughout the day vary with Clout (1989) reporting rates as high as 88% of breeding cockatoo activity budgets, while Chapman and Paton (2005) suggest that this may be substantially lower (36%). Nevertheless, breeding birds appear to spend more time foraging (36% - 40%) than non-breeding birds (sometimes as low as 26%) in the southern parts of their range (Clout 1989, Pepper 1996, Chapman and Paton 2005). These activity budgets may vary considerably among regions in response to food availability. For example, while Cameron (2005) did not measure specific activity budgets for *C. lathamii* in Dubbo, NSW this population was reported to spend relatively large portions of the day feeding. In addition, Pepper *et al.* (2000) showed that of the time spent foraging, the bulk of this time (94%) is spent handling cones as opposed to eating kernels. The birds usually stop feeding to perch, rest and/or preen around midday, the hottest part

of the day, which is also consistent with studies on *C. lathamii* in NSW (Cameron 2005). Approximately one hour prior to dusk, *C. lathamii* flock to drink, and then are usually seen roosting or nesting near to the drinking site. They are rarely observed flying after dusk (Pepper 1996). To determine the feeding patterns of *C. lathamii* on the Gold Coast, it is important to determine whether the birds here display similar daily behaviour.

C. lathamii on the Gold Coast were recorded on various occasions between 2001 and 2005. The percent of time spent feeding, perching (including preening and resting), and in other activities (drinking and flying) was calculated separately for adults and juveniles, as percentage of time in one hour blocks. Many blocks consisted of consecutive hours, including dawn to dusk (i.e. roughly twelve 1-hour blocks; since birds were easiest to find using feeding cues, these long blocks were used to reduce the bias against birds' resting). Using a stopwatch, the birds' activities were recorded for a minimum of an hour where possible, or until the birds flew off. Time spent feeding included picking, chewing/processing and the discarding of the chewings. In addition to being able to determine the time spent feeding it was also possible to determine the number of cones processed during this time for each individual bird.

When *C. lathamii* were observed feeding, the following data were collected for each bird on each feeding occasion¹:

- Total feeding time in minutes (*te*),
- Total number of cones chewed (*ce*),
- Number of chewings produced per cone (*ch*).

The average daily number of cones processed by a single typical *C. lathamii* (*Nd*) was determined as:

$$Nd = \frac{ce}{te} \times fd$$

where *fd* is the average time spent feeding per day.

¹ There are many variable symbols used in this chapter: they are defined where used and summarised in Table 41 at the end of the chapter.

3.1.1.3 Average Duration *C. lathami* Drink Prior to Sunset

Daily activity has two phases, a feeding/general activity period and an end-of-day drinking time. Observations can provide estimates of drinking duration, and the balance of daylight hours is the feeding/general activities period.

The duration that *C. lathami* were observed drinking was recorded and compared to the time of expected sunset. Although 137 evenings were spent at potential and known drinking sites (11 sites), only 14 drinking instances were observed between 2001 and 2005. The amount of time drinking prior to sunset was plotted and fitted with a sine curve, determining the average duration at which *C. lathami* drank prior to sunset, at the various times of the year.

The model fitted was:

$$\text{drinking duration} = \text{mean duration} + \text{amplitude} * \cos ((\text{day number} - p) * 2 * \pi / 365)$$

where *mean duration* is the mean period spent drinking drawn from all observations, *amplitude* is a parameter of variation in drinking time through the year, *p* is a phase parameter which expresses at which *day number* maximum drinking time occurs in the year and the constants are required to scale the estimated effects to convenient values.

Information on the proportion of the feeding/general activities period spent feeding then allow an estimate of daily feeding time (*fd*):

$$fd = (dh - dd) \times fp$$

Where

fd = feeding time

dh = daylight hours

dd = drinking duration

fp = proportion of feeding/general activity period spent feeding

3.1.2 Estimation of the Abundance of Feeding Evidence by *C. lathami* on the Gold Coast

The vegetation types occurring on the Gold Coast containing *A. littoralis* and *A. torulosa* (see list below, Table 28) were mapped using the Gold Coast City Council Strategic Vegetation maps and MapInfo® GIS software (Figure 23). A 500m × 500m grid was placed over these areas, and each grid cell uniquely numbered, totalling an area of approximately 510 km² (i.e. ~ 2040 grid cells).

Study sites (n = 141) were chosen randomly using the =randbetween(x, y) function in EXCEL[®]. The *A. littoralis* sites used in chapter 2 were used, as well as additional sites (some sites weren't appropriate for the feeding status study (Chapter 2), but were for this study i.e. *A. torulosa* sites etc.) At each site studied, three 20 m x 20 m quadrats were marked out (as in Section 2.1), and the quantity (Section 3.1.2.1) and colour (aging, Section 3.1.2.2) of any chewings determined.

Table 28. List of vegetation types on the Gold Coast containing *A. littoralis* and/or *A. torulosa*

Vegetation Type	Area (km ²)	Presence of <i>Allocasuarina</i> sp.	
		<i>A. littoralis</i>	<i>A. torulosa</i>
Bluegum – grey ironbark and/or pink bloodwood/open forest	57.5	+	-
White mahogany – grey gum – Qld white stringybark – broad leaved white mahogany – woodland/open forest	243.3	+	+
Spotted gum and ironbark open forest complex	87.2	+	+
Swamp/oak/broad leaved paper bark open forest	6.2	+	-
Brush box – moist eucalypt open forest complex (often with rainforest understorey)	108.5	+	+
New England blackbutt +/- tallowwood +/- scribbly gum woodland to open forest complex	7.0	-	+
Approx. Total Area (based on GCCC Strategic Vegetation Maps)	509.8 *	(502.7 km²)	(446 km²)

* Areas are only approximate, based on available maps using MapInfo[®]. Vegetation mapping was undertaken by Gold Coast City Council at the 1:200 000 scale for the purpose of identifying communities. The combined expected total area for *A. littoralis* and *A. torulosa* is less than their individual areas, as a result of overlap in their distribution.

The mapping on which this area calculation is based is probably quite precise, but the presence or absence of feed species within, and without, the mapped areas is likely to be less precise. It is estimated that the reasonable error in these estimates is ±10%.

In addition to knowing how well *Allocasuarina* are represented across the landscape as potential foraging habitat for *C. lathamii*, it is also necessary to determine how the current evidence of foraging (chewings) can be used to estimate bird abundance. Two key parameters for consideration here include the number of chewings at foraging sites as well as the age of these chewings.

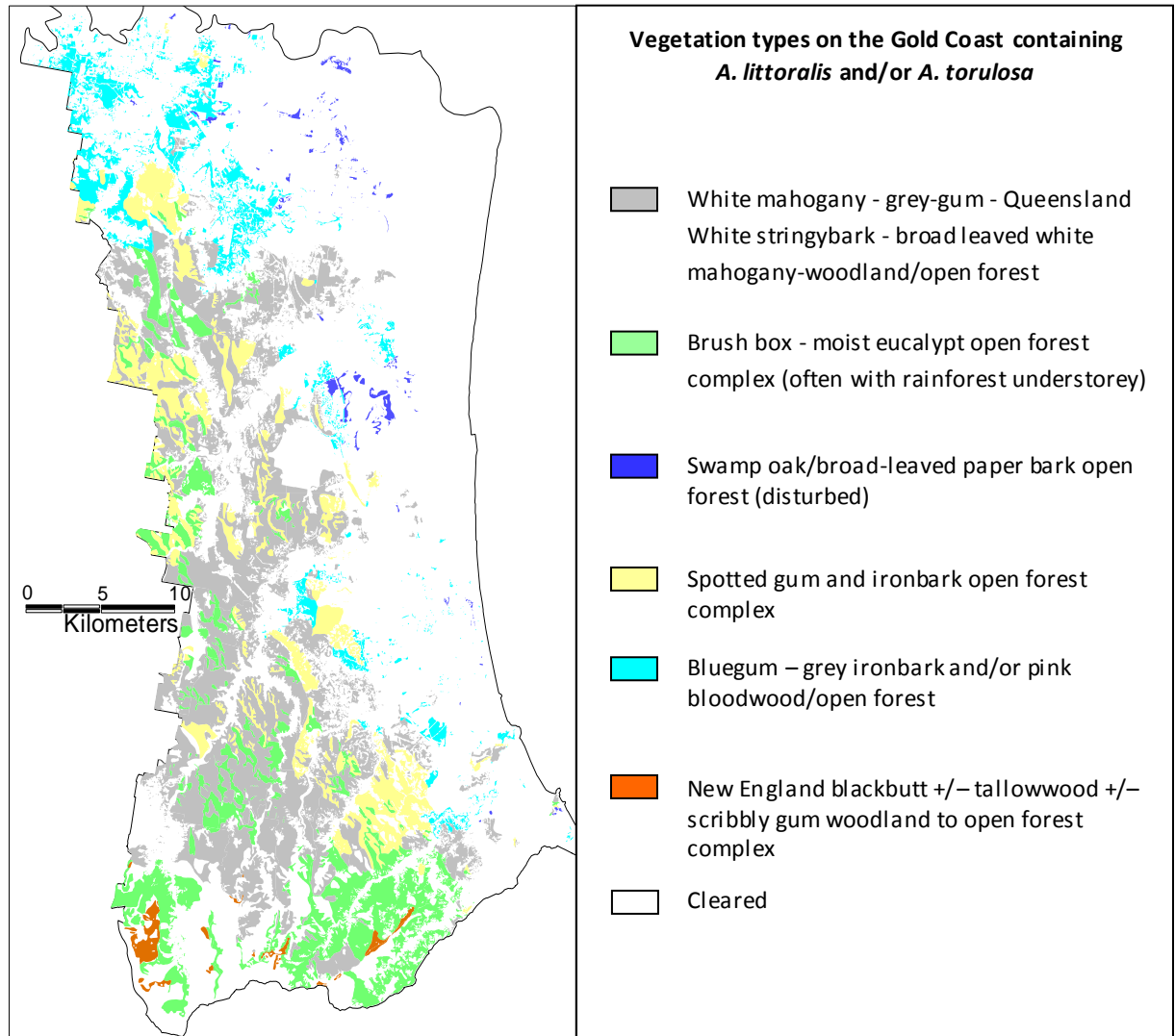


Figure 23. Map of the vegetation types containing *A. littoralis* or *A. torulosa* on the Gold Coast
 Source: Council of the City of Gold Coast (1998).

3.1.2.1 Sub-Sampling of Chewings

Clout (1989) observed that chewings may persist for many months, reflecting the distribution and quantity of recent *C. lathami* feeding. For this work I used a continuous scale of feed tree status based on number of chewings. Since the number of chewings can be several thousands, a sub-sampling method was used to estimate the total number of chewings beneath feed trees.

For twelve feed trees (since there were few feed trees to be found, all of the feed trees observed within the randomly chosen areas were studied), both the total number of chewings was counted and a sub-sampling method used. It was determined using an extensive simulated sampling exercise based on field data that 50cm x 50cm quadrats were preferable to smaller (20cm, 30cm and 40cm) and larger (60cm) quadrat sizes.

Each quadrat was randomly placed at 1/5th, 2/5th, 3/5th or 4/5th the distance between the feed tree and the perimeter of the chewings, along north, south, west and east facing transects (Figure 24). At the tree (0/5th) the proportion of area contribution to the weighted mean is negligible, and at the perimeter of the chewings (5/5th), the chewing quantity is expected to be near to 0 (as that is how the perimeter is defined). The quadrats were placed at various distances to take into account any gradients of chewings numbers that may occur with increasing distance from the tree.

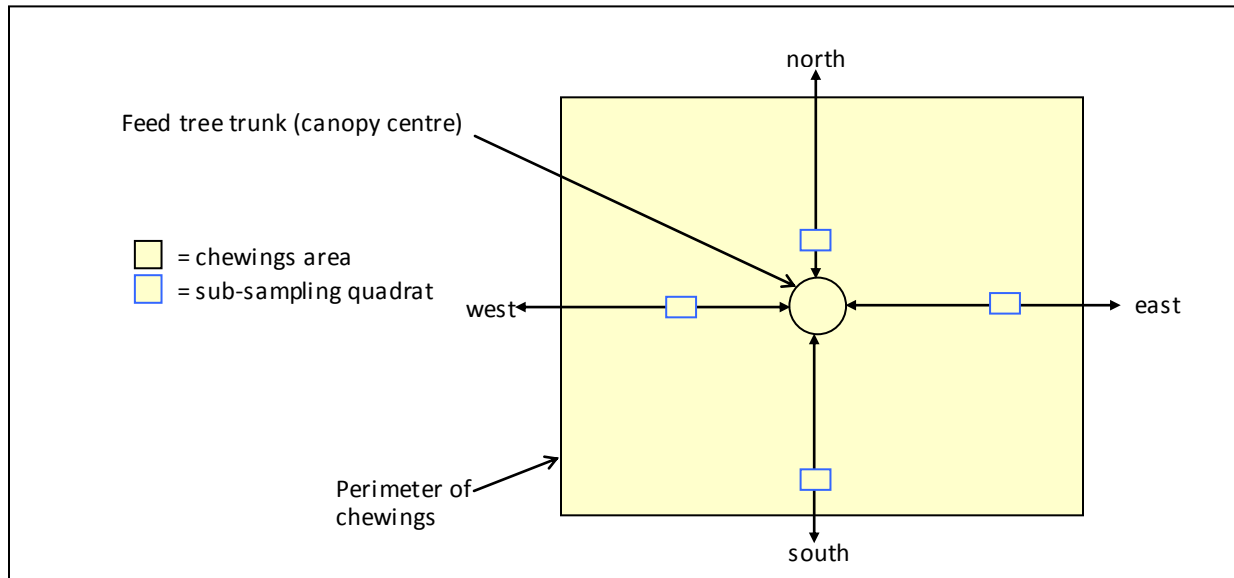


Figure 24. Diagrammatic representation of sub-sampling method of *A. littoralis* chewings

The estimated number of chewings was determined using the formula:

$$\text{Estimated total chewings} = \text{quadrat sum of chewings} \times \text{total area (m}^2\text{)}$$

since the total area of the four sub-sampling quadrats is $4 \times 0.25 \text{ m}^2$ ($50 \times 50 \text{ cm}$) and four were counted.

The distribution of chewings under a tree is not uniform, but based on the extensive simulation exercise, no greater accuracy was gained when the perimeter of chewings was treated as a circle or any other shape. If the perimeter was actually an ellipse, the maximum over-estimate of total area was not greater than 27% and normally much less. Therefore for simplicity, the total area was determined using the product of the greatest length by perpendicular width.

Using this sub-sampling method, the number of chewings beneath all feed trees observed in the random study sites was estimated, and based on the detailed simulation of the sub-sampling process, a reasonable error of $\pm 10\%$ is suggested — see end of section 3.1.3 for an explanation of ‘reasonable error’.

3.1.2.2 Aging Chewings

The persistence of chewings under trees in southeast Queensland was explored by determining the colour change over time. Previous research has alluded to such a colour change, but the methods and colours used to detect this have been vague. For example, Ingram (2001) found in Queensland that *C. lathamii* chewings change from a bright yellow, to rust, to brown, to black and ultimately crumbling after about three months. Cameron (2002) found that *C. lathamii* chewings at Dubbo, New South Wales changes from greeny-yellow (new), to orange, and finally white (with fungus) etc., lasting for around 18 months. Joseph (1982) found fresh chewings to be light sawdust colour, but in a week, darkened to a light reddish-brown; darkening further with age and then decaying in an unstated further time. Chewings were present for “several months” on Kangaroo Island (Pepper 1997).

Between 2002 and 2004, 20 study trees, chosen because *C. lathamii* were known to have fed there on the day or the day before, ensuring accuracy of age of cones, were monitored: 15 for *A. littoralis* across 8 locations, and 5 for *A. torulosa*, across 2 locations. Trees within sites were temporally or spatially (i.e. different azimuth of downslope), separated. At each study tree, ten chewings of the same colour i.e. from the same feeding event, within the perimeter of a feed tree’s canopy were selected. These chewings were covered by a small cage made of galvanised wire netting (13 mm spacing) and sturdy wire frame, preventing the removal and loss of the chewings, for the duration of the study. This ruled out the possibility that chewings might be lost due to mechanical disturbances, or removal by larger invertebrates or small mammals, and facilitated the recovery of the particular chewings upon revisits. Chewings decayed normally through weathering and consumption by smaller litter detritivores, but we do not know the rate of normal loss that may occur from larger animals. This ensured that even after any losses, sufficient chewings remained to determine their colour for this study.

The colour of the chewings was determined weekly for the first month, then once a month, until the chewings had decomposed to an extent that they were no longer easily identifiable as chewings. A Munsell colour chart was used to provide an accurate and repeatable measure of the colour of the chewings. The Munsell system describes colour in three components: hue (colour), value (lightness) and chroma (saturation), as outlined below (Munsell Color 1994):

- Hue is a measure of the chromatic composition or colour of light. The Munsell system is based on five principal Hues, of which two were observed in this study: yellow-red (YR) and yellow (Y). Within these principal Hues, the colour becomes more yellow and less red as the number (score) increases.

- Lightness (value) is a measure of the degree of lightness or darkness of a Hue in relation to neutral grey scale which extends from a theoretically pure black (scored as 0) to a theoretically pure white (scored as a 10).
- Saturation (chroma) is a measure of the degree of departure of a particular hue from a neutral grey of the same lightness.

Each of the colour components were graphed over square-root of time (an increment of time was more likely to be important early in the aging process than later), to determine if trends in the colour of chewings over time is observed in the field. Table 29 lists the scores of each of the components observed in the field (i.e. 3 different Hues, 5 Lightnesses and 4 Saturations giving a total of 60 possible combined scores in this study).

Table 29. Scores observed in the field for the three components of colour (based on the Munsell system).

Hue	Lightness*	Saturation*
2.5 Y	3	3
7.5 YR	4	4
10 YR	5	6
	6	8
	7	

* For both lightness and saturation, the colour gets lighter as the number increases

The graphs in Appendix 2, produced from this study, were used to calculate an average age for each colour (score) observed. This average was then used to estimate the age of chewings found in randomly-chosen quadrats for the estimation of the number of birds on the Gold Coast. For each feed species (i.e. separately for *A. torulosa* and *A. littoralis*), the average age of chewings across the entire field area was determined by;

$$\text{Average age of chewings} = \frac{\# \text{Chewings}_1 \times \text{Age}_1 + \# \text{Chewings}_2 \times \text{Age}_2 + \dots + \# \text{Chewings}_n \times \text{Age}_n}{\# \text{Chewings}_1 + \# \text{Chewings}_2 + \dots + \# \text{Chewings}_n}$$

For the total of n sites at which chewings were observed, which yields an average age, weighted for number of chewings.

3.1.3 Estimation of the Number of Birds on the Gold Coast

Data have been collected for each feed species, with separate values obtained for *A. littoralis* and *A. torulosa*. The data available to facilitate the estimation of the number of *C. lathami* on the Gold Coast are as follows:

1. The total number of chewings of various ages under a number of feed trees (T), found at a small number of sites out of a large number (n) surveyed,
2. An estimate of the total area of the region that contains the particular feed species (At).

Using a sub-sampling method, the total number of chewings (Ts) at n sites studied was estimated.

If the average life of the chewings (Li) and the total area of study sites surveyed (As) is known, the estimated number of chewings produced per day (Td) in the entire study area (At) can be calculated:

$$Td = \frac{Ts \times At}{Li \times As}$$

The cages used in the field prevented the loss of chewings from removal by mammals etc., therefore no data are available on what happens under normal uncaged circumstances. Consequently, ‘decay adjustment’ and ‘longevity’ factors were calculated to determine chewing longevity and loss. There are two possible forms of loss of chewings that may occur, *fixed persistence* and *linear loss*. If chewings have a fixed persistence, all chewings remain and then suddenly all disappear, whereas linear decay, especially since chewings are of variable sizes and losses may occur from animals, chewings decay and/or loss occurs more gradually over time. It is probable that the disappearance of chewings in the field will follow a dynamic somewhere between these two limits, so the best estimate of the number of birds will be between the two estimates, therefore the two estimates will be stated as a range. The mathematical modelling explaining the derivation of these two predicted patterns of loss is outlined in detail in Appendix 3. Since these values are mathematical parameters, they are without error, but they represent the limits of processes which influence the estimation of daily chewings production. Given the uncertainty of which value to use, these limits are used in the calculations to provide a range of values within which the best estimate of the bird population is likely to occur.

Since the birds render a single cone into many pieces, there is an average number of chewings produced per cone (ch). From the number of chewings produced in the entire study area daily and the number of chewings that are produced per cone by *C. lathami* feeding, the total cones eaten per day (Tc) can be calculated as follows:

$$Tc = \frac{Td}{ch}$$

If the number of cones a bird consumes per day (Nd) is known then an estimate of the total number of birds (Tb) can be made as follows:

$$Tb = \frac{Tc}{Na}$$

The calculation of cones per bird per day (Nd) draws upon knowledge of the number of cones eaten, on average, per minute ($Nm = ce/te$) where ce is the number of cones eaten in a feeding event and te is the duration of this event, and the number of minutes of feeding per day (fd), so that:

$$Nd = \frac{\sum ce}{\sum te} \times fd$$

Section 3.2.4 addresses these variables and makes a calculation of the number of birds in the study area.

Calculating the abundance of birds using their feeding quantity is a novel and complex procedure. In estimating the variables required to complete this assessment, there will be varying degrees of error in the estimates. In some cases, multiple estimations of a single variable under effective replication will permit an estimation of the statistical error in the estimate of a variable, but mostly the several available estimates for any one variable are drawn from differing circumstances and a statistical error cannot be calculated, and in the case of some variables, only a single estimate is available (e.g. the area of habitat). In all instances, an estimate of ‘reasonable error’ is made to permit an overall estimate of the precision of the final result. A ‘reasonable error’ is taken to be the range (expressed as a percentage of the estimated value) which is likely to include the true value. Given that this is often based on a qualitative approximation, suggesting precise values for this error range would be misleading, but ‘reasonable errors’ are intended to give confidence (say 75% to 85%) that the true value lies within the range. Reasonable errors associated with the estimates are listed in Table 40, and the overall error of the population estimates is based on the combination of all errors, according to the argument that on the basis of simple probability, if two events (A and B) have associated errors (e_A and e_B), and the errors are independent, then the error associated with both events (AB) is calculated as $e_{AB} = 1 - (1 - e_A) \times (1 - e_B)$. This relationship can be generalised to any number of events with independent associated errors.

3.2 RESULTS

3.2.1 *Calyptorhynchus lathami* Feeding Rates

Using the morphological characteristics observed in Chapter 4 and Appendix 4, it was determined that 15 different family groups were studied, including 27 individual birds. The same bird was sometimes studied on multiple occasions, but on different days and feeding in different trees. Although the use of the same bird may not be statistically independent (i.e. some birds may feed a little differently than others etc.), a total of 27 *different* birds were video-recorded to produce a total of 10 hours of timed feeding.

The majority of *C. lathami* feeding sightings were in *A. littoralis*; 563 cone observations were made on *A. littoralis*, and only 45 on *A. torulosa* (Table 30).

Table 30. Number of *Allocasuarina* spp. cones observed consumed by adult and juvenile *C. lathami* on the Gold Coast.

Cockatoo	# Cones consumed	
	<i>A. littoralis</i>	<i>A. torulosa</i>
Adult male	277	28
Adult female	266	17
Juvenile	20	0
Total	563	45

3.2.1.1 Chewings Per Cone

The number of chewings derived from one cone was recorded from the feeding and handling of 563 cones of *A. littoralis* and 45 cones of *A. torulosa*. The mean number of chewings derived from a single cone for breeding and non-breeding pairs² was calculated separately for *A. littoralis* and *A. torulosa*. These were derived separately for each feed species and the 95 % confidence intervals on these means was calculated (Figure 25). The small amount of data available for *A. torulosa* has produced wide confidence intervals, and the difference between birds of different

² Breeding pairs were pairs accompanied by a juvenile. No juvenile was observed with a non-breeding pair and they were not associated with a nest (birds were followed to roost sites in the evening). Breeding females with an egg or young chick usually stay at the nest, typically only leaving to drink in the evening. They are allo-fed by the male and are commonly heard begging for food (Garnett *et al.* 1997). Non-breeding pairs may have been preparing to breed, but gave no indication that they were currently breeding during this study.

breeding status is both small and poorly estimated. With the larger data set for birds feeding on *A. littoralis*, it is evident that non-breeding birds produce more chewings per cone than breeding birds.

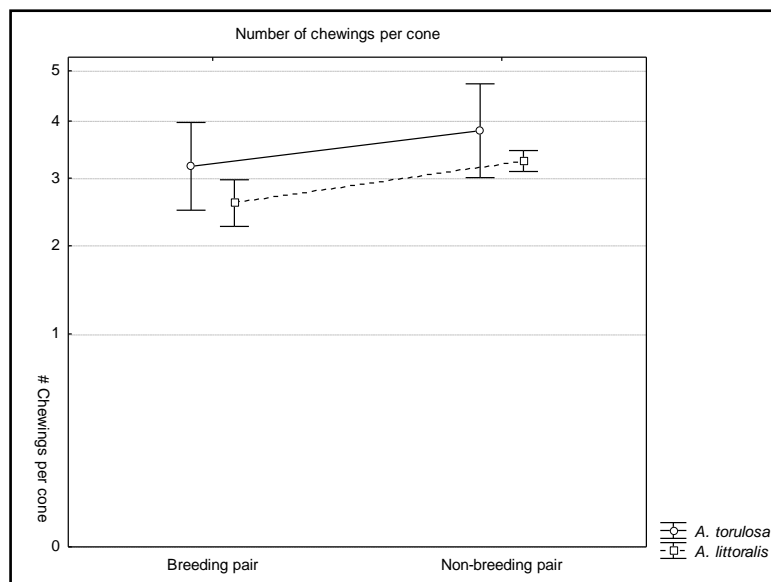


Figure 25. Comparison of the number of chewings derived from one cone between breeding and non-breeding *C. lathami*, feeding on *A. littoralis* and *A. torulosa*, on the Gold Coast (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

No significant interaction between the effort of feed species and bird breeding status was observed (Table 31, $p = 0.86$), the simple effects of these variables are shown in Figure 25. Comparing the number of chewings derived from a single cone between breeding and non-breeding *C. lathami*, feeding on *A. littoralis* and *A. torulosa*, we find that there is no significant difference between the feed species ($p = 0.057$). The mean number of chewings is lower in breeding pairs ($p = 0.028$), and the clear distinction between breeding and non-breeding birds feeding on *A. littoralis* is evident in Figure 25.

Table 31. Univariate Tests of Significance for number of chewings per cone (combined for *A. littoralis* and *A. torulosa*)

	SS	df	MS	F	p
Intercept	497.07	1	497.07	1879.5	~ 0
<i>Allocasuarina</i> spp.	0.96	1	0.96	3.63	0.057
Breeding Status	1.29	1	1.29	4.88	0.028
<i>Allocasuarina</i> spp. × Breeding Status	0.01	1	0.01	0.033	0.86
Error	144.93	548	0.26		

Testing the effects of gender, breeding status, and their interaction on the number of chewings derived from a single *A. littoralis* cone reveals an appreciable interaction between the two main effects ($p = 0.015$) (Table 32).

Examination of just the *A. littoralis* data indicates that there is a clear difference between female breeding and non-breeding birds, with non-breeding females producing more chewings per cone than breeding females (Figure 26). Female non-breeding birds produce more chewings per cone than males, regardless of their breeding status (Figure 26).

Table 32. Univariate Tests of Significance for number of chewings per *A. littoralis* cone

	SS	df	MS	F	p
Intercept	3359.16	1	3359.16	903.3	~ 0
Gender	6.30	1	6.30	1.69	0.19
Breeding Status	35.48	1	35.48	9.54	0.0021
Gender × Breeding Status	22.02	1	22.02	5.92	0.015
Error	2037.97	548	3.72		

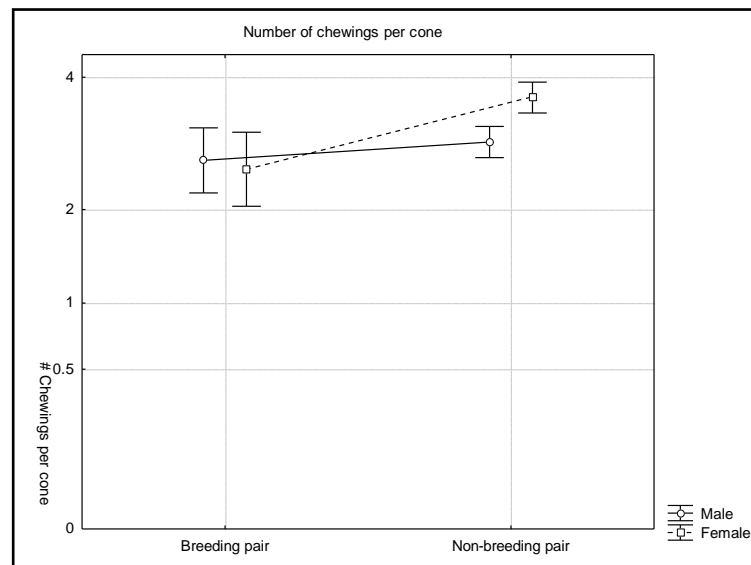


Figure 26. Comparison of the number of chewings derived from a single *A. littoralis* cone between gender and breeding status (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled)

A *post hoc* test on the *A. littoralis* data showed that breeding pairs produce significantly fewer chewings per cone than non-breeding pairs (Table 33, $p = 0.034$).

Table 33. Approximate Probabilities for *Post Hoc* Contrasts (unequal N) — number of chewings

Age/Group	Breeding pair	Non-breeding pair	Juvenile
Breeding pair			
Non-breeding pair	0.034		
Juvenile	0.856	0.776	

When feeding on *A. torulosa*, the relatively sparse data indicates that the average number of chewings per cone is 3.7 (Table 34). In *A. littoralis* the average number of chewings per cone for breeding birds is 2.6 and for non-breeding birds 3.3 chewings (Table 34). The very few observations of juveniles feeding on *A. littoralis* indicate a very poorly estimated 2.9 chewings per cone (Table 34, Figure 27). For the purpose of estimating the size of the *C. lathamii* population, it is simply necessary to obtain a best estimate of the number of chewings derived from a single cone; therefore we have used the average of 3.14 chewings per cone for *A. littoralis* and 3.71 for *A. torulosa*. Based on these standard errors, the reasonable error on these estimates is about $\pm 10\%$.

Table 34. Comparison of the number of chewings derived from a single cone between adults (breeding and non-breeding) and juveniles ($p = 0.0048$) (data were square root transformed)

Feed Sp.	Age/Group	Mean	Std Error	- 95% CI limit	+ 95% CI limit	N
<i>A. torulosa</i>	All	3.71	0.28	3.19	4.28	45
<i>A. littoralis</i>	Breeding pair	2.58	0.16	2.23	2.97	85
<i>A. littoralis</i>	Non-breeding pair	3.27	0.10	3.09	3.46	422
<i>A. littoralis</i>	Juvenile	2.87	0.46	2.15	3.69	20

Note: data were square root transformed prior to analysis, and are detransformed here. As a consequence, in the original units of measure the confidence interval on the mean is asymmetric, and so the upper and lower limits are reported here.

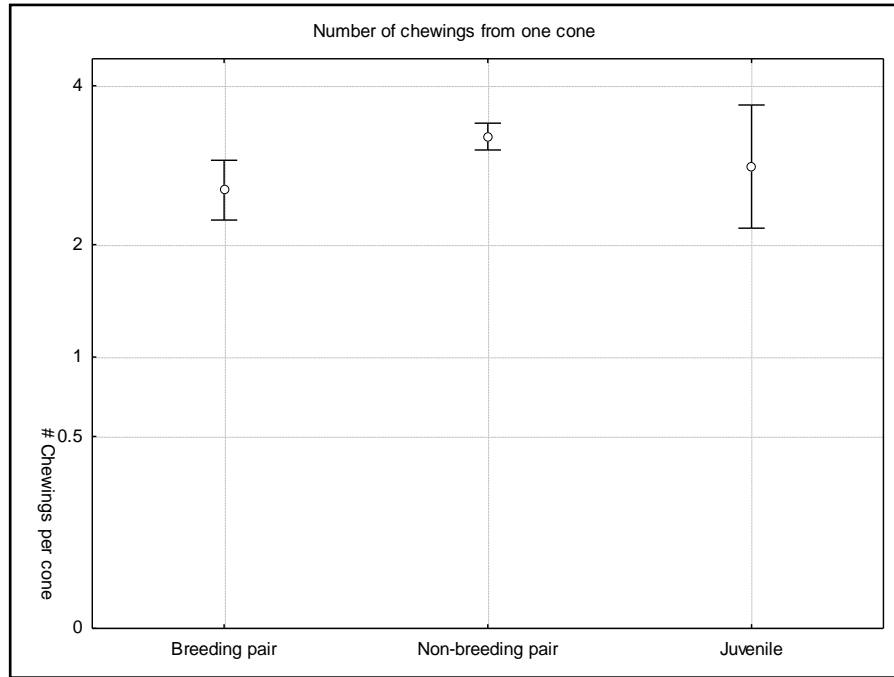


Figure 27. Comparison between adult (breeding and non-breeding) and juvenile *C. lathami* for the mean number of chewings per cone (means in untransformed units and 95% confidence intervals — note that the y-axis is not linearly scaled on some charts)

3.2.1.2 Mean Handling Time Per Cone

The data recorded on the feeding and handling of 563 cones of *A. littoralis* and 45 cones of *A. torulosa* afforded the opportunity to estimate typical handling time per cone. Figure 28 shows the mean handling times separately from breeding and non-breeding pairs on each feed species and the 95% confidence intervals on these means. In common with the chewings per cone data, the small amount of data available for *A. torulosa* produced very wide confidence intervals, and so the difference between birds of different breeding status is both small and poorly estimated.

With the larger data set for birds feeding on *A. littoralis*, it is evident that non-breeding birds take more time to handle cones than breeding birds (Figure 28).

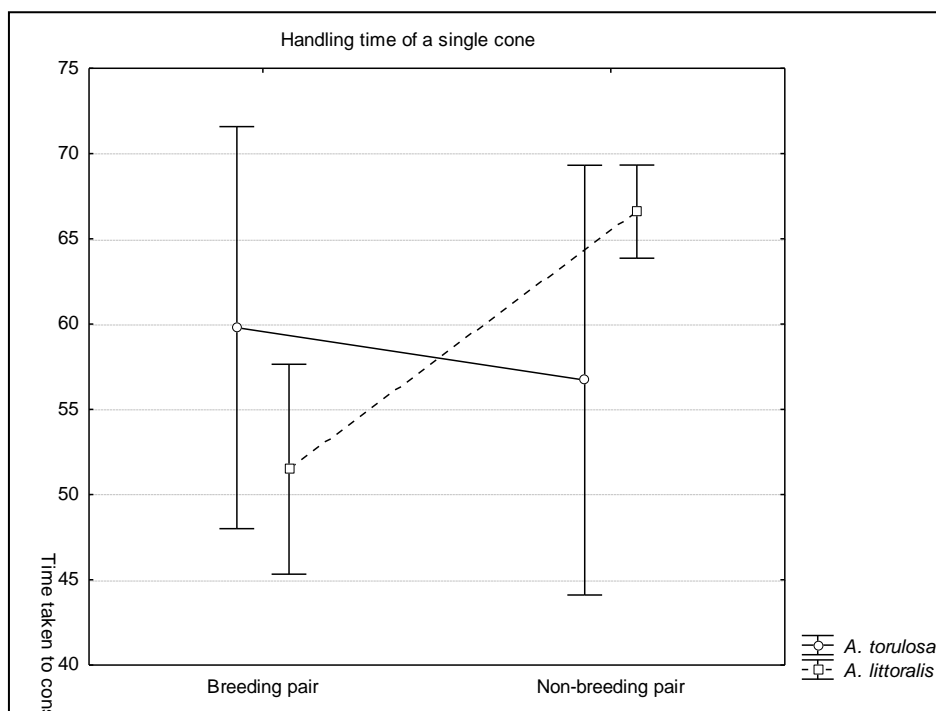


Figure 28. Comparison of the time taken to consume one cone, between *Allocasuarina* species and the breeding status of adult *C. lathamii* (means and 95% confidence ranges)

An ANOVA of these data tested the effects of breeding status, feed species and their interaction on handling time (Table 35). None of these variables had a significant effect on handling time, although the interaction was almost significant ($p = 0.054$).

Table 35. Univariate Tests of Significance for the mean handling time per cone – species \times breeding status (*A. littoralis* and *A. torulosa*)

	SS	df	MS	F	p
Intercept	534894	1	534894	618.5	~ 0
<i>Allocasuarina</i> sp.	24.3	1	24.3	0.028	0.87
Group (breeding status)	1406	1	1406	1.63	0.20
<i>Allocasuarina</i> sp. \times Group	3214	1	3214	3.72	0.054
Error	498145	576	864.8		

When the data for only *A. littoralis* were examined, it is clear from Figure 29 that there is little difference between male and female birds, but the considerable difference between breeding and non-breeding pairs is immediately clear. Table 36 reports the ANOVA testing the effects of gender, breeding status and their interaction on handling time of *A. littoralis* cones. There is no appreciable interaction between the two main effects ($p = 0.23$) nor is there a significant difference in handling time between male and female birds ($p = 0.70$), but breeding pairs handle cones rather faster than non-breeding birds ($p \sim 0$).

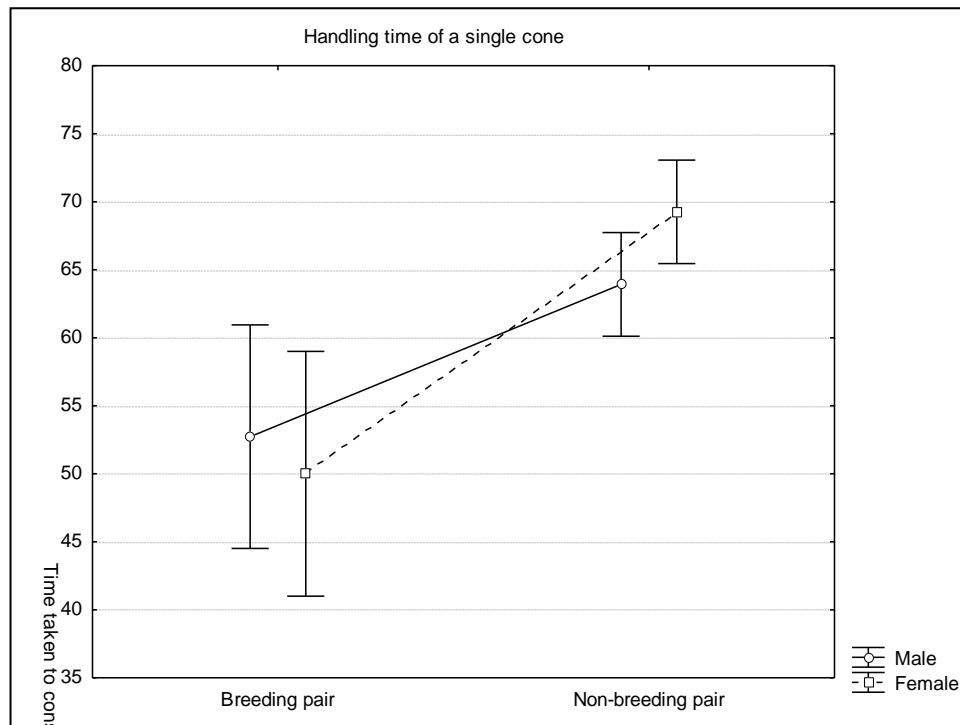


Figure 29. Comparison of time taken to consume a cone between gender and breeding status (means and 95% confidence ranges)

Table 36. Univariate Tests of Significance for the mean handling time per *A. littoralis* cone – gender × breeding status

	SS	df	MS	F	p
Intercept	1015926	1	1015926	1210	~ 0
Gender	124	1	124	0.15	0.70
Breeding Status	16929	1	16929	20.2	9.0×10^{-6}
Gender × Breeding Status	1187	1	1187	1.41	0.23
Error	445820	531	840		

Comparisons between breeding pairs, non-breeding pairs and juveniles in terms of handling time of *A. littoralis* cones were hampered by the small data set for juveniles (only 20 cones recorded) and their variable handling times (Figure 30, differences by ANOVA significant $p = 7.0 \times 10^{-2}$). Analysis of different handling times by *post hoc* tests (Table 37) revealed that breeding and non-breeding adults had different handling times, but juveniles did not differ significantly from either. Most juveniles fed irregularly, and did not always complete the eating of a cone before dropping it, while adults dropped incompletely eaten cones only rarely (~ 3% of cones). When they did finish a cone, juveniles took noticeably longer than adults (observations only).

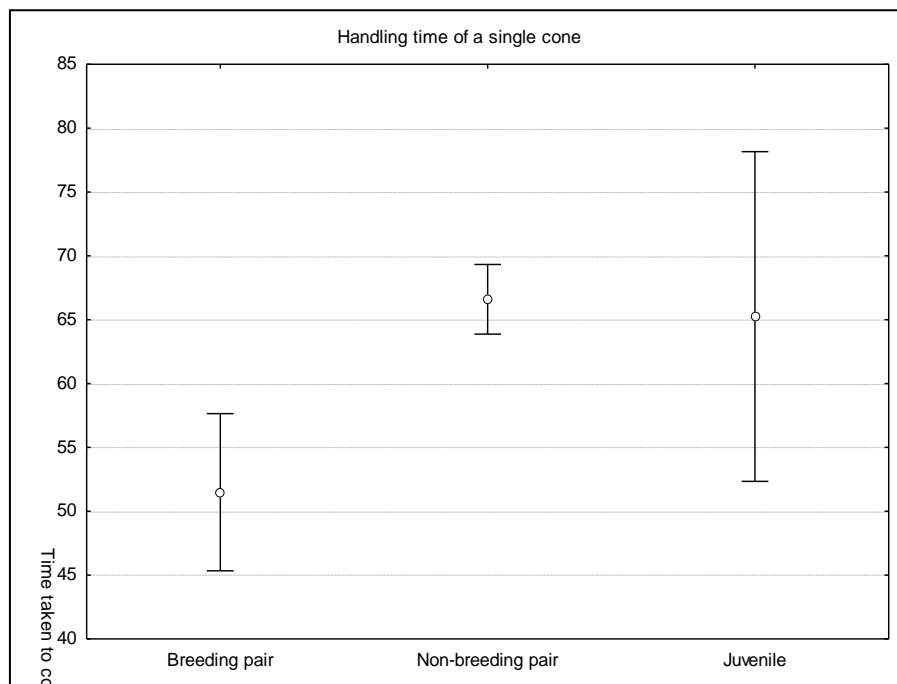


Figure 30. Comparison between adult (breeding and non-breeding) and juvenile *C. lathami* for the mean *A. littoralis* handling time per cone (means and 95% confidence intervals)

Table 37. Approximate Probabilities for *Post Hoc* Contrasts (Unequal N) - Handling Time of *A. littoralis* cones

Age/Group	Breeding pair	Non-breeding pair	Juvenile
Breeding pair			
Non-breeding pair	0.002		
Juvenile	0.300	0.99	

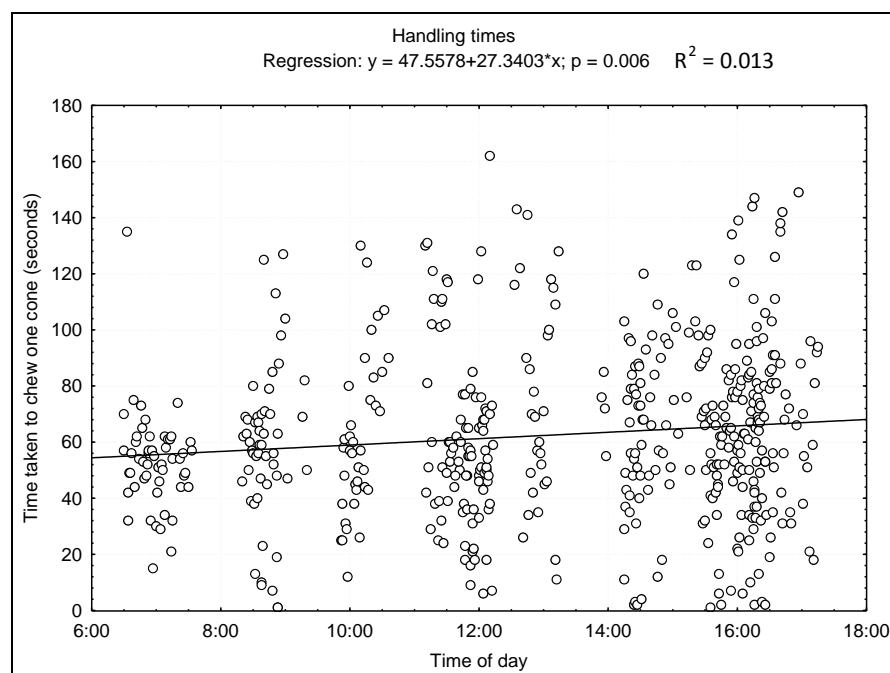
For the purpose of the estimate of overall handling time, it is simply necessary to obtain a best estimate of the time taken to handle a cone. From these data it is clear that when feeding on *A. torulosa*, the relatively sparse data indicates that average handling time can be taken as 58.4 seconds, with no evidence of any appreciable departure from this for breeding or non-breeding birds (Figure 28). In *A. littoralis* the average handling time for non-breeding birds is 66.6 seconds per cone and for breeding birds 51.5 seconds (Table 38). The very few observations of juveniles feeding on *A. littoralis* indicate a poorly estimated handling time of 65 seconds per cone (Table 38).

Table 38. Comparison of time taken to handle one cone between adults (breeding and non-breeding) and juvenile *C. lathami*

Feed Species	Bird Group	Mean Handling Time (secs)	Standard Error	-95% CI limit	+95% CI limit	N
<i>A. torulosa</i>	All	58.4	4.98	48.3	68.4	45
<i>A. littoralis</i>	Non-breeding	66.6	1.39	63.9	69.3	447
<i>A. littoralis</i>	Breeding	51.5	3.13	45.3	57.6	88
<i>A. littoralis</i>	Juvenile	65.3	6.57	52.3	78.2	20

For the purpose of the population census, a mean of 64 seconds was calculated for birds handling *A. littoralis* cones (0.94 cones/minute) and 1.03 cones/minute for *A. torulosa*. Reasonable errors are somewhat less than 10% for *A. torulosa* and very small, around 2% for *A. littoralis*.

Calyptorhynchus lathami feed more intensively in the early morning, at which times the birds are easier to find due to the loud, quick crunching of cones. Plotting the handling times against time of day (Figure 31) does in fact indicate that feeding was more efficient in the early morning i.e. a shorter time was required to handle one cone. With one anomalous exception, feeding was more efficient between 6am and 8am than any other time of day. Feeding tended to become more leisurely during the day, and more time was spent resting, especially in the heat around midday (observation). Although there was a significant association (as indicated by the regression line included in the graph) the explanation was very small (1.3%) and hardly affects the average handling time for the purpose of estimating *C. lathami* abundance.

**Figure 31.** Differences in the duration to chew one cone at different times of day

3.2.1.3 Time Spent Feeding Per Day

The daily behaviour of *C. lathami* was determined from three years of field observations (120 hours, notes taken in the field, as well as video recordings analysed at a later time) on the Gold Coast, Queensland. It was observed that the birds spent 66% of their time feeding, 23% resting and preening, and 11% other (drinking, socialising and flying — see Appendix 8 for original field data).

A total of 5 hours was recorded and analysed for juvenile daily behaviour. While collecting adult information in the field, juveniles were sometimes observed begging, therefore unrecorded (e.g. un-timed) behaviour showed consistent juvenile activities. The recorded information indicates that juveniles spend approximately 44% of their time attempting to feed, 52% begging and 4% other (flying etc. — Appendix 9).

3.2.1.4 Average Duration *C. lathami* Drink Prior to Sunset

The time that *C. lathami* stopped feeding and congregated at drinking sites on the Gold Coast was highly variable throughout the year (Figure 32), ranging from 5 minutes to 30 minutes prior to the time of local astronomical sunset, with drinking commencing earlier before sunset in summer (i.e. days 1-50 and 300-365). Observations in areas supporting multiple family groups indicated that these groups were congregating apparently to socialize prior to flying off to drink during summer in the longer hours of daylight. After socializing, the birds all kept within the same vicinity, although not all birds drank from the same place or source, depending on water availability.

The sinusoidal curve fit to the data of time (minutes) prior to sunset to day of year is shown in Figure 32. The parameters of this best fit-curve and their significance are given in Table 39. In Table 39, m is the mean time before sunset that drinking commenced (18.9 ± 3.9 minutes; mean \pm standard error) and a is the variation in this value through the year (12.2 ± 6.3 minutes, $p = 0.080$). There is some evidence that birds commenced drinking closer to sunset in winter, but the variation through the year was not significant ($p = 0.080$).

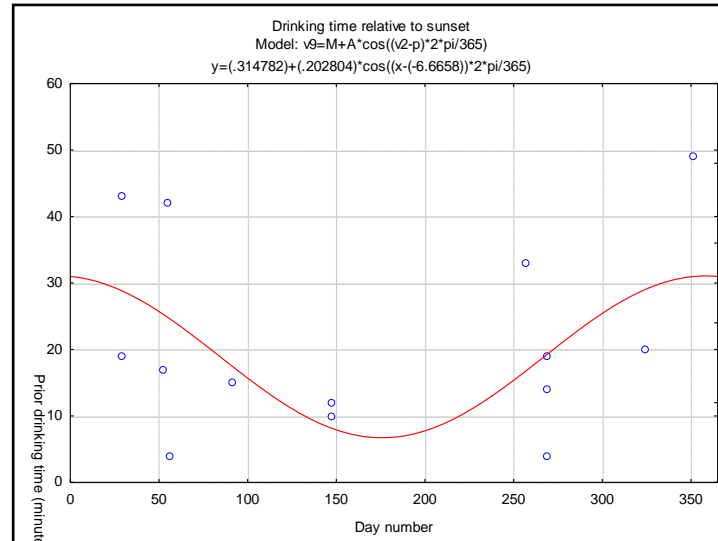


Figure 32. *Calyptorhynchus lathami* drinking time prior to sunset

Table 39. Parameters of the best-fit curve for time *C. lathami* drink prior to sunset

Variable	Estimate	Standard Error	t-value	p-level	+ 95% CI	- 95% CI
<i>m</i>	18.9	3.9	4.85	0.00051	10.3	27.5
<i>a</i>	12.2	6.3	1.93	0.080	-1.7	26.1
<i>P</i>	- 6.7	22.3	- 0.30	0.77	- 55.8	42.4

As shown in Table 39, on average *C. lathami* commenced drinking 18.9 min (*m*) prior to sunset, with a reasonable error of about 20%. Based on a 12 hour day (sunset to sunrise), averaged through the year this equates to 11.69 hours per day, of non-drinking activities. Since data from this study has shown that *C. lathami* spent 66 % of their time feeding, the total time spent feeding each day (*f*) can be calculated as:

$$f = 11.7 \times 66 \% = 7.7 \text{ hours} \times 60 = 462 \text{ minutes}$$

3.2.2 Estimation of the Abundance of Feeding Evidence by *C. lathami* on the Gold Coast

After exhaustive sampling (141 sites)³, only 11 foraged sites were found (3 *A. littoralis* and 8 *A. torulosa*). As outlined in Chapter 2, many sites, although containing *Allocasuarina*, had very

³ In Chapter 2 112 sites were examined, but a further 32 sites were areas that contained *A. littoralis*, but were not suitable (i.e. had no feeding potential due to lack of cones) for that study, but are for this study. Three of the feed sites were not used in this study since they were ‘chosen’ rather than randomly -located sites.

little *potential* for *C. lathami* feeding; hence *C. lathami* feeding was scarce across the Gold Coast, with feeding heavily concentrated in a few areas.

3.2.2.1 Aging Chewings

Chewings were monitored over time to determine if chewing colour could be used to determine chewing age. Hue is given in the Munsell Colour Chart (Munsell Color 1994) as a measure of the chromatic composition. For chewings of both *Allocasuarina* species, only two colours were observed: yellow (Y) and yellow-red (YR). Fresh chewings are a cream colour with a green tinge, turning a red colour after approximately 2-3 days. Lightness and saturation were useful indications of age, while hue offered little to discriminate among age categories. Cones found in the field were aged against the means of cones of known ages (Appendix 2) i.e. if an *A. littoralis* chewing had a lightness of 6 and saturation of 8, its age was established to be $4.33\sqrt{\text{days}}$ by lightness and $5.28\sqrt{\text{days}}$ by saturation. A simple average age of $4.805\sqrt{\text{days}}$ or 23 days was estimated. Appendix 3 list the data for *A. littoralis* (mean 33.1 days) and *A. torulosa* (mean 73.1 days) respectively. These estimates are probably subject to appreciable variability, and a reasonable error of $\pm 15\%$ for *A. littoralis* and $\pm 20\%$ for *A. torulosa* is postulated.

3.2.2.2 Estimation of the Number of Birds on the Gold Coast

Bringing all the information on number and age of chewings and *C. lathami* feeding requirements together, we are able to estimate how many birds *A. torulosa* and *A. littoralis* are supporting on the Gold Coast (Table 40).

The combined estimates of *A. littoralis* and *A. torulosa* estimates that the chewings observed on the Gold Coast during 2003 are estimated to be attributable to the feeding of between ~250 birds and ~690 birds (210 – 591 birds based on fixed persistence of chewings and 283 – 797 birds for progressive (linear) loss).

Table 40. Abundance of *C. lathami* feeding on *A. littoralis* and *A. torulosa* based on chewings quantities on the Gold Coast

Variables	Fixed Persistence		Linear Loss		Reasonable Error	
	<i>A. littoralis</i>	<i>A. torulosa</i>	<i>A. littoralis</i>	<i>A. torulosa</i>	<i>A. littoralis</i>	<i>A. torulosa</i>
Total chewings	5 818	17 625	5 818	17 625	± 10 %	± 10 %
# Sites	141	141	141	141	–	–
Average # chewings	41.3	125.0	41.3	125.0	± 10%	± 10 %
Total area (m ²)	509 800 000	509 800 000	509 800 000	509 800 000	± 10 %	± 10 %
Sample area (m ²)	1200	1200	1200	1200	–	–
Average chewing age	33.1	73.1	33.1	73.1	± 15 %	± 20 %
Decay adjustment	2.00	2.00	2.96	2.97	–	–
Average Chewing life	66.2	146.2	97.9	217.1	± 15%	± 20 %
Total chewing per day	264 791	363 246	357 992	489 124	± 22%	± 28 %
Chewings per cone	3.14	3.71	3.14	3.71	± 10 %	± 10 %
Total cones per day	84 328	98 175	114 010	132 196	± 30 %	± 35 %
Cones per bird	434	475	434	475	± 20 %	± 20 %
Total # birds ± error	194 ± 45 %	207 ± 50 %	263 ± 45 %	278 ± 50 %	≈± 45 %	≈± 50 %
	106 – 281	104 – 310	144 – 380	139 – 417		
	= 203 – 570 birds		= 273 – 767 birds			

3.3 DISCUSSION

This Chapter aimed to determine the abundance and distribution of *C. lathami*, providing the first objective estimation of their population size on the Gold Coast. This represents the first attempt at such an estimation for this species using foraging signs as a measure of their abundance, and is a significant advancement in our understanding of *C. lathami* ecology. The population size was calculated using the quantity and age of *C. lathami* feeding on the Gold Coast and their daily food requirements. Using these variables, we were able to estimate a population of 250–690 *C. lathami* on the Gold Coast depending on the manner in which the chewings decay within the environment. Considering the elusiveness of the bird, and the inaccessibility of many parts of the Gold Coast region, this method of indirectly estimating bird abundance was considered superior over commonly-used methods (Harrington *et al.* 2008a), and provides the first approximation of their population size in this region. An important caveat of this estimate is that it is based on feeding evidence of *C. lathami* and not birds themselves. Furthermore, this is only a single estimate and future estimates are required to enable the determination of effective population size. Even so Mace and Lande (1991) suggest that effective population size may be considerably smaller than actual population estimates. Importantly, this abundance estimate appears to lie at the lower threshold for maintaining a robust, genetically diverse population that is able to persist in the face

of ongoing habitat loss, demographic stochasticity, and environmental perturbation (Traill *et al.* 2010).

Nevertheless, the explicit randomness of the location of field sites and the intensiveness of the fieldwork across a large area has provided a valuable insight into understanding the feeding ecology of *C. lathami* on the Gold Coast, thereby providing a theoretically robust estimate of abundance. The insights gained through this approach can readily be applied to other sites where *C. lathami* are present to evaluate the relative differences in regional populations (Engeman 2005). Estimates can also be compared with other measures of population abundance or density such as banding, demographic analyses and measures of reproductive success to provide useful information about the conservation status of the species.

3.3.1 *Calyptorhynchus lathami* Feeding Ecology

This study observed that *C. lathami* were spending approximately 66% of their time feeding, similar to Pepper's (1996) findings on Kangaroo Island. In contrast, Chapman and Paton (2005) on Kangaroo Island found they only spend 26% - 36% of their time feeding, depending on the bird's breeding status. Chapman and Paton (2005) suggest that this discrepancy arises from the differing assessment methods used: Pepper (1996) determined percentage of time spent feeding from blocks of 30 minute observations, using auditory cues to locate *C. lathami*, as opposed to recording for the entire day. Chapman and Paton (2005) concluded that Pepper's (1996) methods would bias for feeding, (since most *C. lathami* auditory cues result from feeding) thereby underestimating the time spent perching etc., and hence the large variation in their amount of time spent feeding. Due to time constraints, accessibility and difficulties in tracking the movement by *C. lathami*, the length of observations in this present study ranged from 1 hour to an entire day. On average, most observations were at least 3 hours long, occurring at various times of the day. It is believed that 66% foraging time is an unbiased estimate of *C. lathami* activity on the Gold Coast, during the study period. As discussed by Cameron (2004), climatic conditions, such as drought etc., have an effect on the availability and nutritional content of *Allocasuarina* seeds, which means *C. lathami* feeding, both in terms of feeding rates and time spent feeding, may vary between seasons and between years.

The feeding rates on a large number of cones were timed for both genders, and birds of different ages. For the purpose of estimating *C. lathami* abundance, the average of all birds was used. On Kangaroo Island females took significantly longer to process cones than males, and Pepper (1996) found that, in monogamous pairs, the male fed 20% more efficiently than the female, the female presumably younger and less experienced than the male. Chapman (2005) however, attributes the

efficiency difference between genders on Kangaroo Island to males not always consuming all kernels within a cone and females being more vigilant whilst feeding, than males. These findings are supported by those of the current study where breeding females took longer to process cones than breeding males when feeding on *A. littoralis* on the Gold Coast. However, the opposite was evident for non-breeding birds, but neither of these differences was statistically significant. No significant differences between feeding rates was observed between the sexes at Dubbo (Cameron 2004, 2005), which supports the same subspecies as the Gold Coast (i.e. *C. l. lathamii*). However, Cameron (2005) did report greater efficiencies amongst adult birds than juveniles.

A hierarchical foraging system has been observed in the Kangaroo Island *C. lathamii* population, with breeding birds obtaining access to better foraging habitat than non-breeding birds, and non-breeding pairs over single birds (Pepper 1996). In this study only pairs (breeding and non-breeding – including one bachelor pair), and no single males, were observed. It is unusual to see single females due to mate guarding (Pepper 1996). It is thus possible that the areas monitored were prime sites, from which single males were excluded. Observations in our study sites indicated that breeding and non-breeding birds were feeding in the same area, including neighbouring trees, indicating that no hierarchical mechanisms were limiting which birds were utilising the area.

Furthermore, field sites were located randomly, with the results indicating that many sites were not currently being utilised. Many sites were either unsuitable (little to no cone production) or were apparently less profitable than those sites where feeding was observed, i.e. foraging sites had more trees bearing abundant cones, as reported elsewhere (Cameron and Cunningham 2006). The majority of active searches for birds in suitable habitat were unsuccessful, highlighting that the bird is extremely cryptic in its behaviour and selection of areas. The use of feeding signs to estimate the population size of this species is therefore a significant advancement in improving our knowledge of the species.

Only a short duration of juvenile feeding was recorded, but considering the consistency in which juveniles begged to be fed and occasionally attempted to feed independently, this recorded feeding is considered typical juvenile feeding behaviour. Despite the paucity of data for juvenile birds, the current results support observations made by Clout (1989), where juveniles were slow and clumsy feeders, often opting to beg for food from parents, especially from the female, although both the female and the male were observed regurgitating for juveniles. Cameron (2005) also reported longer cone handling times amongst juveniles and sub-adult birds than adults. Juveniles in the current study were identified due to differences in spotting on the plumage, their foraging efficiency and level of begging (personal observation). Older juveniles attempted to feed,

but still begged for additional food several times during the day, whereas younger juveniles had more difficulty feeding and were commonly observed begging for hours, with limited attempts at feeding: hence only the small data set for feeding rates of juveniles. It seems that many learning juveniles have difficulty breaking the pedicel, sometimes opting to pilfer a cone from the female. Since juveniles only processed a small number of cones, and were not necessarily consuming all available seeds from the cones (as expected for adults), feeding rates are more representative of adult feeding, including additional feeding by breeding birds for regurgitation for juveniles.

3.3.2 Estimate of Abundance of *C. lathami* on the Gold Coast

There are no pre-existing population data of *C. lathami* on the Gold Coast, although previous estimates suggest that there are 1000-2500 in *Queensland* (Garnett 1997). In order to manage any species effectively, reliable estimates of population size are required. However, given the generally limited resources for biodiversity management, species-specific knowledge, particularly about extinction risk, is required to manage populations effectively (Brook *et al.* 2006). Uncertainty surrounding population estimates could misdirect limited funds to areas in little need of attention, or result in failure to identify the vulnerability of a species. To determine the vulnerability of *C. lathami* on the Gold Coast, and hence determine an appropriate management strategy, trends in their population need to be determined, as recommended by Garnett and Crowley (2000). This study provides the baseline data required to monitor future trends in their population through ongoing monitoring of the feeding signs across the coast.

This study estimated that there are between 250 and 690 *C. lathami* on the Gold Coast. This equates to 0.5-1.3 birds / km². Originally, based on the limited number of bird sightings, and difficulty in finding *C. lathami* when intensively searching for them, it was anticipated that the (permanent) population of *C. lathami* on the Gold Coast would be quite low, approximating 200 birds. However, it is unknown whether low bird numbers is indicative of actual low bird numbers, or low reporting rates by observers (Anonymous 2002, Stock and Wild 2005). However, the level of feeding observed on the Gold Coast indicates that the population exceeds 200 birds, highlighting just how elusive *C. lathami* really is. This numerical estimate should be considered within some degree of caution as equating the estimate to known densities would require further statistical modelling in areas with known population densities (Engeman 2005). Further, additional suitable habitat, no doubt supporting additional birds, exists contiguous to the study area to the west, and nearby to the south. Nonetheless, this estimated number lies at the lower limit of an effective population size able to persist in the face of ongoing threat (Traill *et al.* 2010), and suggests that further research is required to monitor the long-term trends within this

population. The current estimate therefore provides a measure for future comparisons within this region to assess possible longer-term fluctuations within the population.

Twice in the past, a census was conducted to determine *C. lathami* abundance on the Gold Coast (this author organised censuses with the Wildlife Preservation Society for Queensland Glossy Black Cockatoo Branch, separate from the one discussed in Chapter 4). On both occasions only 15 birds were observed, indicating limitations of this method in estimating regional bird abundance. This is likely to be limited by the number of observers, size of Gold Coast, accessibility of much of the Gold Coast hinterland, abundance of potential drinking water sources, and duration of surveys. As discussed in Chapter 4, the Gold Coast was in drought conditions during the study period, limiting available *natural* drinking sources, but *C. lathami* have been observed drinking from artificial water bodies, including bird baths and culverts etc. Effort went into finding any commonly-used drinking sources by advertising the need for observers to report sightings. Announcements were placed in newsletters and newspapers, and on the radio, but with little success (most reports were of the Yellow-tailed Black-Cockatoo).

The literature indicates that many techniques have limitations (Grice *et al.* 2004, Williams *et al.* 2001); however consistency of methods at different times can at least provide an indication of change in relative abundance. The utility of using signs to estimate bird abundance has been hampered by the relationship between the bird, its habitat use and state of the signs themselves (e.g. production, decay, distribution) (Westcott 1999). In the case of *C. lathami* however, many of these limitations were accounted for in the methods used here, as outlined in previously in this Chapter as well as Chapter 2. For *C. lathami* its high degree of specialisation may actually stand in its favour when attempting to use indirect measures to estimate absolute abundance, as this reduces the uncertainty associated with variables linked to such estimation.

If we consider that the estimation of bird abundance is realistic, when we extrapolate the data on studied birds to the total population, we find that the estimated population size may potentially consist of 35 - 95 breeding pairs (since ~29 % of the study population was breeding⁴: estimating 70 – 194 individuals). This estimate of the number of breeding pairs indicates an enormous need in terms of *C. lathami* nesting requirements. Considering that only a small percentage of *C. lathami* habitat was examined, especially in terms of nesting, it is unknown whether there is suitable nesting opportunities available to *C. lathami* on the Gold Coast to provide for this many

⁴ It is not known if this figure is representative of the overall population, since only ~10% (35/240-670) of the estimated population was studied.

breeding pairs. As discussed in Chapter 4, there are only three known *C. lathami* nests on the Gold Coast, of which only one is known to have successfully fledged a chick. There have been reports of an additional eight *C. lathami* nests but these could not be confirmed as no *C. lathami* nested in these known hollows during the study period. Radio-tracking may provide a better understanding of *C. lathami* movements, including assisting in locating and identifying their nesting requirements. However, this also has limitations such as the ability to trap birds to fit collars, the retention of collars on birds etc. Their level of movement will give an indication of whether the Gold Coast is able to provide the necessary nesting habitat (if the birds are permanent residents), or whether *C. lathami* are being forced to travel further to find adequate habitat (making them relatively nomadic). This information will assist in identifying the stability of the *C. lathami* population on the Gold Coast.

Table 41. Variables used in development of the estimate of the regional population

Variable	Meaning
<i>A</i>	Average number of chewings found at a survey site
<i>a</i>	Amplitude of any annual cycle in different drinking time at different times of the year
<i>As</i>	Total area of sites sampled
<i>At</i>	Total area of the habitat in the study region
<i>ce</i>	Number of cones 'eaten' in a feeding event (period of observation)
<i>ch</i>	Number of chewings a bird produces from each cone
<i>d</i>	Cardinal number of day in the year
<i>dd</i>	Length of time a bird spends drinking at the end of each day
<i>dh</i>	Length of daylight per day (= length of bird activity accounted per day)
<i>fd</i>	Amount of time a bird spends feeding per day
<i>fp</i>	Proportion of the non-drinking activity time each day spent feeding or foraging
<i>Li</i>	Lifetime of chewings in field
<i>n</i>	Number of sites surveyed
<i>Nd</i>	Number of cones processed per bird per day
<i>Tb</i>	Total number of <i>C. lathami</i> in the study region
<i>Tc</i>	Total number of cones eaten across the entire habitat area per day
<i>Td</i>	Total number of chewings produced across the entire habitat area per day
<i>te</i>	Duration of a feeding event (period of observation)
<i>Ts</i>	Total chewings found at all sites

3.4 REFERENCES

- Acevedo, M.A. and Villanueva-Rivera, L.J. 2006. Using automated digital recording systems as effective tools for the monitoring of birds and amphibians. *Wildlife Society Bulletin*. **34**(1): 211-214.
- Anonymous. 2002. *Sightings and Records*. Unpublished report of the Wildlife Preservation Society of Queensland, Glossy Black-cockatoo Branch Inc., Gold Coast.
- Barnes, R.F., Beardsley, K., Michelmore, F., Barnes, K.L., Alers, M.P.T. and Blom, A. 1997. Estimating forest elephant numbers with dung counts and a geographic information system. *Journal of Wildlife Management*. **61**: 1384-1393.
- Brook, B.W., Traill, L.W. and Bradshaw, C.J.A. 2006. Minimum viable population sizes and global extinction risk are unrelated. *Ecology Letters*. **9**: 375-382.
- Brown, G.W. and Triggs, B. 1989. Diets of wild canids and foxes in East Gippsland 1983-1987, using predator scat analysis. *Australian Mammalogy*. **13**: 209-13.
- Cameron, M. 2002. Glossy Black Cockatoo *Calyptorhynchus lathami*. New South Wales National Parks and Wildlife Services. Pers. comm.
- Cameron, M. 2004. *Ecology of the Glossy Black-cockatoo (Calyptorhynchus lathami) in central New South Wales*. PhD Thesis. University of New England. Armidale. 168 pp.
- Cameron, M. 2005. Group size and feeding rates of Glossy Black-Cockatoos in central New South Wales. *Emu*. **105**: 299-304.
- Cameron, M. and Cunningham, R.B. 2006. Habitat selection at multiple spatial scales by foraging Glossy Black-cockatoos. *Austral Ecology*. **31**: 597-607.
- Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology*. **63**: 215-244.
- Chapman, T.F. 2005. *Cone production by the Drooping Sheoak Allocasuarina verticillata and the feeding ecology of the Glossy Black-cockatoo Calyptorhynchus lathami halmaturinus on Kangaroo Island*. PhD Thesis. University of Adelaide. Adelaide. 124 pp.
- Chapman, T.F. and Paton, D.C. 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.
- Clout, M. 1989. Foraging behaviour of Glossy black-cockatoos. *Australian Wildlife Research*. **16**: 467-473.
- Costello, J. 1981. Birds Observed in the Mungindi Area, Northern N.S.W. *Australian Bird Watcher*. **9**: 55-67.
- Council of the City of Gold Coast. 1998. *Gold Coast Nature Conservation Strategy*. The Council, Gold Coast, Queensland. 10 maps.
- Crowley, G.M. and Garnett, S.T. 2001. Food value and tree selection by glossy black-cockatoos *Calyptorhynchus lathami*. *Austral Ecology*. **26**: 116-126.
- Engeman, R.M. 2005. Indexing principles and a widely applicable paradigm for indexing animal populations. *Wildlife Research*. **32**: 203-210.
- Farmer, D. 2001. *Patterns of use of lowland eucalypt forests in southeast Queensland, by winter migrating forest birds*. Honours Thesis. Faculty of Environmental Sciences. Griffith University. 124 pp.
- Ford, H.A. 1985. A synthesis of the foraging ecology and behavior of birds in Eucalypt forests and woodlands. Ch. 21, pp 249-254 in *Birds of Eucalypt forests and woodlands. Ecology, conservation and*

Chapter 3 — Abundance and Distribution

- management. Keast, A., Recher, H., Ford, H. and Saunders, D. (eds). Surrey Beatty and Sons. Chipping Norton NSW. 384pp. ISBN 0949324061.
- Forshaw, J. and Cooper, W. 1981. *Australian Parrots*, 2e. Lansdowne Press, Melbourne. 312pp. ISBN 0701810351.
- Franklin, I.R. 1980. Evolutionary change in small populations. pp 135-149 in M.E. Soulé and B.A. Wilcox *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland. 380pp. ISBN 0878938001.
- Garnett, S. 1997. *Conservation plan for the Gold Coast population of Glossy black-cockatoos* (*Calyptorhynchus lathami*). *Gold Coast*. unpublished report. 6pp.
- Garnett, S.T. and Crowley, G.M. 2000. *The Action Plan for Australian Birds*. Environment Australia, Canberra. 673pp. ISBN 0642546835.
- Garnett, S.T., Crowley, G.M., Dennis, T.E. and Chapman, T.F. 1997. *Recovery Plan for the South Australian subspecies of the Glossy black-cockatoo* (*Calyptorhynchus lathami halmaturinus*). *Kangaroo Island, South Australia*. Unpublished report to the Threatened Species and Communities Section, Environment Australia. 16pp.
- Gregory, R.D., Gibbons, D.W. and Donald, P.F. 2004. Bird census and survey techniques. Pp. 17-56 in W.J. Sutherland, I. Newton and R.E. Green. *Bird Ecology and Conservation: A Handbook of Techniques*. Oxford University Press, Oxford, UK. 408pp. ISBN 978-0-19-852086-3.
- Grice, P., Evans, A., Osmond, J. and Brand-Hardy, R. 2004. Science into policy: the role of research in the development of a recovery plan for farmland birds in England. *Ibis*. **146** (2): 239-249.
- Harrington, L.A., Harrington, A.L., Hughes, J. and MacDonald, D.W. 2008a. Estimating the relative abundance of American mink *Mustela vison* on lowland rivers: evaluation and comparison of two techniques. *European Journal of Wildlife Research*. **54**: 79-87.
- Harrington, L.A., Harrington, A.L., Hughes, J. and MacDonald, D.W. 2008b. Distinguishing tracks of mink *Mustela vison* and polecat *M. putorius*. *European Journal of Wildlife Research*. **54**:367-371.
- Harrington, L.A., Harrington, A.L., Hughes, J., Stirling, D. and MacDonald, D.W. 2010. The accuracy of scat identification in distribution surveys: American mink, *Neovison vison*, in the northern highlands of Scotland. *European Journal of Wildlife Research*. **56**: 377-384.
- Haselmayer, J. and Quinn, J.S. 2000. A comparison of point counts and sound recording as bird survey methods in Amazonian southeast Peru. *The Condor*. **102**(4): 887-893.
- Hass, C.C. 2009. Competition and coexistence in sympatric bobcats and pumas. *Journal of Zoology*. **278**: 174-180.
- Ingram, G.J. 2001. Glossy Black Cockatoo *Calyptorhynchus lathami*. Pers. comm.
- Jeffress, M.R., Paukert, C.P., Sandercock, B.K. and Gipson, P.S. 2011. Factors affecting detectability of river otters during sign surveys. *Journal of Wildlife Management*. **75**(1): 144-150.
- Joseph, L. 1982. The glossy black cockatoo on Kangaroo Island. *Emu*. **82**: 46-9.
- Krebs, C.J. 2009. *Ecology: the experimental analysis of distribution and abundance*. 6e. Benjamin Cummings, Sydney. 655pp. ISBN 0-321-60468-7.
- Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity, and random catastrophes. *American Naturalist*. **142**: 911-927.
- Lara-Romero, C., Virgos, E. and Revilla, E. 2012. Sett density as an estimator of population density in the European badger *Meles meles*. *Mammal Review*. **42**(1): 78-84.

- Lunney, D., Law, B.A. and Rummery, C. 1996. Contrast between the Visible Abundance of the Brush-tailed Rock-wallaby, *Petrogalepenicillata*, and its Rarity in Fox and Dog Scats in the Gorges East of Armidale, New South Wales. *Wildlife Research*. **23**: 373-80.
- Mace, G.M. and Lande, R. 1991. Assessing extinction threats: towards a reevaluation of IUCN threatened species categories. *Conservation Biology*. **5**: 148-157.
- Marchant, S. and Higgins, P.J. (eds) 1990. *Handbook of Australian, New Zealand and Antarctic Birds vol. 1*. Royal Australasian Ornithologists' Union and Oxford University Press, Oxford. 1048pp. ISBN 0-19-553244-9.
- Munsell Color. 1994. *Munsell Soil Colour Charts* (rev. edn). Munsell Publishing Company New York. 10pp.
- Pepper, J.W. 1993. A new food source for the glossy black cockatoo. *South Australian Ornithologist*. **31**: 144-5.
- Pepper, J.W. 1996. *The behavioural ecology of the Glossy black-cockatoo* *Calyptorhynchus lathami halmaturinus*. PhD Thesis. University of Michigan. Michigan. 307 pp.
- Pepper, J.W. 1997. A survey of the South Australian glossy black cockatoo (*Calyptorhynchus lathami halmaturinus*) and its habitat. *Wildlife Research*. **24**: 209-223.
- Pepper, J.W., Male, T.D. and Roberts, G.E. 2000. Foraging ecology of the South Australian glossy black-cockatoo (*Calyptorhynchus lathami halmaturinus*). *Austral Ecology*. **25**: 16-24.
- Plumptre, A.J. and Harris, S. 1995. Estimating the biomass of large mammalian herbivores in a tropical montane forest: a method of faecal counting that avoids assuming a 'steady state' system. *Journal of Applied Ecology*. **32**: 111-120.
- Roberts, G.J. and Ingram, G.J. 1976. An annotated list of the land birds of Cooloolo. *Sunbird*. **7**: 1-20.
- Stock, M.J. and Wild, C.H. 2005. Seasonal variation in Glossy Black-Cockatoo sightings on the Gold Coast. *Corella*. **29**: 94-96.
- Traill, L.W., Brook, B.W., Frankham, R.R. and Bradshaw, C.J.A. 2010. Pragmatic population viability targets in a rapidly changing world. *Biological Conservation*. **143**: 28-34.
- Watson, D.M. 2004. Comparative evaluation of new approaches to survey birds. *Wildlife Research*. **31**: 1-11.
- Westcott, D.A. 1999. Counting cassowaries: what does cassowary sign reveal about their abundance? *Wildlife Research*. **26**: 61-67.
- Whisson, D.A., Engeman, R.M. and Collins, K. 2005. Developing relative abundance techniques (RATs) for monitoring rodent populations. *Wildlife Research*. **32**: 239-244.
- Williams, M.R., Abbott, I., Liddelow, G.L., Vellios, C., Wheeler, I.B. and Mellican, A.E. 2001. Recovery of bird populations after clearfelling of tall open eucalypt forest in Western Australia. *Journal of Applied Ecology*. **38**: 910-920.
- Wilson, G.J. and Delahey, R.J. 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observations. *Wildlife Research*. **28**: 151-164.
- Witmer, G.W. 2005. Wildlife population monitoring: some practical considerations. *Wildlife Research*. **32**: 259-263.

4 CALYPTORHYNCHUS LATHAMI FIELD OBSERVATIONS

4.1 INTRODUCTION

As discussed by Oertel (1998 p5), “low density and low reproductive output, large home range, highly specialised nutrient requirements and foraging methods, and lack of long distance migration may all decrease a species’ resilience to habitat fragmentation”. Other than the lack of long-distance migration, as *C. lathami* can fly more than 100 km in search of food (Garnett *et al.* 2000), these attributes accurately reflect the habits of *C. lathami*. Numerous studies have shown that the range occupied by *C. lathami* has decreased over the last century (Cleland and Sims 1968, Joseph 1989, Garnett 1993, Pepper 1997). Habitat destruction and fragmentation has resulted in fewer areas containing suitable feeding, nesting and drinking habitat (Cleland and Sims 1968, Paltridge 1994, Pepper 1997); all essential requirements of *C. lathami* (Crowley *et al.* 1996, Garnett *et al.* 1997). Furthermore, Owens and Bennett (2000) demonstrate that birds face a higher extinction risk through habitat loss if these species show a high level of habitat specialisation, as demonstrated above and in preceding chapters for *C. lathami*. Availability of these strict requirements may also be affected by unpredictable events, such as drought, fire and disease (Pepper 1997).

It is unknown whether *C. lathami*’s habitat requirements are readily met on the Gold Coast, enabling them to breed widely here, or if the birds observed are generally non-breeding or post-breeding. Although a few nests are known, a poor fledgling rate has been observed (1 in 5; Anonymous 2002).

Chapter 3 determined that between 250 - 690 birds appear to be feeding on the Gold Coast, but little is known about their movement. Ultimately, small isolated populations may become extinct as a result of insufficient foraging availability resulting from drought, fire or random processes. There is therefore a need to have a greater understanding of the patterns of habitat use by *C. lathami* on the Gold Coast in order to improve our understanding of their need for specific areas for feeding, nesting and drinking. Consequently, this chapter collates observational data on the day-to-day behaviour of *C. lathami*, including nesting, feeding and drinking, on the Gold Coast, and combines this with a preliminary radio-tracking study to characterise these patterns.

4.2 METHODS

A greater understanding of *C. lathami* foraging behaviour (Chapter 2), and nesting and drinking requirements, was gained from intensive field monitoring efforts. Throughout the field studies a database of distinguishing features was collated for all cockatoos observed and this was used to identify different family groups as well as individual birds. In addition to the aforementioned observations all nesting and drinking sites encountered were profiled (i.e. various characteristics such as tree species and height for nests, and water body type and size for drinking sites etc.); a preliminary radio-tracking study was also undertaken.

4.2.1 Morphological Characteristics

Morphological characteristics have been used extensively to identify individuals from a variety of different animals including; elephants (shape, nicks and scars of ears; Whitehouse and Hall-Martin 2000), dolphins and whales (mottling colourations and shape of dorsal fins etc.; Mazzoil *et al.* 2004), snow leopards (pelage patterns on limbs, tail; Jackson *et al.* 2006) and birds (plumage colouration, patterns etc.; Bretagnolle *et al.* 1994, Arroyo and Bretagnolle 1999, Garnett *et al.* 1999). The distinctive plumage patterns in *C. lathami*, particularly in female birds, are specifically the tail barring and the pattern of yellow face feathers (Forshaw and Cooper 1981, Morcombe 2000). These features combined with the longevity of *C. lathami* make the species a suitable candidate for the use of such field-based individual recognition methods.

Morphological characteristics of *C. lathami* were used to determine if the same individuals were being observed at various drinking and feeding sites. The number, age, sex and group associations of the birds, as well as the locations in which they were observed, were used to identify individuals. This method of identification has previously been used on a moderately-sized populations of *C. lathami* (approximately 200 birds: Pepper 1996, Garnett *et al.* 1999), working best on particularly distinctive birds (Garnett *et al.* 1999).

Unlike some of the other Black-Cockatoo species, *C. lathami* are not particularly gregarious (Pepper 1996, Garnett *et al.* 1997, Chapman 2000), often being observed only in groups of two or three birds (Forshaw and Cooper 1981, Pepper 1996, Marchant and Higgins 1990). The demographic structure of these groups is commonly (i) a mating couple (adult male and female, or adult male but sub-adult female), (ii) two males, or (iii) a mating couple with a juvenile (Pepper 1996). If seen individually, which is very rare (Pepper 1996), it will most likely be a male as *C. lathami* populations are male-biased, resulting in females being mate-guarded (Joseph 1982, Schodde *et al.* 1993, Pedler 1995, Pepper 1997, Garnett *et al.* 1997).

Furthermore, the combination of a pair's external morphological features enables most groups to be easily identified given that the species is essentially monogamous (Pepper 1996, Crowley *et al.* 1998) thereby precluding any mixing among groups.

All juvenile *C. lathami* have barred red tail feathers (Figure 33, A and B), with males gaining unbarred tail feathers progressively with each moult (i.e. adult males have a single wide red band across their tail feathers: Figure 33, E and F). The first moult of *C. lathami* is only a partial moult and occurs at approximately 18 months, and then each retrix is retained for 2 years (Courtney 1986). At each moult, the birds lose half their retrices staggering the replacement of these feathers. Males start to lose their barring at approximately 24 months, and are usually completely unbarred by 60 months (Figure 33, E and F).

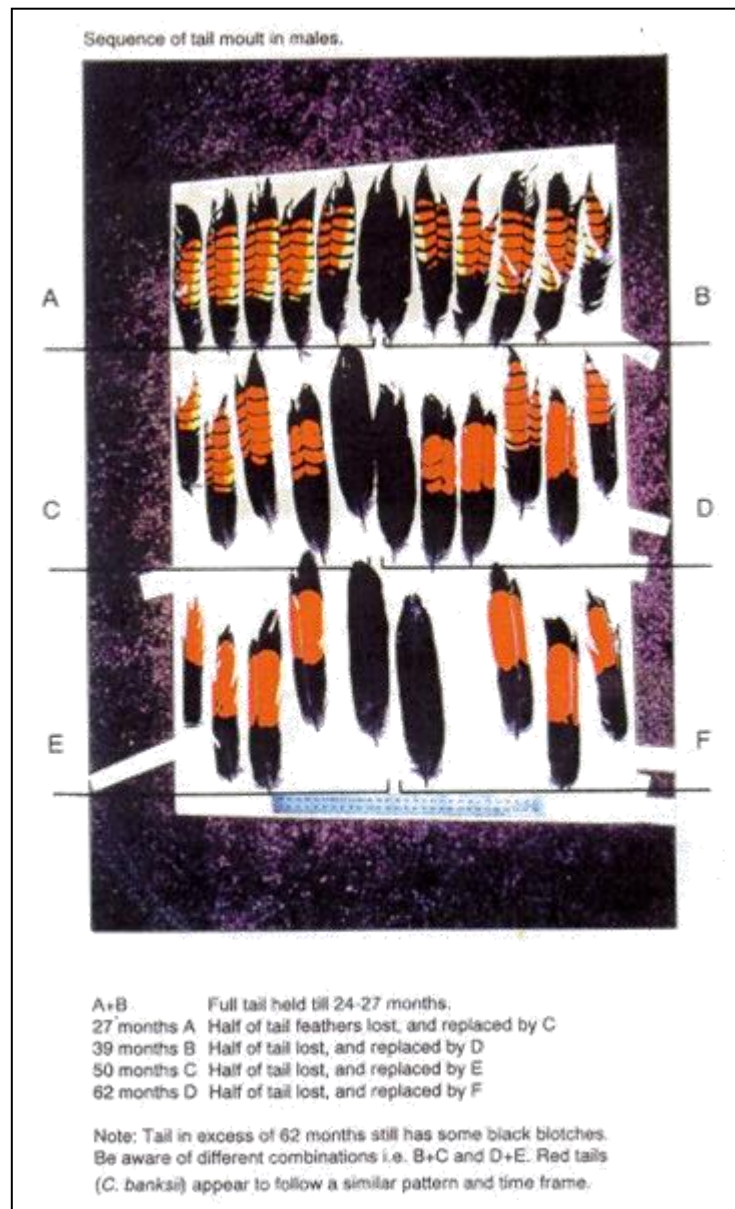


Figure 33. Tail barring in male *C. lathami*, Source: QDEH (1993)

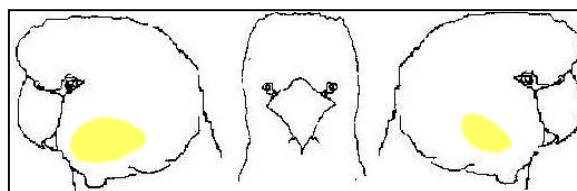
Female *C. lathami* start to grow yellow cranial feathers at approximately 12 months of age, with profuse yellow by two years (Courtney 1986): the quantity and pattern of the yellow enables identification of individual females (e.g. Figure 34).



Figure 34. Differences in tail barring and yellow face feathers in male and female *C. lathami*
Left: pair of *C. lathami*, male (left) with unbarred red tail feathers, and female (right) with barred red tail feathers and yellow face feathers.
Right: Variations in the quantity and pattern of the yellow face feathers in females, enabling identification of females.

During the study, when *C. lathami* were observed the following information was recorded:

- Number of birds in each group (pair or pair with juvenile)
- A description of the quantity and pattern of yellow face feathers of females (details given diagrammatically as per example below)



- Degree of tail barring in males
- Presence/absence of yellow spotting in juveniles

4.2.2 Drinking

Water bodies in the vicinity of known roosting and feeding sites were monitored for *C. lathami* drinking, initially to trap individuals for the purposes of radio-tracking. As stated in the literature review, drinking is the only time *C. lathami* come to the ground, making trapping somewhat easier. The following information was collected from known *C. lathami* drinking sites:

- Drought persistence – presence of water during the dry season and classification of water bodies as perennial or ephemeral
- Regularity of *C. lathami* drinking (i.e. commonly used, or only during drought or rain etc.)
 - Water sites were visited regularly by the researcher for the purpose of locating birds and collecting observational data. Additional information on regularity of *C. lathami* drinking was obtained from landowners, including using the records collated since 1990 (Anonymous 2002).
- Water body type – creek, dam or pond
- Width and depth – estimated at time of drinking
 - Where possible a measuring tape was used to measure width, otherwise the distance was estimated.
- Foliage density around drinking site – categorically ranked as scarce or profuse
 - Areas considered ‘scarce’ were very open, usually consisting of a few Eucalypts and/or Casuarinas. ‘Profuse’ provided a high level of cover around the watering site, consisting of Eucalypts and Casuarina in higher numbers, as well as other, denser species, such as Acacias and Paperbarks.
- Dominant tree species
 - The most dominant was species visually determined, and identified to species level or genus. As practicable. Non-flowering Eucalypts could not be identified so were only listed as ‘Eucalypts’.
- Canopy overhang height
 - Visually estimated. At known watering sites, this is the height of the vegetation overhang (if any) where birds would land immediately prior, and after, drinking. This was usually a Eucalypt branch overhanging within metres of a preferred drinking spot.
- Distance to nearest known nest
 - Reported to the nearest 100 m using GIS maps of *C. lathami* drinking and nesting sites.
- Distance to nearest known feeding site
 - Reported to the nearest 100 m using GIS maps of *C. lathami* drinking and feeding sites.

This profile was used as a guideline to determine suitability of water bodies in *C. lathami* habitat of unknown drinking status.

4.2.3 Nesting

Nests were not explicitly searched for, but reported nests were investigated for potential trapping purposes. Although only one nest was known to be active during the study period, two other trees with hollows were known to have been previously used by *C. lathami*. Unfortunately such a small sample is far from an adequate data set for statistical analysis on *C. lathami* nesting trees, but the following information was collected for current and known previously-used nests:

- Years used (reported sightings and personal observations)
- Tree species (where possible, bark and fruit were used to identify species)
- Tree height (determined using an inclinometer)
- DBH at 50cm (measuring tape was used)
- Hollow height (determined using an inclinometer)
- Dead branch order (visually determined using Whitford (2002), see below)
- Crown senescence (visually determined using Whitford (2002), see below)
- Distance to nearest known drinking site (reported to the nearest 100 m using GIS maps of *C. lathami* nesting and drinking sites)
- Distance to nearest known feeding site (reported to the nearest 100 m using GIS maps of *C. lathami* nesting and feeding sites)
- Dominant plant species
- Hollow details, including aspect and hollow type (trunk part) (determined using a compass and Whitford (2002) diagram of trunk parts, see below).

Crown senescence, dead branch order and hollow details were based on the schematic diagrams used by Whitford (2002), as shown in Figure 35.

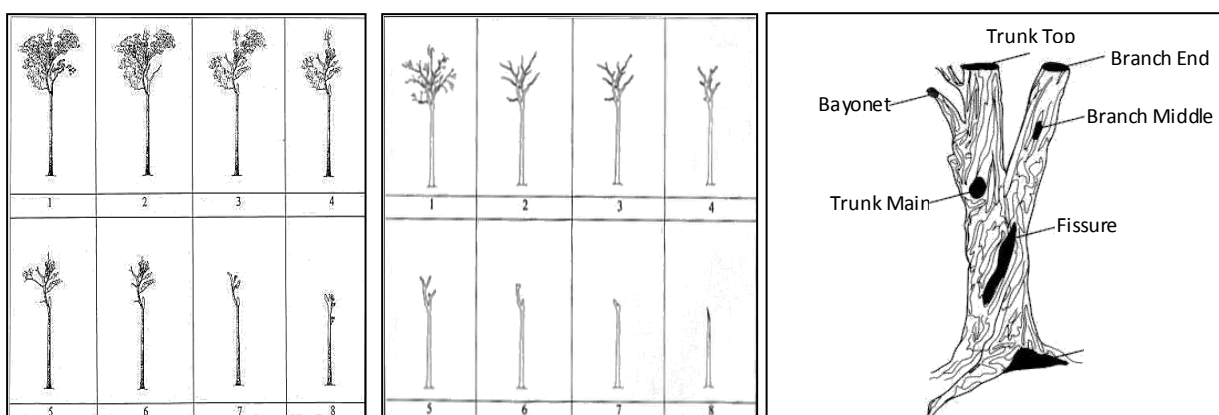


Figure 35. Crown Senescence, Dead branch order and trunk parts. Source: Whitford (2002)

Time was spent monitoring an active nest and the pair's drinking site in Mudgeeraba from 11 May to 4 July 2004. The intention was to capture and attach a radio-transmitter to the hen, but to minimise stress on the chick, capturing was to be delayed until the chick was approximately 70 days old, at which time it would be nearly ready to fledge. Tracking the hen would also track the chick, since chicks stay with the parents for at least 6-12 months (Pepper 1996). Details of the nest monitoring were recorded.

4.2.4 Census of *C. lathami* numbers

Intensive searches in the field were unsuccessful in locating *C. lathami* in May-June 2004. This was unexpected, since this is normally time of peak abundance, in terms of actual bird numbers (Clout 1989, Pepper 1996), and bird sightings (Stock and Wild 2005), coinciding with juvenile recruitment and peak cone abundance (Clout 1989). To assist in locating *C. lathami* for trapping and radio-tracking purposes, a census was organised for 5 July, 2004. The census was conducted between 12:00 and 17:30: late enough to observe any flocking for drinking. Sites were randomly chosen from known *Allocasuarina* areas. The number of sites was limited by the number of observers (five). Observers walked around the site (site size varied according to *A. littoralis* growth), recording any visual or auditory signs of *C. lathami*. Observers were given a roughly systematic path to follow. For an example, the observer in Nerang State Forest, would essentially walk parallel to, but some distance from, a walking track, ensuring that they were walking through *Allocasuarina* stands and nearby eucalypt stands.

4.2.5 Radio-Tracking

Radio tracking was intended to gain a greater understanding of *C. lathami* movement on the Gold Coast. *Calyptorhynchus lathami* usually return daily to their current feeding site until the majority of, if not all, cones have been removed, before relocating to a new feed site (Clout 1989, personal observations). The radio tracking could show what distances are typically being covered daily, flying between feed, drinking and roosting sites, as well as what distances *C. lathami* travel between feed sites. Only preliminary radio-tracking was done due to the difficulty of finding and trapping birds.

4.2.5.1 Pre-test – Determining the Mode of Transmitter Attachment

A variety of transmitters are available to radio-track various bird species, but the flexibility and strength typical of parrots, means that they are able to remove many types of transmitters using their beaks and/or feet. A transmitter with a neck harness was used (Titley Electronics Pty Ltd,

model number PICTXV60.asm, 16.5g weight), positioning the bulk of the transmitter on the anterior, concave section of the throat, with a 12cm antenna attached posteriorly (Figure 36), where the bird cannot easily reach.

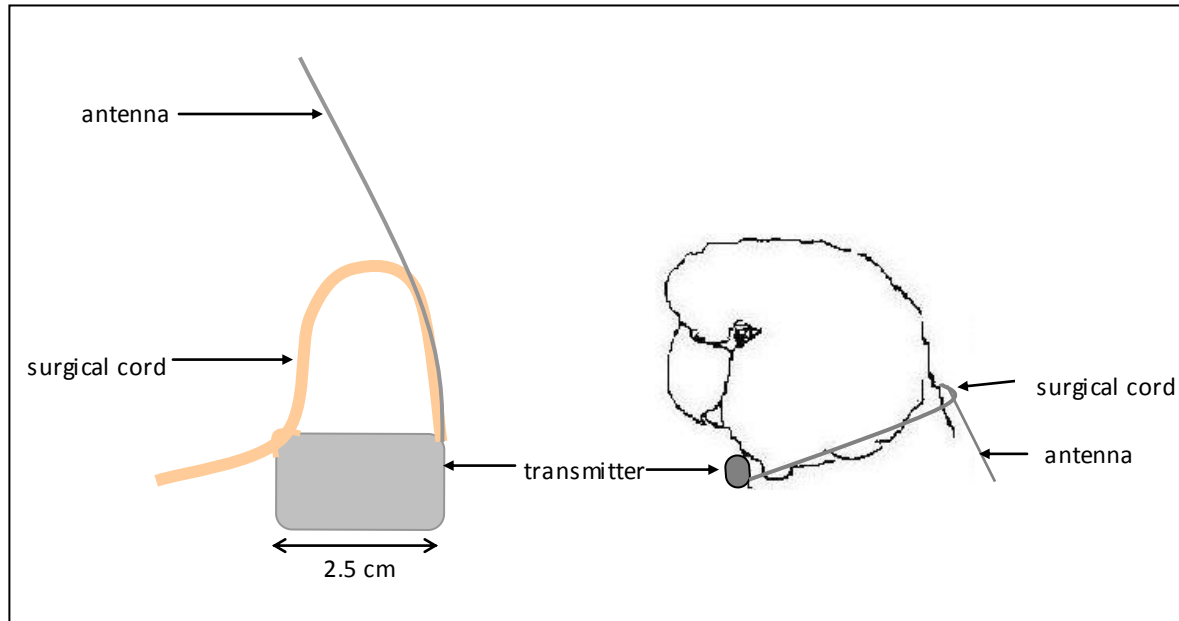


Figure 36. Neck harness with transmitter on *C. lathami*

The batteries of the transmitter were on a timer, turning off at 9pm and turning on at 4am (between these times, birds are expected to be roosting or nesting, with little to no activity), to increase the number of days the transmitters were powered. On clear days, it was expected that the transmitter signal could be detected up to several kilometres away using a standard handheld VHF receiver and YAGI directional antennae.

A dummy transmitter was placed on a captive male *C. lathami*, prior to capturing wild *C. lathami*. This bird was kept by a private breeder in northern New South Wales: it was kept in a large cage ($\sim 5\text{m} \times 3\text{m} \times 2\text{m}$ [$l \times w \times h$] which provided minimal flying space), in order to assess whether these birds are capable of removing this type of transmitter attachment. It was hypothesized that a caged bird, having less stimuli, is more likely to spend more time and effort attempting to remove the transmitter than a wild bird (although this does not take into account preening by its mate). The captive bird appeared indifferent to the attachment of the transmitter.

Only one bird could be used for this exercise, as there are relatively few birds of this species in captivity and the other known captive birds were breeding at the time and were not available for this study.

4.2.5.2 Trapping Methods

Approximately half an hour prior to dusk, a single *C. lathami* was caught flying in to a drinking site using a mist net. The bird was held overnight in a well-ventilated PetPack (66 × 45 × 43 cm) and taken to a local wildlife sanctuary (Fleay's Wildlife Sanctuary, Gold Coast) the following morning, where a veterinarian sedated the bird with isoflurane, reducing any further distress. The radio-transmitter was attached to the bird and the following information was collected:

- weight (g)
- wing length (cm)
- bill length (mm)
- tarsus length (mm)
- tail length (cm)
- heart beat and respiration
- physical health description
- photo identification: red tail feathers (male) and yellow face feathers (female)
- indication of age (feather colouration (tail and face), general indications of wear)

After attaching the transmitter and the bird had regained activity, it was transported back to the capture site and released. The bird was followed throughout the day, but at a distance, as it was showing signs of wariness. The transmitter was found on the ground after four days, with beak marks.

The veterinary check had indicated that the bird showed signs of poor health, therefore it was preferable not to re-capture the same bird. To ensure the bird was not caught, no further trapping was undertaken at the same drinking site, as the family group were still in the vicinity.

It was intended to have four transmitters on birds at the same time (all four birds caught within a short time period i.e. a week or two). Tracking of birds would have allowed for more data to be collected for Chapter 3. It was intended that each bird be tracked, obtaining points for each of the four birds one day a week for six months (a total of 25 points for each bird), allowing a comparison of each bird's movements between weeks. One day per week, one bird would be monitored intensively from dawn until dusk, providing 25 days of tracking time, with each bird tracked a minimum of 6 days. This would yield the following information:

- Time spent flying, feeding and preening each day
- Distances (in km) flown daily
- Find and record unreported drinking, nesting and feeding sites

- Number of feeding events per day
- Quantity of feeding per day (count the chewings of feed trees)

The size and difficulty of access of much of the Gold Coast, combined with the elusiveness of *C. lathami*, made locating and trapping *C. lathami* very difficult. Mist nets were chosen as the most suitable trapping method, but the when and where to trap proved problematic. The probability of capture from feed trees was quite low, since it is difficult to predict which trees and which direction and height the birds will fly in and out, making trap placement challenging. Similarly for drinking, it is difficult to predict where *C. lathami* will drink, especially after rain, when there is an abundance of potential drinking sites. Even though only one bird was radio-tracked, limiting the analysis of movement patterns, much of the remaining habitat use and morphological information was still collected through direct observations of several family groups over several months.

4.3 RESULTS

4.3.1 Morphological Characteristics

In total, 35 birds were observed in the field and studied; determining feed rates and recording drinking observations. Individual birds were identified using morphological features (see Appendix 3). These 35 birds consisted of 15 family groups: 10 non-breeding pairs (including one bachelor pair) and 5 pairs with a juvenile.

Three groups of *C. lathami* were identified as having been observed at more than one study site at different times during the 26 month survey period (January 2003 to March 2005) (Figure 37). Due to minor changes in plumage over time, there is a possibility that these groups were incorrectly identified, but most family groups had distinctive traits, and identification was made with a reasonable degree of confidence.

- Group 1 was observed in the southern end of Nerang State Forest on multiple occasions between August and October in 2004, and then again in Bonogin in December of the same year. There is approximately 16 km between the two feed sites. Bonogin residents said they had observed *C. lathami* feeding and drinking there irregularly for 2-3 months.
 - This group was distinguished by the female – her tail feathers were considerably more yellow than other females, as well as having spotting on her wings and belly (see photo Appendix 4).
- Group 5 was observed on the western side of Nerang State Forest and 6.8 km away at Gilston. The pair with an older juvenile was observed in Nerang in August 2003, feeding

on *A. torulosa*. The same pair (without the juvenile) was observed again in July 2004, feeding on *A. littoralis*.

- This group was distinguished by the female – she had no obvious tail barring and had distinctly different yellow feather pattern on the left and right side of her face.
- Group 15 members were observed drinking at Guanaba in January 2003, and then feeding in the southern end of Nerang State Forest (Maudsland; ~8 km away) in October 2004.
 - This group was distinguished by the female – she had typical red barred tail feathers but a single medium sized yellow patch on each side of her face.

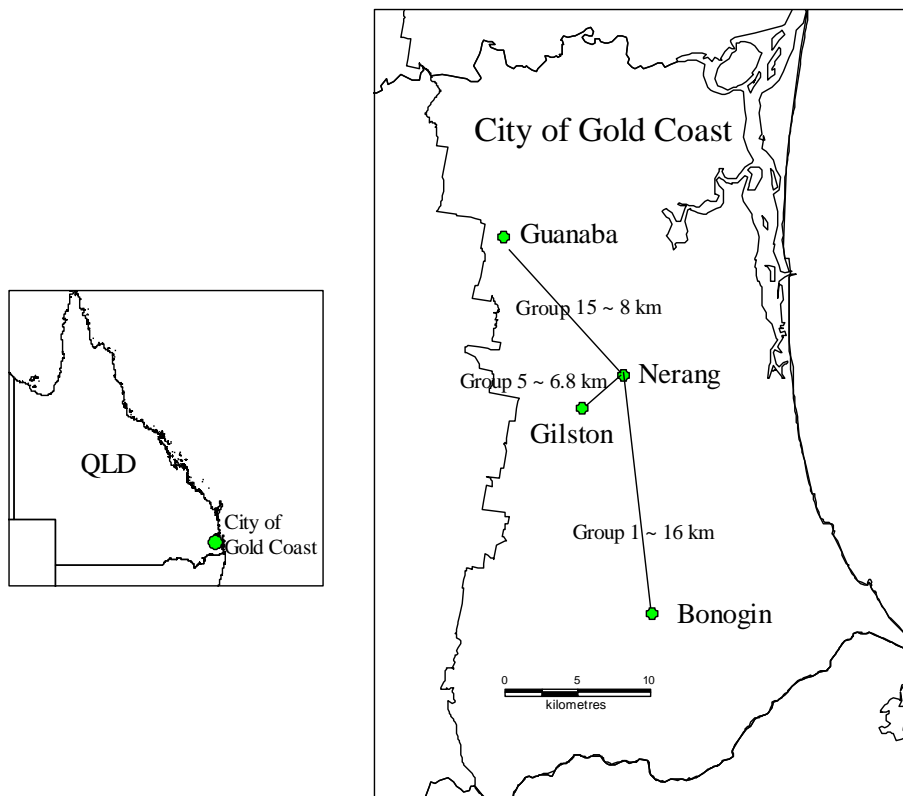


Figure 37. Distances between observations of groups of birds sighted at different locations
Source: Gold Coast City Council: Gold Coast suburbs

While only three groups were observed at multiple sites these data suggest that the movement patterns of the birds are confined to the Gold Coast region with the birds not moving more than 20km, over either short (2 month) or long (11 and 21 month) periods. The Nerang State Forest is one of the largest habitat remnants remaining on the Gold Coast lowlands and appears to act as a central node for movement of *C. lathami* across the Gold Coast, at least for the groups observed in this study.

Tail feather patterns of female *C. lathami* on the Gold Coast revealed two obvious deviations from expected patterns where adult male *C. lathami* are expected to have unbarred red tail feathers, and females have barred red (with some yellow) tail feathers (Figure 34, Morcombe

2000). One female had particularly yellow tail feathers — mainly yellow, but proximal tail feathers are red: Figure 38 (Group 1), with some yellow spots on her left wing. This cockatoo was paired with an adult male, in a group of approximately eight *C. lathami*. To reinforce the confidence in her identity, she had the vocal call and feeding characteristics typical of *C. lathami*.

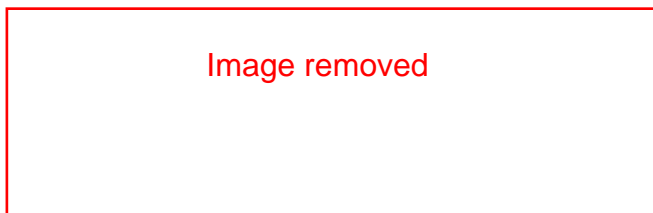


Figure 38. Comparison of the red and yellow tail feathers of ♀ *C. lathami* to *C. funereus* and *C. banksii*

A further two female *C. lathami* were observed with seemingly unbarred red tail feathers. One bird had very little yellow face feathers, whilst the second bird had extensive yellow patches (Figure 39), clearly identifying two separate birds. Both individuals were paired with a juvenile.



Figure 39. Female *C. lathami* with unbarred red tail feathers

4.3.2 Drinking Sites

Although not explicitly studied, it was evident that water is potentially limiting for *C. lathami* during the dry season. Three of the twelve known drinking sites on the Gold Coast dried up completely during drought conditions and others were mostly dry with one or two relatively stagnant pools (Table 42). Seven of the sites were rocky creeks, where *C. lathami* could land on a rock, where they could easily drink (Figure 40).



Figure 40. *Calyptorhynchus lathami* drinking at a rocky creek

Surveys over 137 nights were spent observing drinking sites, on only 26 of which did any *C. lathami* attend the site. The birds arrived at drinking sites after 16:30 but as late as 18:20 with arrival times apparently influenced by the time of year with birds arriving earlier in autumn / winter months and later during the summer (Table 43). All known drinking sites were close to feeding sites, and were predominantly in eucalypt forests with a canopy height of between 15 and 20 m (Table 42).

Field observations of *C. lathami* drinking have shown that some anthropogenic disturbances may limit where they drink. Birds appear to be more vigilant whilst drinking and are easily disturbed, but for feeding there were no significant differences in anthropogenic disturbance factors between foraged and non-foraged sites (Chapter 2, section 2.2). Several times birds have flown off mid-drink due to dogs and loud mechanical noises (such as lawnmowers) nearby. A few of the drinking sites were on Council reserves and birds were disturbed by children playing in the vicinity, but mostly, drinking sites are either in bushland or on residential acreage, distant from the house, minimising the level of any direct human disturbance.

Chapter 4— Field Observations

Table 42. Profiles of known *C. lathami* drinking sites on the Gold Coast

Site	Dry season condition	Regularity of drinking	Water body type	Width	Depth	Foliage density **	Dominant tree species **	Canopy overhang height **	Distance to nearest known nest	Distance to nearest known feeding area
Arjuna	1 or 2 puddles	Regular	creek	2 m	0.2 m	scarce	eucalypts, fig trees, casuarinas	2-18 m	no known nest nearby	20 m
Saunders	dry	irregular*	creek	1-2 m	0	profuse	casuarinas, eucalypts	20 m	500 m	5 m
Glenmore	dry	irregular*	creek	1-2 m	watermark at 60 cm	scarce	<i>Leptospermum</i> , casuarina	1-10 m	500 m	5 m
Nicole	various sized pools	Regular	creek	5 m	< 30 cm	scarce	eucalypts	20 m	500 m	2 m
Evanita	pools	during drought	dam	15 m × 15 m	0	profuse around edge	eucalypts	15-20 m	100m	100 m
Lynwood	pools	during drought	dam	15 m × 25 m	3 m	scarce	eucalypts	15-20 m	no known nest nearby	20 m
Hidden Valley	dry	irregular*	creek	2-2.5 m in wet season	0	scarce	eucalypts	15 m	3 km	150 m
Olsen	ponds	Regular	pond	5 m × 4.5 m	unknown	profuse	paperbark, acacia	13 m	100 m	30 m
Blemiss	various sized pools	Regular	creek	2 m	unknown	scarce	paperbark	8 m	no known nest nearby	15 m
Lyons	pools	Regular	creek	7 m	20 cm	profuse	<i>Casuarina cunninghamiana</i>	15-20 m	no known nest nearby	5 m
Canopy	dry	only during rain	ephemeral pond	0.5 m	0.2 cm	scarce	ornamentals	No canopy	500m	20 m
Bonogin	various sized pools	Regular	creek	1.5 m	20-50 cm	scarce	<i>A. littoralis</i>	5 m	800 m	10 m

* irregular: residents report high *C. lathami* usage when water is available
 ** information given for the immediate area around where *C. lathami* were observed drinking

Table 43. Details of *C. lathami* observations at drinking sites on the Gold Coast

Site	Dates birds observed	# Birds	Time of Arrival
Arjuna	29/03/2001	5	17:00
	01/04/2001	5	17:30
	27/05/2001	5	?
	15/05/2002	2	16:40
	20/04/2002	?	?
	24/04/2002	5	?
	26/09/2002	5	17:25
Saunders	01/04/2001	6	17:20
	16 - 25/07/2001	6	?
Glenmore	19/04/2004	1	17:10
Nicole	01/04/2001	2	?
	13/09/2004	1	16:50
	16/09/2004	1	16:56
Evanita	Reported by members of the public but no recordings, no drinking observed by researcher		
Lynwood	29/01/2003	2	17:40
	29/01/2003	6	18:05
Hidden Valley	Reported by members of the public but no recordings, no drinking observed by researcher		
Olsen	21/02/2005	3	18:10
	23/02/2005	3	?
	24/02/2005	10	17:50
Blemiss	24/02/2005	5	17:43
	25/02/2005	5	18:20
Lyons	10/11/2003	5	17:51
	20/11/2003	6	17:55
Canopy	Regular reports by members of the public but no recordings, no drinking observed by researcher		
Bonogin	02/12/2004	4	?
	15/12/2004	2	?
	16/12/2004	2	?
	17/12/2004	3	?

4.3.3 Nesting

4.3.3.1 Active Nest

The active nest was in a hollow of a dead Eucalypt, approximately 31 m tall. As with observations made on Kangaroo Island (Garnett *et al.* 1999), the hen left the egg nightly for 10-30 minutes to

drink with the cock. After drinking, the cock would allo-feed the female, before returning to the nest. The cock roosted approximately 500 m from the nest, even though numerous *Eucalyptus* trees were present closer to the nest. From the start of July 2004, when the chick was 2–3 weeks old, the hen was no longer observed returning to the nest. Using a 50 m cherry picker, we viewed the chick in the nest hollow after the hen left the nest to drink in the evening (Figure 41). On 4 July, Sulphur-crested Cockatoos (*Cacatua galerita*) were seen hovering around the nest, with one entering the hollow, remaining inside for about 10 minutes – there was no visual or auditory sign of the hen or chick. Due to lack of any further observations of the chick or hen in the following week, it was presumed that the nest had been abandoned.

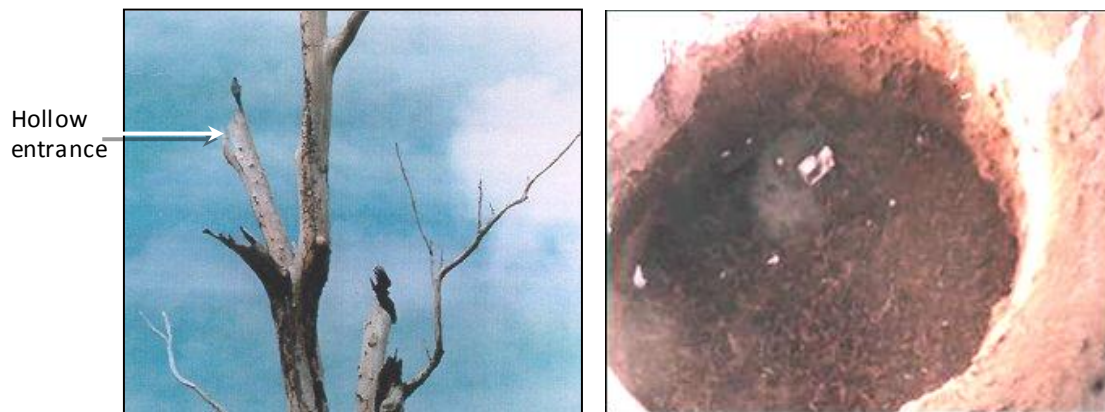


Figure 41. Picture of (left) the nest hollow and (right) inside the hollow and 2-3 week old chick

4.3.3.2 Previously Known and Current Nest Sites

All three known nest trees, two of which were dead trees, had attained a height greater than 25 m with a DBH greater than 145 cm, with hollows a minimum of 20 m high. All three nests were very close to feed trees and a potential drinking site (Table 44). In these three nests, there have been five known nesting attempts, only one of which resulted in a fledgling (nest 3). The attempts in nest 1 are believed to have been abandoned after repetitive harassment by Sulphur-crested Cockatoos, and a goanna was observed entering nest 2 prior to the nest being abandoned. This was reported by a local resident and no details of species of goanna, etc. were available.

Table 44. Attributes of *C. lathami* nests on the Gold Coast

Nest #	Nesting frequency	Tree species	Tree height (m)	DBH at 50cm (cm)	Crown senescence	Dead branch order	Dominant species in surrounding area	Distance to drinking site	Distance feeding area	Hollow height from ground	Hollow details
1	1996 2001 2004	dead eucalyptus	32	148.5	8	4	cleared	0.5 km	400 m	22 m	facing north, branch end/middle
2	1999	dead eucalyptus	25	146.5	8	6	<i>A. torulosa</i> and eucalypts	40 m	20 m	25 m	facing south, trunk top
3	1996	<i>Eucalyptus</i> sp.*	25	186	1	1	disturbed, rainforest species	20 m (unconfirmed drinking site)	30 m	20 m	faces south, trunk main

* This tree was alive, but due to lack of fruiting, the species was not identified

4.3.4 Census

The July 2004 census indicated that there was very little observable *C. lathami* activity at this time (Table 45). Subsequent observations at the Gilston site revealed two pairs of *C. lathami* currently feeding in the area, even though they were not present at the time of the census. Feeding data were recorded but no trapping was possible. Large amounts of feeding were observed (excess of 20 000 chewings, representing ~6000 cones) but within a few days of sighting these *C. lathami*, they relocated to a new food source.

Table 45. *C. lathami* census results from surveys conducted at five locations on the Gold Coast

Location	# Chewings	<i>Allocauarina</i> sp.	Chewing Colour	Age* (approx. days)	# <i>C. lathami</i>	
					5 th July	6 th July
Bonogin	0	–	–	–	0	0
Austinville	> 700	<i>A. torulosa</i>	10 yr 4 6 10 yr 5 8 10 yr 6 8	123 33 69	0	possible <i>C. lathami</i> calls
Nerang	0	–	–	–	0	0
Gilston	> 20 000	<i>A. littoralis</i>	2.5 yr 7 4 7.5 yr 5 6 10 yr 4 6 10 yr 5 6 10 yr 7 6 10 yr 6 6	0 64 89 64 72 40	2	0
Numinbah	0	–	–	–	0	0

*Calculated using mean chewing age determined using colour, as determined in Chapter 3: Aging Chewings

4.3.5 Radio-Tracking

Ultimately, only one bird was radio-tracked — a breeding male. Figure 42 shows the radio-tracking area in Southport (Gold Coast, Queensland), and Figure 43 the bird's feeding, roosting and perching sites over four days. The habitat of this group was semi-urban with busy roads, university buildings, private houses, and some areas of moderately-disturbed bushland, covering some tens of hectares (see Figure 42). The family of *C. lathami* being tracked were only moving very small distances on a daily basis. The total area that the birds were consistently recorded in was only 1 km² and they did not leave the area during the four day study period. The longest recorded distance flown was approximately 1.2 km, between a feed site and drinking site (see Figure 43).

To summarise, the radio-tracked bird's behaviour throughout the day consisted of leaving the roosting area at approximately 5:00 am and flying to their feeding site. They would feed intensively in the morning, and then around midday roost within the feeding area. They would resume feeding in early afternoon and continue feeding (in this locality, these birds were observed feeding from three different trees on any given day) until about 5:00 pm, when the birds would fly off and congregate near a drinking site. After drinking they would fly off to their roost site. At the roost site the birds would fly around and call out before settling for the night.

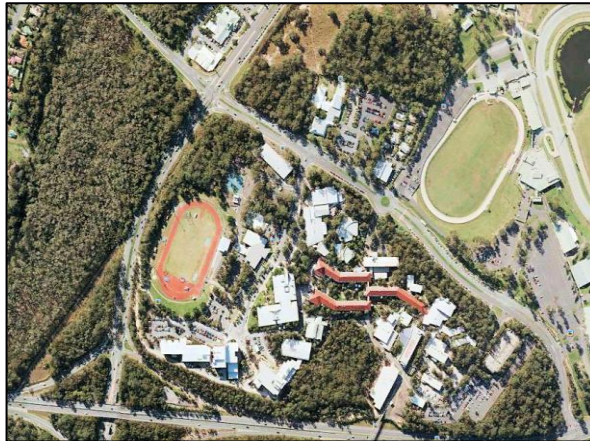


Figure 42. Radio-tracking area: aerial photography showing vegetation and development.
Source: Google Earth. Image © 2012 Whereis® Sensis P.L. Image date 23 June 2008

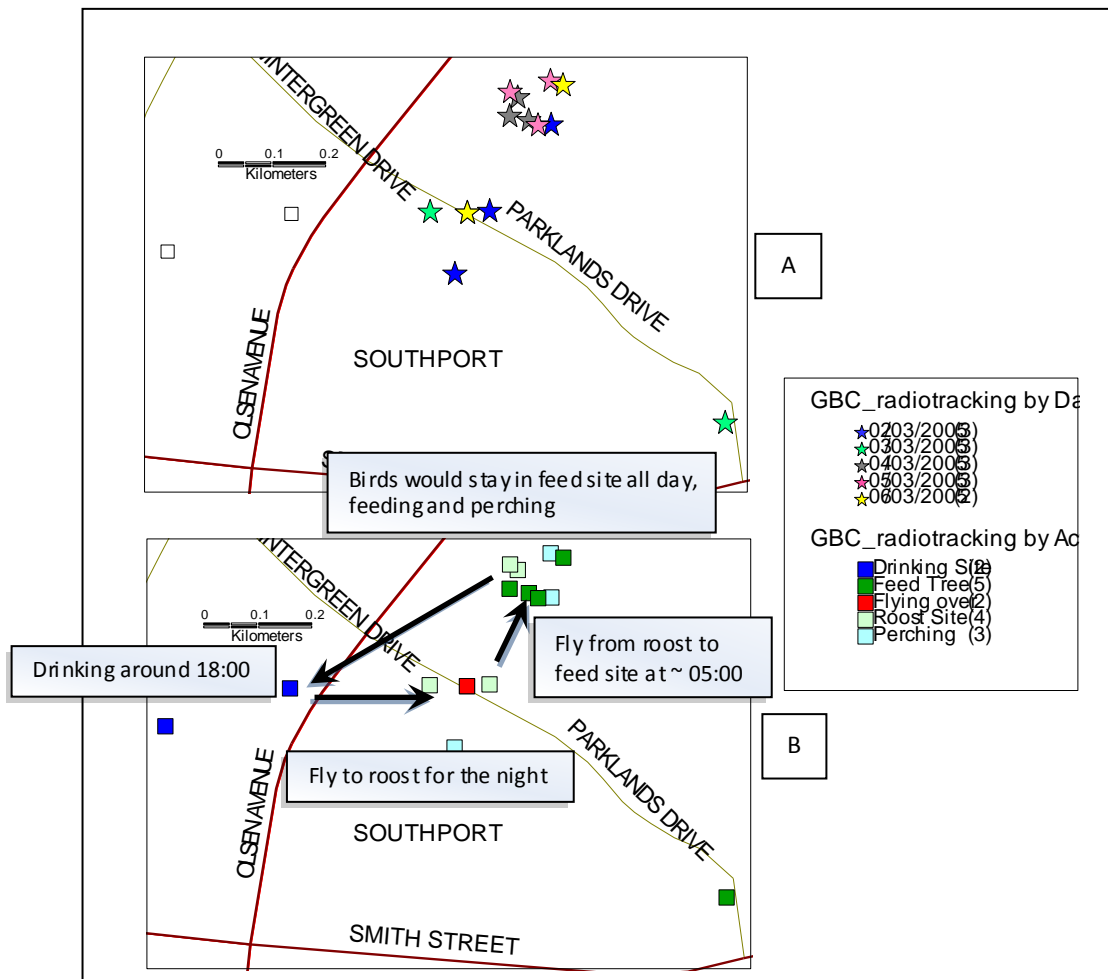


Figure 43. Radio-tracked *C. lathami* in Southport – grouped by (a) day and (b) activities
Map: Australian Bureau of Statistics

Although little radio-tracking was completed, much data was collected from general observations on *C. lathami* feeding and movements. In areas containing abundant cone-bearing *A. littoralis*, *C. lathami* were observed to return daily: feeding, drinking and roosting in a predictable pattern,

enabling easy location of birds. Many groups studied also had juveniles, the clearly audible begging allowing easy tracking of the family group — chicks could be heard ~100 m away.

Birds were monitored in Southport for approximately one year. Four groups were regularly seen: 2 breeding pairs, 1 non-breeding pair and a bachelor pair (1 adult male with a juvenile male). For approximately 14 months there was at least one group of *C. lathami* on the university campus at any time. As discussed below, the radio-tracked bird did not appear healthy; therefore, no further trapping was attempted at this site. No trapping was attempted at drinking sites, since it was not predictable which individual birds would be trapped (i.e. could not guarantee that it would not be the previously trapped bird); nor at feeding sites, as these locations were not suitable for mist-netting due to roads, canopy heights, etc.

Similar results to the daily *C. lathami* movements in Southport were observed at Nerang State Forest (Nerang, Gold Coast, Queensland). *A. littoralis* grows alongside the road (extends beyond Yarrayne road, see Figures 44 and 45), following a small gully. *C. lathami* started off near the southern entrance to the State Forest (Yarrayne Road) and literally progressed further along the road as they stripped trees, enabling easy location of the birds. *C. lathami* were studied in the area between August and October 2004.

The birds were thought to be drinking at two sites near houses. There is a series of creeks in the area but all were completely dry during this period. In the evening, *C. lathami* groups congregated near houses and were either did not drink (although this is unlikely given the hot weather at the time) or drank from artificial water bodies on private property.

Feed trees, probable drinking sites and roosting sites were all within an area of just 0.18 km². There was a maximum distance of 500 m between feed trees and drink/roosting sites (Figure 45).

Calyptorhynchus lathami fed intensively in this section of Nerang State Forest in 2000 and again in 2004. In 2004, *C. lathami* (8 birds) were easily found as they were feeding in the same area every day, often feeding in the same tree all day.



Figure 44. Nerang State Forest monitoring area: aerial photography showing vegetation and development
Source: Google Earth. Image © 2012 Whereis® Sensis P.L. Image date 2 March 2003, courtesy NASA

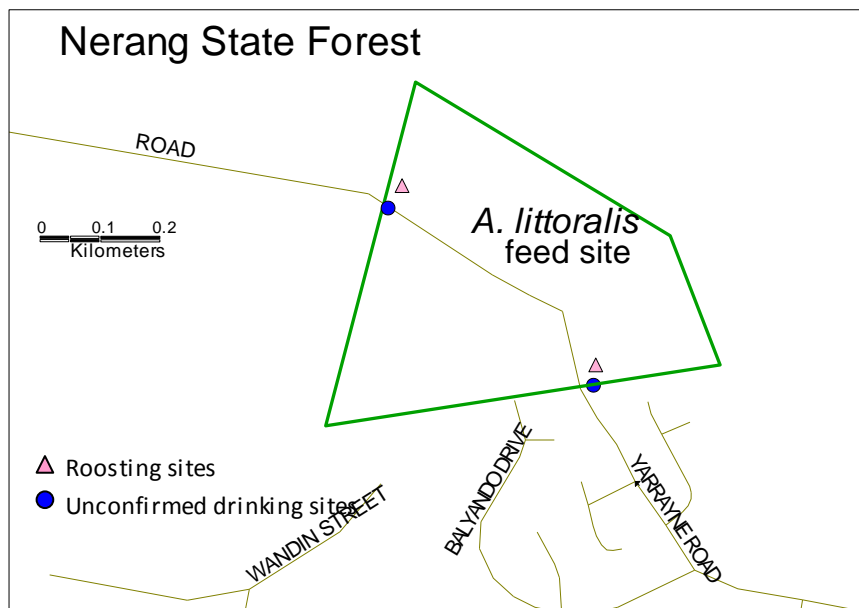


Figure 45. *Calyptorhynchus lathami* feeding habitat in Nerang State Forest
Source: Gold Coast City Council, "Gold Coast region and streets"

4.3.5.1 Physical Attributes of Radio Tracked Bird

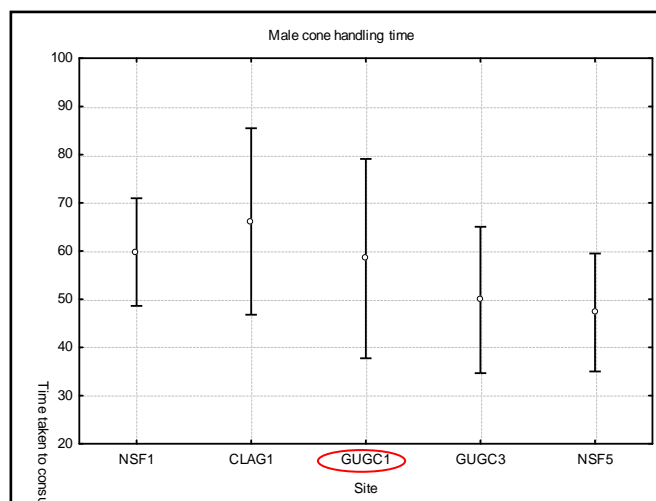
One adult breeding male was tracked for four days between 2 and 6 March 2005. It was anticipated that more birds would be caught, and their physical attributes recorded and compared, allowing for baseline data on expected wild *C. lathami* health. Unfortunately this could only be done for a single bird (Table 46).

Table 46. Radio tracked *C. lathami* - physical details

Details	Description
Family	Breeding pair with juvenile
Sex	Male
Date banded	01-02 March 2005
Location trapped	Olsen Ave (opposite Griffith University) – drinking site
Location released	Corner of Olsen and Parklands Dr (GU) – roosting site
Weight	396 g
Wing length	33.25 cm
Bill length	47.2 mm
Tarsus	27.7 mm
Tail length	22.8 cm
Heart beat	168/min
Respiration	16
Age	no barring (5+), worn feet, wings and beak*

* Degree of wear would suggest an old bird but no comparison available to better age the bird

The veterinarian’s opinion of the bird’s overall health was that it was in poor condition and underweight. It is reported in Chapter 3 that breeding birds (male and female) fed faster than non-breeding birds, most likely to overcome additional feeding requirements to regurgitate for the juvenile: the demands of breeding may, at least in part, account for its condition. Both cocks and hens were observed regurgitating for juveniles. Comparing this male to other breeding males, there is no significant difference in his feeding time (Figure 46, $p = 0.39$).



Radio-tracked bird

Figure 46. Comparison of feeding rates between breeding males (ANOVA, overall $p = 0.39$; means and 95% confidence intervals)

4.4 DISCUSSION

4.4.1 Morphological Characteristics

Individual *C. lathami* family groups were identified using morphological features of the female. Unusual colouration of some females facilitated identification. Pepper (1996) and Joseph (1984) state that female adults always have at least some bars on the tail panel (i.e. at least have proximal barring), and are usually fully barred. Joseph (1984) determined that in birds with only proximal barring, the barring would not be detected from field observations, particularly since females do not display, resulting in incorrectly describing the individual as having no barring. Therefore, it is quite possible that the females observed here with no apparent barring may have had proximal barring.

Spots on wings, ear coverts and/or breasts are characteristic of juvenile *C. lathami* (up to 18 months (Joseph 1984, Courtney 1986)), but are retained by some adult females (Courtney 1986 – up to 5 years, QDEH 1993). Courtney (1986) concludes that spotting and barring in *C. lathami* is highly variable subsequent to evolutionary divergence from *C. banksii*. Previous studies investigating the evolutionary history and phylogenetics of cockatoos in Australia have shown that *C. lathami* and *C. banksii* (previously *C. magnificus*) are distinct from the other Black-cockatoos (*C. funereus*, *C. latirostris*, *C. baudinii*), but there is little detailed information about the divergence within the Red-tailed Black-cockatoo subgroup (Brown and Toft 1999, White *et al.* 2011), except a passing reference by Adams *et al.* (1984) to the “four allopatric subspecies of *C. magnificus*”. In parts of their range where all three species coexist, such as in southeast Queensland, it is conceivable that, as a result of these morphological variations, a novice could easily incorrectly identify some individuals of *C. lathami* as *C. funereus* or *C. banksii*.

4.4.2 Drinking

Three of the known regular and long-used drinking sites were completely dry in 2004. Obviously, there are other available water sources, including artificial water bodies, which would have provided accessible drinking sources, but the sites studied here were known regular *C. lathami* drinking sites (at least outside of periods of drought), indicating that water availability may be a limiting factor. Stock and Wild (2005), found significantly more sightings of *C. lathami* during winter than summer, and hypothesised that *C. lathami* movement may be dependent on water availability, their dispersion increasing during the wet season when water is more readily available. Cameron (2005) has shown that *C. lathami* form larger groups when resources are

limited, and that food availability is be linked to rainfall patterns and hence water distribution. Furthermore, drought can also affect the breeding performance of the species (Cameron 2009).

4.4.3 Nesting

Very little information was able on the nesting habitat of *C. lathami*. All three known nests were in tall trees with large diameters, but with nesting hollows facing different directions. Two of the hollows were in vertical spouts, reported by Cameron (2004, 2006) to be the preferred hollow type.

The nesting trees were all in different vegetation types, with one nest tree in a cleared paddock that offered very little protection against other birds and the effects of the weather. Two of the three known nest trees were dead (snags), whilst the third was still alive with abundant foliage (although in the absence of flowers, its species could not be determined). Although less abundant than live trees with hollows, snags have been shown to be preferred by *C. lathami* (Cameron 2006). All three known nests were in close proximity to a water source (two of which are known drinking sites, the third is unconfirmed as such but there is a small creek considered a potential drinking source) and known feed trees. The Kangaroo Island studies have shown that, due the tight energy budget when breeding, it is essential that nests be within close proximity to drinking and feeding resources. It has been reported that, while breeding, *C. lathami* can fly no more than 12 km a day between their feeding, nesting and drinking sites to retain a positive net energy balance (Crowley *et al.* 1996, Pepper 1996, Garnett *et al.* 1999).

Only 20% success rate for nesting has been observed on the Gold Coast (1 in 5 attempts — but with such limited data the 95% confidence limits on the actual fraction as very wide — 0.005 to 0.72). Similar results were found on Kangaroo (23% success rate), but this increased to 42% when nests were protected against brush-tail possums (*Trichosurus vulpecula*) (Garnett *et al.* 1999).

4.4.4 Radio-Tracking

Observations of *C. lathami*, through radio-tracking, incidental observations and other studies (Chapman 2005) have indicated that *C. lathami*, at any one time, need only a small area, as long as they have suitable drinking, nesting/roosting and abundant feed trees. It was observed here that the family of *C. lathami* being radio-tracked in Southport in 2005 were flying less than 1 km each day, travelling between feed, drinking and roosting sites. The area being used covered approximately 1 km², sufficiently feeding 10 birds (4 family groups) for approximately a year. On

Kangaroo Island, however, in one instance, *C. lathami* were observed travelling 3 km between feed and roosting sites (Crowley *et al.* 1998, Chapman and Paton 2005).

4.4.4.1 Distance Travelled

The preliminary observations on daily movement patterns suggest that *C. lathami* on the Gold Coast do not travel very far, both within and between feed sites, a situation similar to that on Kangaroo Island (Chapman 2005). The present study was unable to show that *C. lathami* were travelling large distances (i.e. moving distant from the Gold Coast), and birds are seen year round.

Identifying individual birds has determined that several groups of *C. lathami* were seen repeatedly (i.e. at two different locations at different times). Distances between these sites ranged between 6 and 16 km. Sightings suggest that Group 1 had finished feeding at Nerang State Forest and then moved to Bonogin, a distance of approximately 16 km. The other two instances were not from consecutive feed locations, but one of the reports of Group 15 was a drinking observation in January. This time of year is normally the wet season, when it was thought that *C. lathami* might disperse from the Gold Coast to inland food sources. At the time, though, there was low rainfall, reducing the availability of water sources for *C. lathami*, possibly restricting any potential dispersal. This drink site was at a dam which, through observations in the study region, is not a preferred water body type; typically being utilised when nearby preferred creeks and other small water sources are dry, as was the case at time of this report.

4.4.4.2 Morphological Features of Radio-Tracked *C. lathami*

Although little is known about the health of wild *C. lathami*, the veterinarian who inspected the bird considered the male to be undernourished. The bird weighed only 396 g, while typical adult male weight is 420 - 430 g (Forshaw and Cooper 1981, Marchant and Higgins 1990). Cocks were observed regurgitating for juveniles, which may potentially result in weight loss, but other parenting cocks observed in the field did not display evident signs of poor health. Relatively few data were collected on feeding rates for males with juveniles, but examination of these data (Figure 46), revealed that the feeding efficiency of the collared male is similar (if not better), than the other males with juveniles, yet these other birds appeared healthier. If anything, the juvenile of the radio-tracked bird appeared to be older (in terms of feeding efficiency, level of begging and plumage) than the other juveniles seen in this study, therefore, theoretically, would be less dependent on parental regurgitation. The cock's feet and beak displayed signs of severe wearing, typical of older birds, and therefore may be towards the end of his suitable breeding age.

4.4.5 Distribution of *C. lathami* Requirements on the Gold Coast

As outlined in the literature review, other studies (Garnett *et al.* 1999, Garnett 1997 etc.) have shown that *C. lathami* has three strict habitat requirements: drinking sites, hollows for nests and *Allocasuarina* feed trees. It has also been observed that the abundance and distribution of these in relation to each other is extremely important, having a major impact on *C. lathami* breeding success. In the study region all three of the known nests are close to feed trees and a drinking site — although while nest 3 is only 30 m from a creek, the nest was not active during the study period, and it was not confirmed if this site was actually used as a drinking site during nesting. Over a nine-year period, nest 1 was used three times by *C. lathami*, but none of these events is known to have resulted in a fledging: each time the hen had been harassed by Sulphur-crested Cockatoos and the nest was apparently abandoned for the season.

The combined effect of total loss of areas to development (e.g. Figures 42 and 44), with temporary losses due to drought/fire and the slow replenishment of recent previous *C. lathami* feed sites, is expected to have a significant effect on the long-term population, including noticeable fluctuations in population size and distribution. The highly specialised habitat requirements of *C. lathami* are expected to increase the species' risk of extinction, from ongoing habitat loss and fragmentation, as predicted by Owens and Bennett (2000) for birds in general. As is widely reported, *Calyptorhynchus lathami* not only have a restricted diet (Clout 1989, Pepper *et al.* 2000, Crowley and Garnett 2001, Cameron and Cunningham 2006), but are also obligate hollow nesters (Marchant and Higgins 1990, Cameron 2006). Either one, or a combination, of these resources may be limiting for *C. lathami* on the Gold Coast where urbanisation continues to remove remnant habitats. For example, the ongoing clearing of natural habitats since European colonisation has resulted in major declines in the abundance of hollow-bearing trees (Gibbons and Lindenmayer 2002).

4.5 REFERENCES

- Adams, M., Baverstock, P.R., Saunders, D.A., Schodde, R. and Smith, G.T. 1984. Biochemical systematics of the Australian cockatoos (Psittaciformes: Cacatuinae). *Australian Journal of Zoology*. **32**: 363-377.
- Anonymous. 2002. *Sightings and Records*. Unpublished report of the Wildlife Preservation Society of Queensland, Glossy Black-cockatoo Branch Inc., Gold Coast.
- Arroyo, B. and Bretagnolle, V. 1999. Field identification of individual Little Bustard *Tetrax tetrax* males using plumage patterns. *Ardeola*. **46**: 53-60.
- Bretagnolle, V., Thibault, J.C. and Dominici, J.M. 1994. Head patterns allow field identification of individual Ospreys. *Journal of Wildlife Management*. **58**: 175-178.
- Brown, D.M. and Toft, C.A. 1999. Molecular systematics and biogeography of the cockatoos (Psittaciformes: Cacatuidae). *The Auk*. **116**(1): 141-157.
- Cameron, M. 2004. Ecology of the Glossy Black-cockatoo (*Calyptorhynchus lathami*) in central New South Wales. PhD Thesis. University of New England. Armidale. 168 pp.
- Cameron, M. 2005. Group size and feeding rates of Glossy Black-Cockatoos in central New South Wales. *Emu*. **105**: 299-304.
- Cameron, M. 2006. Nesting habitat of the glossy black-cockatoo in central New South Wales. *Biological Conservation*. **127**: 402-410.
- Cameron, M. 2009. The influence of climate on Glossy Black-cockatoo reproduction. *Pacific Conservation Biology*. **15**: 65-71.
- Cameron, M. and Cunningham, R. B. 2006. Habitat selection at multiple spatial scales by foraging Glossy Black-cockatoos. *Austral Ecology*. **31**: 597-607.
- Chapman, T. 2000. Fussy Black Cockatoo. *Nature Australia*. **26**(7): 49-55.
- Chapman, T.F. 2005. *Cone production by the Drooping Sheoak Allocasuarina verticillata and the feeding ecology of the Glossy Black-cockatoo Calyptorhynchus lathami halmaturinus on Kangaroo Island*. PhD Thesis. University of Adelaide. Adelaide. 124 pp.
- Chapman, T.F. and Paton, D.C. 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.
- Cleland, J.B. and Sims, E.B. 1968. Food of the Glossy black-cockatoo. *South Australian Ornithologist*. **25**: 47-52.
- Clout, M. 1989. Foraging behaviour of Glossy black-cockatoos. *Australian Wildlife Research*. **16**: 467-473.
- Courtney, J. 1986. Plumage development and breeding biology of the Glossy black-cockatoo. *Australian Bird Watcher*. **11**: 261-273.
- Crowley, G., Garnett, S. and Pedler, L. 1996. *Assessment of the role of captive breeding and translocation in the recovery of the South Australian subspecies of the Glossy black-cockatoo Calyptorhynchus lathami halmaturinus, Kangaroo Island, South Australia*. Report prepared for the South Australian Glossy black-cockatoo Recovery Team,. 40 pp.

Chapter 4 — Field Observations

- Crowley, G., Garnett, S., Meakins, W. and Heinrich, A. 1998. *Protection and re-establishment of glossy black-cockatoo habitat in South Australia: Evaluation and recommendations, Kangaroo Island*. Report prepared for the Glossy black-cockatoo Rescue Fund, South Australian National Parks Foundation. 45 pp.
- Crowley, G.M. and Garnett, S.T. 2001. Food value and tree selection by glossy black-cockatoos *Calyptorhynchus lathami*. *Austral Ecology*. **26**: 116-126.
- Forshaw, J. and Cooper, W. 1981. *Australian Parrots 2e*. Lansdowne Press, Melbourne. 312 pp. ISBN 0701810351.
- Garnett, S. 1993. *Threatened and extinct birds of Australia*. Royal Australian Ornithologists Union Victoria. 212 pp. ISBN 0008158012.
- Garnett, S. 1997. *Conservation plan for the Gold Coast population of Glossy black-cockatoos (Calyptorhynchus lathami)*. Unpublished Report, Gold Coast. 6pp.
- Garnett, S.T., Crowley, G.M., Dennis, T.E. and Chapman, T.F. 1997. *Recovery Plan for the South Australian subspecies of the Glossy black-cockatoo (Calyptorhynchus lathami halmaturinus) Kangaroo Island, South Australia*. Unpublished report to the Threatened Species and Communities Section, Environment Australia, 16pp.
- Garnett, S.T., Crowley, G.M., Pedler, L.P., Prime, W., Twyford, K.L. and Maguire, A. 2000. *Recovery Plan for the South Australian subspecies of the Glossy Black Cockatoo (Calyptorhynchus lathami halmaturinus) Kangaroo Island, South Australia: 1999-2003. ver 3.0*. Unpublished report to the Threatened Species and Communities Section. Environment Australia.
- Garnett, S.T., Pedler, L.P. and Crowley, G.M. 1999. The breeding biology of the glossy black-cockatoo *Calyptorhynchus lathami* on Kangaroo Island, South Australia. *Emu*. **99**: 262-279.
- Gibbons, P. and Lindenmayer, D.B. 2002. *Tree Hollows and Wildlife Conservation in Australia*. CSIRO Publishing, Victoria. 240pp. ISBN 0643067059.
- Jackson, R.M., Roe, J.D., Wangchuk, R. and Hunter, D.O. 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. *Wildlife Society Bulletin* **34**(3): 772-781.
- Joseph, L. 1982. The glossy black cockatoo on Kangaroo Island. *Emu*. **82**: 46-9.
- Joseph, L. 1984. Some notes on the plumage phases of the glossy black cockatoo. *Corella*. **8**: 16-18.
- Joseph, L. 1989. The glossy black cockatoo in the South Australian Mount Lofty Ranges. *South Australian Ornithologist*. **30**: 202-204.
- Marchant, S. and Higgins, P.J. (eds) 1990. *Handbook of Australian, New Zealand and Antarctic Birds vol. 1*. Royal Australasian Ornithologists' Union and Oxford University Press, Oxford. 1048pp. ISBN 0-19-553244-9.
- Mazzoil, M., McCulloch, S.D., Defran, R.H. and Murdoch, E.M. 2004. Use of Digital Photography and Analysis of Dorsal Fins for Photo-Identification of Bottlenose Dolphins. *Aquatic Mammals*. **30**: 209-219.
- Morcombe, M. 2000. *Field Guide to Australian Birds*. Steve Parish Publishing Australia. 448 pp. ISBN 187628210X.
- Oertel, A.S. 1998. *Use of small eucalypt forest remnants by birds in southeast Queensland*. BSc (Hons) Thesis. Australian School of Environmental Studies. Griffith University, Brisbane. 103 pp.

- Owens, I.P.F. and Bennett, P.M. 2000. Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences of the United States of America*. **97**(22): 12144-12148.
- Paltridge, A. 1994. *The feeding and nesting resources of the glossy black cockatoo Calyptorhynchus lathami halmaturinus on western Kangaroo Island, South Australia*. BSc (Hons) thesis. University of Adelaide, Adelaide. 66 pp.
- Pedler, L.P. 1995. *Glossy black-cockatoo Recovery Plan, Kangaroo Island, South Australia*. Unpublished Progress report.
- Pepper, J.W. 1996. *The behavioural ecology of the Glossy black-cockatoo Calyptorhynchus lathami halmaturinus*. PhD Thesis. University of Michigan. Michigan. 307 pp.
- Pepper, J.W. 1997. A survey of the South Australian glossy black cockatoo (*Calyptorhynchus lathami halmaturinus*) and its habitat. *Wildlife Research*. **24**: 209-223.
- Pepper, J.W., Male, T.D. and Roberts, G.E. 2000. Foraging ecology of the South Australian glossy black-cockatoo (*Calyptorhynchus lathami halmaturinus*). *Austral Ecology*. **25**: 16-24.
- QDEH. 1993. Glossy Cockatoo *Calyptorhynchus lathami*. Queensland Department of Environment and Heritage, Brisbane. pp 11-14.
- Schodde, R., Mason, I.J. and Wood, J.T. 1993. Geographic differentiation in the Glossy black cockatoo. *Emu*. **93**: 156-166.
- Stock, M.J. and Wild, C.H. 2005. Seasonal variation in Glossy Black-Cockatoo sightings on the Gold Coast. *Corella*. **29**: 94-96.
- White, N.E., Phillips, M.J., Gilbert, M.T.P., Alfaro-Núñez, A., Willerslev, E., Mawson, P.R., Spencer, P.B.S. and Bunce, M. 2011. The evolutionary history of cockatoos (Aves: Psittaciformes: Cacatuidae). *Molecular Phylogenetics and Evolution*. **59**: 615-622.
- Whitehouse, A.M. and Hall-Martin A.J. 2000. Elephants in Addo Elephant National Park, South Africa: reconstruction of the population's history. *Oryx*. **34**: 46-55.
- Whitford, K.R. 2002. Hollows in jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) trees. I. Hollow sizes, tree attributes and ages. *Forest Ecology and Management*. **160**: 201-214.

5 OVERALL DISCUSSION AND RECOMMENDATIONS

5.1 DISCUSSION

This research was completed to provide: (i) base-line population data on *C. lathami* on the Gold Coast, as well as (ii) an indication of how the species utilises available habitats and resources. Previously, insufficient data were available on this bird's abundance and distribution to enable a comprehensive regionally-appropriate management plan to be compiled for the species. While *C. lathami* on the Gold Coast appear to be foraging in a manner consistent with an optimal foraging strategy (Charnov 1976, Perry and Pianka 1997), this is clearly in response to forage availability. Food abundance and quality are important determinants in influencing feed tree choice by *C. lathami* (Crowley and Garnett 2001, Cameron and Cunningham 2006), and certainly influence habitat use on the Gold Coast.

The results indicate that, during the study period, there were only a few feeding sites across the Gold Coast at any one time, with most sites being *currently* unsuitable. The apparent shortage of active foraging sites during the study period would infer that the population of *C. lathami* in the region is limited by their food supply. This finding supports that of Cameron (2009) but it should be noted that food availability is linked to climatic conditions, and rainfall in particular (Cameron 2005). It is therefore imperative that this study is repeated in the short-term, in order to determine if the population size has changed, as the estimates in themselves are of little value in providing a measure of numerical abundance (Engeman 2005). Replicating the population estimation measures using 'chewings' on the Gold Coast, but also in neighbouring regions, will enable future assessments of trends within the local and regional populations.

Repeated surveys of the distribution, presence/absence and relative abundance of the forage resources (i.e. *Allocasuarina* feed trees) is also required. As highlighted in Chapter 3, the estimates derived from *C. lathami* feeding evidence require further surveys to link confidently these estimates to actual population density. Nevertheless, it does appear that the *C. lathami* population on the Gold Coast may be at the lower limit threshold for an effective minimum population (Traill *et al.* 2010), highlighting that this species may indeed be in need of conservation intervention. Future forage assessments will confirm whether limited food presents a continuing threat to the species, as this may be a factor contributing to the decline of the population. While it has been demonstrated that highly specialised bird species face greater extinction risks from the loss of habitat (Owens and Bennett 2000, Purvis *et al.* 2000), this pattern is less clear for dietary specialists (Safi and Kerth 2004). Should future surveys not detect any significant change within forage resources, the dynamics of *Allocasuarina* and *Casuarina* feed

species in southeast Queensland may simply represent multiple stable states (Sutherland 1990) that are influenced at various times by drought, wild-fires and ongoing habitat clearing and recovery. Fire, in particular, has been shown to be a driving factor in transitions from one ecological community to another (Westoby *et al.* 1989, van Wilgen *et al.* 2003, Noble *et al.* 2007). It is therefore conceivable that a large percentage of casuarinas are always going to be unavailable to *C. lathami*, and that the *C. lathami* population has adapted to these fluctuating resources, reflecting a sustainable population that is able to utilise the resources that are available.

Since it does seem that *C. lathami* are restricted to a few areas on the Gold Coast at any one time, it would be advantageous to be able to predict where they will go. Intensively foraged areas were observed in stands of *Allocasuarina* growing in soils with low clay content in the Horizon A, as well as containing at least several large mature trees supporting abundant cones. Furthermore, Cameron and Cunningham (2006) have also shown that forage profitability differs both amongst feed tree species as well as with individual trees within a species. Unfortunately, since the number of cones changes over time, the feeding status of trees or areas is not stable, and therefore future foraging status cannot be predicted, especially since *Allocasuarina* were shown to have a poor survival rate during periods of drought stress. This information, though, can potentially help locate *C. lathami* in future studies by eliminating areas that have low cone abundance and are clearly ‘not currently suitable foraging areas’ and focusing fieldwork in areas containing high cone abundance where it is more likely that birds will be located.

Unfortunately, even though radio-tracking proved difficult in this study, but the information that could potentially be collected by this means on *C. lathami* movements and distribution would make this project worth pursuing. An extensive census covering a larger area of both known presence and absence locations in the future would prove invaluable in terms of determining a better estimate of the population size, which can then be related back to the amount of food resources available on the coast. The information gained from an extensive census may also make radio-tracking more achievable. Ultimately, long-term radio-tracking could clarify the movements of *C. lathami* in southeast Queensland. Already the preliminary observations from this study have shown that when the suite of resource requirements of *C. lathami* are met (i.e. forage, nesting and drinking sites), they travel less than a kilometre a day. Further research is required to determine how these movement patterns would change under times of resource limitation. As discussed in section 3.3.1, after a fire at Boonah, some 70 km away, more birds were reported on the Gold Coast. It is unclear whether they were the same birds, nor how often or regularly they travel between the Coast and Boonah. It may be that they travel regularly, or only when their resources are unusually depleted. These are all questions for future research to gain a better understanding of the site fidelity of local *C. lathami* populations within the broader regional landscape.

The *C. lathami* studied here spent $\frac{2}{3}$ of daylight hours feeding, with the remaining time spent socialising, flying and drinking. This is largely consistent with previous research (Clout 1989, Pepper 1996), with only Chapman and Paton (2005) suggesting that foraging does not comprise the bulk of daily activity budgets. This highlights potential regional variability within *C. lathami* and that this may be a function of behavioural, physiological, or environmental cues. Typically, the capacity of a species to allocate time to socialising and other activities, as opposed to maximising feeding, may indicate a surplus of adequate food resources. Low sightings of nesting activity on the Gold Coast may indicate that there are sufficient food resources for non-breeding birds but perhaps not breeding birds, therefore nesting resources rather than food resources may be limiting the population, if the population is in fact limited. Although *C. lathami* nesting was only a small part of this study, and only three nests are known, many more potential nesting hollows with no confirmed nesting activity were observed during this study. It is matter of considerable concern that only 1 of the 5 nesting events observed resulted in a fledgling. More research is needed on nesting potential and success on the Gold Coast to determine if there is sufficient availability of suitable nest hollows, and if competition and/or nest predation is the reason why so little nesting activity and success was observed.

As a result of drought during the study period, many commonly-used *C. lathami* drinking sites were dry or only consisted of mostly stagnant pools. Since many birds were, nonetheless, observed to be evidently permanent residents in the study area, it is believed that they may drink from artificial water sources. There have been a few popular reports of this occurring. While there may be adequate water sources for non-breeding birds, the need for reliable drinking sites near to suitable nesting sites may prevent birds from breeding, if drinking sites are limited. Unconfirmed reports of drinking from bird baths on private property suggest that non-breeding birds have access to reliable year-round water, but such properties tend to contain ornamental plants rather than large, old eucalypts etc., which would provide breeding hollows. Thus, more urbanised areas may be suitable for non-breeding birds, but lack hollows necessary for breeding.

This study was able to provide base-line data to enable future monitoring of the population on the Gold Coast, but more study into movements of *C. lathami* is required. The following is a list of recommendations for the conservation of *C. lathami*.

5.2 RECOMMENDATIONS

The following recommendations are based on the fact that the majority of field sites studied currently had little to no feeding potential, highlighting the importance of maintaining *Allocasuarina* where possible. The formal conservation status of *C. lathami* is ‘vulnerable’, but there is no declared status for *Allocasuarina*, other than the Vegetation Management Act, which prevents the destruction of trees that are in excess of 4m in height, and/or circumference exceeding 40cm (DBH ~ 1.3m). Environmental considerations to underpin management plans in terms of *C. lathami* need account for a number of important points:

1. Loss of habitat from development – the importance of individual areas need to be assessed as part of the “entire Gold Coast habitat”, especially since residential areas support only a few trees. Clear-felling for development may mean the loss of key feed areas with little ability for regeneration. Furthermore, monitoring of *Allocasuarina* trees to determine the stability of the feeding status indicated poor survival rates during the few years investigated.
2. Temporary loss of habitat from fire management – even though ‘low intensity’, prescribed (hazard reduction) burns are likely to cause *Allocasuarina* to shed their seeds, resulting in the area being unsuitable as a foraging site for *C. lathami* for a number of years. A fire management plan needs to assess areas in terms of the “entire Gold Coast” to ensure that not all key foraging sites are burnt simultaneously.

More intense fires can also result in over-dense, even-aged stands of unthrifty *Allocasuarinas*. This study indicated that these stands are of little food value to *C. lathami*, due to subsequent low cone production as a result of competition-induced growth preventing reproduction. It is not known whether culling of trees will enhance cone production in terms of providing more resources to remaining trees.

Since hazard-reduction burns are generally of low intensity, they should not be hot enough to kill trees, except for seedlings. Therefore a fire regime needs to be a minimum of 3 years apart to allow time for cones to replenish. Since heat causes trees to shed their seeds, if the tree is still healthy and environmental conditions are suitable, the tree will flower the following season, but it will be at least another year before the trees have mature cones potentially suitable for *C. lathami*. Furthermore, this study has shown that *C. lathami* are preferentially forage on trees with abundant cones, so the area needs time to replenish cones, and since cones are retained, this may take a few years.

3. The importance of an area as a major foraging site needs to be investigated, over the long term. Any previous foraging history makes the site a potential future foraging site (i.e. the

trees are known to be palatable due to previous feeding, and an increase in cone abundance over time will again make the site a future suitable foraging site).

4. Due to the high incidence of unsuitable sites, an apparently suitable area needs to be treated as an important foraging area, including in parks and backyards. Residential areas containing a few isolated trees have proven to be important feeding areas. In some rural-residential sites *C. lathami* have returned repeatedly and chews number in the thousands — such sites therefore need to be retained.
5. Need to ensure recruitment and retention of apparently suitable feed trees:
 - i. It appears that trees most likely to be *current* feed trees are those mature trees (average DBH ~14 cm and height ~12 m) bearing abundant, soft, brownish cones.
 - ii. It is shown that foraged sites occurred on soils with lower clay content in Horizon A, compared to non-foraged sites.
 - iii. Feed trees may have traits that have some genetic determination; therefore seeds from known feed trees are preferable for regeneration purposes.
 - iv. Since a high percentage of sites investigated were currently not suitable foraging areas, planting and regeneration of disturbed *Allocasuarina* areas is important in terms of providing future potential feed areas.
 - v. It is important to preserve existing feed trees, and those that have the characteristics of a potential feed tree, but it is also critically important to ensure a supply of future feed trees by nurturing and protecting sufficient (large) numbers of young trees that will mature into feed trees in due course.
6. Some of the birds studied were seen on multiple occasions at different times of the year at different locations on the Gold Coast (see section 4.3.1). This may mean that these birds are permanent residents. It is not clear how this observation relates to the numerous birds and groups seen only once. They may have been difficult to find because they had travelled further, perhaps out of the study region. Radio-tracking will aid in identifying the range of more mobile *C. lathami* and in identifying major drinking and nesting habitat. This will help determine whether the Gold Coast is able to provide *C. lathami* habitat requirements for a large population or if some members are forced to be more nomadic. Although many difficulties were encountered attempting to radio-track *C. lathami* in this study, the information that would be gained from radio-tracking makes any future attempts to radio-track a valuable and worthwhile endeavour.
7. The reason for the observed low number of nesting attempts is unknown. Low availability of hollows, and competition for these, is suspected, but requires further investigation. Hollow-bearing trees should be retained in all possible instances, in recognition of their

essential value to many species including *C. lathami*. Importantly, hollow-bearing trees occur in vegetation communities that do not provide important forage resources, highlighting that a mixture of habitats may require protection to ensure the persistence of this species on the Gold Coast.

8. It is important that no loss of habitat surrounding drinking areas occurs. Although different family groups have been observed to react differently to anthropogenic disturbances, in general *C. lathami* are little affected by disturbances at forage sites. They have been observed feeding near people and busy roads with no signs of distress. They are, however, sensitive to disturbances at drinking sites, and studies have shown *C. lathami* to ignore otherwise apparently suitable drinking sites that are too open.
9. Typically, *A. littoralis* occurs in the lowlands, with *A. torulosa* growing in the more pristine hinterland. Both species have shown to be important feed trees of *C. lathami* and thus need to be protected.

5.3 REFERENCES

- Cameron, M. 2005. Group size and feeding rates of Glossy Black-Cockatoos in central New South Wales. *Emu*. **105**: 299-304.
- Cameron, M. 2009. The influence of climate on Glossy Black-cockatoo reproduction. *Pacific Conservation Biology*. **15**: 65-71.
- Cameron, M. and Cunningham, R.B. 2006. Habitat selection at multiple spatial scales by foraging Glossy Black-cockatoos. *Austral Ecology*. **31**: 597-607.
- Chapman, T.F. and Paton, D.C. 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.
- Charnov, E.L. 1976. Optimal foraging, the marginal value theorem. *Theoretical Population Biology*. **9**(2): 129-136.
- Clout, M. 1989. Foraging behaviour of Glossy black-cockatoos. *Australian Wildlife Research*. **16**: 467-473.
- Crowley, G.M. and Garnett, S.T. 2001. Food value and tree selection by glossy black-cockatoos *Calyptorhynchus lathami*. *Austral Ecology*. **26**: 116-126.
- Engeman, R.M. 2005. Indexing principles and a widely applicable paradigm for indexing animal populations. *Wildlife Research*. **32**: 203-210.
- Noble, J.C., Hik, D.S. and Sinclair, A.R.E. 2007. Landscape ecology of the burrowing bettong: fire and marsupial biocontrol of shrubs in semi-arid Australia. *Rangeland Journal*. **29**: 107-119.
- Owens, I.P.F. and Bennett, P.M. 2000. Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences of the United States of America*. **97**(22): 12144-12148.
- Pepper, J.W. 1996. *The behavioural ecology of the Glossy black-cockatoo Calyptorhynchus lathami halmaturinus*. PhD Thesis. University of Michigan. Michigan. 307 pp.
- Perry, G. and Pianka, E.R. 1997. Animal foraging: past, present and future. *Trends in Ecology and Evolution*. **12**(9): 360-364.
- Purvis, A., Gittleman, J.L., Cowlishaw, G. and Mace, G.M. 2000. Predicting extinction risk in declining species. *Proceedings of the Royal Society of London Series B*. **267**: 1947-1952.
- Safi, K. and Kerth, G. 2004. A comparative analysis of specialization and extinction risk in temperate-zone bats. *Conservation Biology*. **18**(5): 1293-1303.
- Sutherland, P.J. 1990. Perturbations, resistance, and alternative views of the existence of multiple stable points in nature. *American Naturalist*. **136**: 270-275.
- Traill, L.W., Brook, B.W., Frankham, R.R. and Bradshaw, C.J.A. 2010. Pragmatic population viability targets in a rapidly changing world. *Biological Conservation*. **143**: 28-34.
- Van Wilgen, B.W., Trollope, W.S.W., Biggs, H.C., Potgieter, A.L.F. and Brockett, B.H. 2003. Fire as a driver of ecosystem variability. In Biggs, H.C., Du Toit, J.T., and Rogers, K.R. *The Kruger Experience: ecology and management of savannah heterogeneity*. Island Press, Washington. 536pp. ISBN 9781559639811.
- Westoby, M., Walker, B. and Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*. **42**: 266-274.

6 APPENDICES

6.1 APPENDIX 1

Mathematical modelling for determining the accuracy of the non-foraged status for sites (Chapter 2)

If at feed sites 1 in each n apparently suitable trees is an actual feed tree and we go to a site where this ratio applies and evaluate k trees, the chance that all k trees would be non-feed trees as a result of chance sampling [$p(k_{non-feed})$] is:

$$p(k_{nonfeed}) = \left(1 - \frac{1}{n}\right)^k$$

If the probability that we would find a certain number of apparently suitable trees to be all non-feed is low, we would have some confidence that the proportion of actual feed trees in the area (in the quadrat and around it) is less than 1 in n . Confidence that the proportion of actual feed trees in the area is less than 1 in n is a rather weak assumption, and we might prefer to certify the site as non-feed if we had confidence that the proportion of actual fed trees was very likely less than some fraction of 1 in n . We adopted, somewhat arbitrarily, the rule that

“we would conclude that the site is non-feed if the probability that we would find k apparently suitable trees to be all non-feed trees was less than 0.05, given that the proportion of actual feed trees amongst the apparently suitable trees was one fifth of $1/n$ ”.

In order to determine k , the number of trees we must evaluate, we simply need a value for n , since the test is that:

$$\left(1 - \frac{1}{5n}\right)^k = 0.05 \quad \text{which simply rearranges to} \quad k = \frac{\log 0.05}{\log\left(1 - \frac{1}{5n}\right)}$$

At two distinct reference sites where feed trees were present, values of n were 2.9 and 5.2. Using these values in the above equation, we obtain values for k of 41.9 and 61.4 respectively.

For this research a minimum number of 60 apparently suitable feed trees were to be examined before a site could be assigned to the non-feed site category, and only if all these trees were not actual feed trees. Actual field studies showed that examination of all potential feed trees within a site was possible, since their numbers were small.

6.2 APPENDIX 2

Aging chewings by colour (Chapter 3)

Hue

Hue for both *A. littoralis* and *A. torulosa*, were mainly 5 or 7.5, but some had values of 2.5 and 10: ranging from a reddish-yellow to a yellowish-red. It seems that after a few days chewings become reddish, eventually becoming slightly more yellowish, but there seems to be no strong trend. The depth of the hue does not seem to be a good predictor of chewing age.

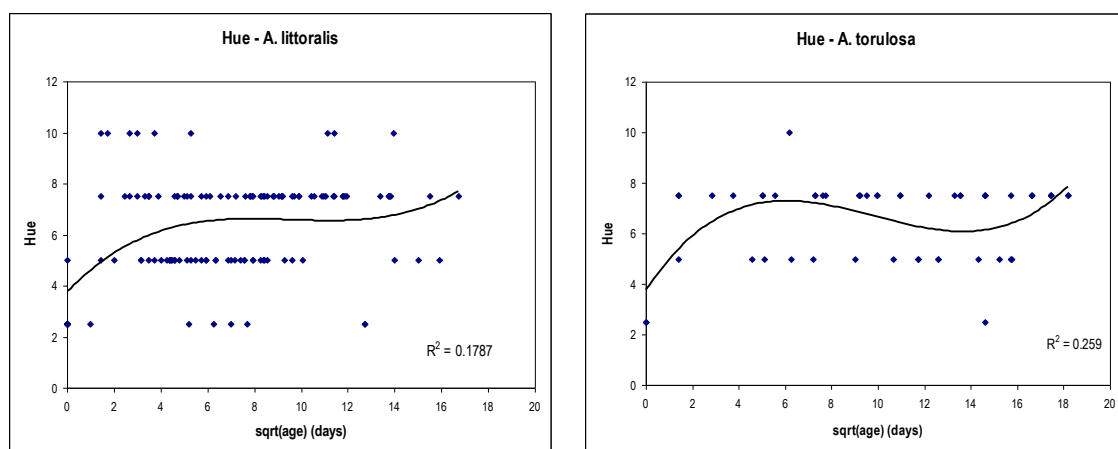


Figure 6.2.1 Scatterplot of the hue of chewings of *A. littoralis* (left) and *A. torulosa* (right)

Lightness (Munsell 'Value')

The lightness decreased steadily as chewings aged. A similar trend was observed for both *A. littoralis* and *A. torulosa*, and it is evident that lightness can give a reasonable estimation of chewings age.

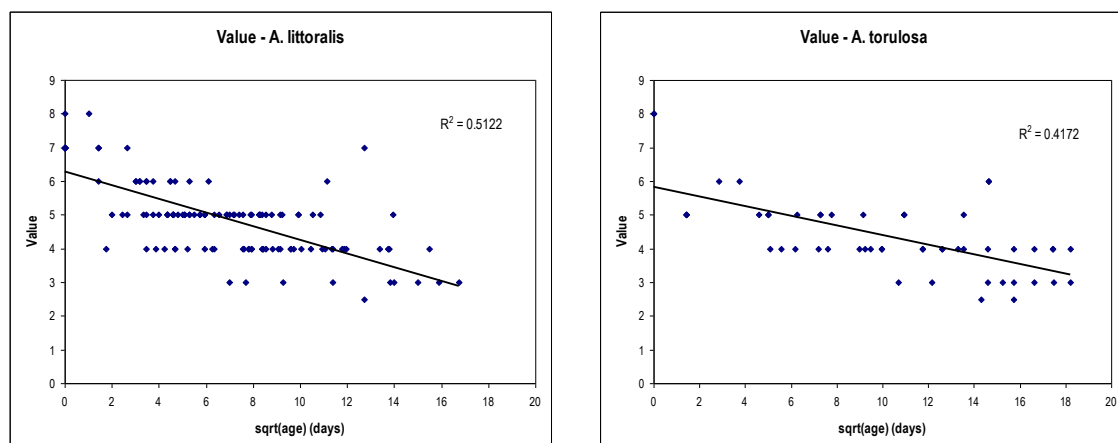


Figure 6.2.2 Scatterplot of the value of chewings of *A. littoralis* (left) and *A. torulosa* (right)

Saturation (Munsell ‘Chroma’)

The colour of chewings has a low saturation (i.e. neutral, closer to grey) when fresh, then become strongly coloured by about 14 days and gradually return to neutral with age.

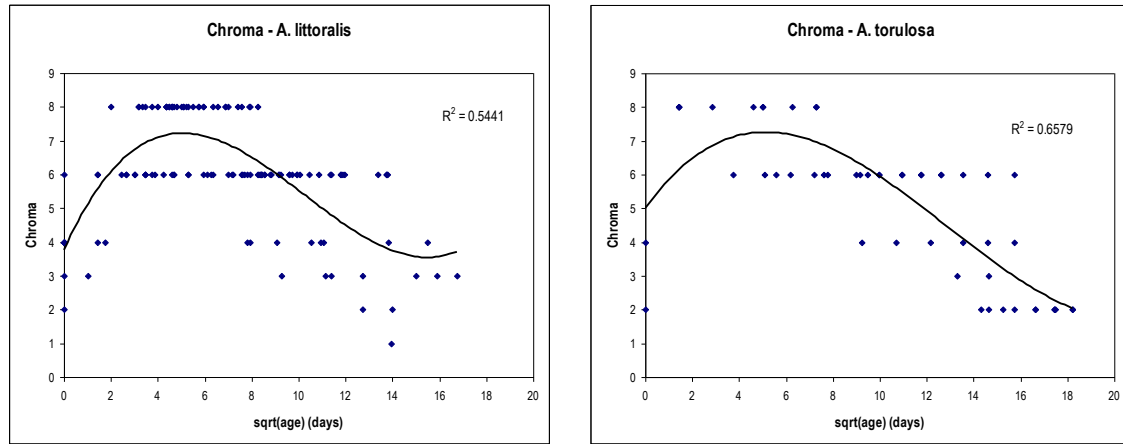


Figure 6.2.3 Scatterplot of the chroma of chewings of *A. littoralis* (left) and *A. torulosa* (right)

Table 6.2.1 Aging *A. littoralis* chewings using colour

Hue	Value	Chroma	Chewings	Value			Chroma			Mean		# Chewings × age	St. error	
				Estimate	St. error	1/st. error	Estimate	St. error	1/st. error	Weighted	Detransformed			
5	4	4	10	89.34	8.85	0.11	123.75	22.20	0.05	99.15	9831	992	14.0	
2.5	7	4	2134	12.36	11.52	0.09	0.50	0.34	2.93	0.84	0.7	1795	1.98	
10	4	6	66	89.34	8.85	0.11	88.89	7.16	0.14	89.09	7938	5862	7.96	
7.5	4	6	850	89.34	8.85	0.11	88.89	7.16	0.14	89.09	7938	75728	7.96	
5	5	6	1	47.18	5.11	0.20	88.89	7.16	0.14	64.54	4166	65	6.05	
2.5	4	8	850	89.34	8.85	0.11	30.03	2.46	0.41	42.92	1842	36482	4.66	
2.5	4	8	511	89.34	8.85	0.11	30.03	2.46	0.41	42.92	1842	21932	4.66	
2.5	4	8	2	89.34	8.85	0.11	30.03	2.46	0.41	42.92	1842	86	4.66	
2.5	5	8	850	47.18	5.11	0.20	30.03	2.46	0.41	35.60	1267	30261	3.54	
2.5	5	8	33	47.18	5.11	0.20	30.03	2.46	0.41	35.60	1267	1175	3.54	
5	5	8	511	47.18	5.11	0.20	30.03	2.46	0.41	35.60	1267	18192	3.54	
Total chewings			5818							Total	192568			
												Weighted Mean Age	33.1	days

Each row is the colour of chewings from one feeding bout from one tree

Table 6.2.2 Aging *A. torulosa* chewings using colour

Hue	Value	Chroma	Chewings	Value			Chroma			Mean		# Chewings × age	St. error	
				Estimate	St. error	1/st. error	Estimate	St. error	1/st. error	Weighted	Detransformed			
5	4	6	2921	149.50	20.27	0.05	105.24	13.76	0.07	123.13	15162	359673	16.7	
5	5	8	1218	56.36	14.32	0.07	23.00	6.34	0.16	33.23	1105	40480	9.53	
2.5	3	6	326	233.25	26.26	0.04	105.24	13.76	0.07	149.25	22275	48655	19.0	
2.5	3	6	251	233.25	26.26	0.04	105.24	13.76	0.07	149.25	22275	37386	19.0	
7.5	4	6	251	149.50	20.27	0.05	105.24	13.76	0.07	123.13	15162	30845	16.7	
5	3	3	569	233.25	26.26	0.04	195.50	18.50	0.05	211.10	44564	120117	22.0	
5	3	4	200	233.25	26.26	0.04	165.00	24.93	0.04	198.24	39298	39548	25.6	
7.5	4	6	569	149.50	20.27	0.05	105.24	13.76	0.07	123.13	15162	70063	16.7	
7.5	5	8	73	56.36	14.32	0.07	23.00	6.34	0.16	33.23	1105	2426	9.53	
10	3	4	267	233.25	26.26	0.04	165.00	24.93	0.04	198.24	39298	52882	25.6	
7.5	5	8	7371	56.36	14.32	0.07	23.00	6.34	0.16	33.23	1105	244977	9.53	
5	4	6	990	149.50	20.27	0.05	105.24	13.76	0.07	123.13	15162	121902	16.7	
7.5	5	8	1902	56.36	14.32	0.07	23.00	6.34	0.16	33.23	1105	63213	9.53	
7.5	4	6	360	149.50	20.27	0.05	105.24	13.76	0.07	123.13	15162	44266	16.7	
7.5	5	8	360	56.36	14.32	0.07	23.00	6.34	0.16	33.23	1105	11948	9.53	
Total chewings			17625							Total	1288381			
											Weighted Mean Age	73.1	days	

Each row is the colour of chewings from one feeding bout from one tree

6.3 APPENDIX 3

Rate of chewing loss (Chapter 3)

The logic behind the estimation of total birds based on chewings.

Let the total habitat area be At (509,800,000 m²) and the total area sampled be As (141 sites × 1200 m² per site = 172 800 m²).

Let Td chewings be deposited per day across the entire habitat area, and they remain visible in the field for exactly Li days.

Thus at any one time there will be $Td \times Li$ chewings in the entire habitat area.

When sampling is done Ts chewings will be found in the As area sampled ($Ts = 47,901$ or $17,625$ for *A. littoralis* and *A. torulosa* respectively).

Thus:

$$\frac{T_s}{T_d \times Li} = \frac{A_s}{A_t}$$

And so:

$$T_d = \frac{T_s \times A_t}{Li \times A_s}$$

We have a problem with Li , as we do not know either how long chewings remain detectable in the field, or the rate at which they disappear, but it is unlikely that they all remain detectable until at a particular age they all suddenly disappear. We do know their average age (weighted by their numbers at particular ages) and from this we can estimate Li , their longevity.

Initially, assume that all chewings do have a fixed survival period in the field. Their average age will thus be one half their maximum age, and Li will be twice their weighted average age, i.e. 2×33.1 or $2 \times 73.1 = 66.2$ or 146.2 (for *A. littoralis* and *A. torulosa* respectively).

It is more likely that the chewings will disappear progressively with time, perhaps linearly from the day they are deposited to the day that the last one is lost. Modelling this decay indicates that the maximum persistence (Li) is three times the weighted average age, and so their longevity will be $3 \times 48.3 = 145$ or $3 \times 68 = 204$ days (for *A. littoralis* and *A. torulosa* respectively). If a linear decay of chewings is assumed, the number present in the field at any time will be half $Td \times Li$ and the equation above will need to be adjusted accordingly, i.e. as:





$$T_d = \frac{2 \times T_s \times A_t}{Li \times A_s}$$

It is probable that the disappearance of chewings in the field will follow a dynamic somewhere between the two limits presented above, and so the best estimate of the number of birds will be between the two estimates produced by this logic. The estimate based on sudden and entire disappearance of chewings is 194 birds supported by *A. littoralis* and 207 by *A. torulosa*. A linear decay in identifiable chewings yields estimates of 263 birds on *A. littoralis* and 278 on *A. torulosa* (Table 40).

6.4 APPENDIX 4






Database of *C. lathami* studied on the Gold Coast (Chapter 4)




Individual birds studied (feeding rates) on the Gold Coast

Group	Sex	Distinguishing features	Locations	Dates observed	Female markings *	
1	Male	Unbarred, bill scarring (old?)	Nerang (NSF4)	23/09/2004		
	Female	Very yellow tail feathers, proximal feathers red, yellow spotting on wings and belly	Nerang (NSF2) Nerang (NSF3) Nerang (NSF7) Bonogin	04/10/2004 05/10/2004 13/10/2004 16/12/2004		
2	Male	Unbarred, missing in tail feathers	Nerang (NSF4) Nerang (NSF3)	23/09/2004 05/10/2004		
	Female	Single main yellow spot				
3	Male	No barring	Southport (GUGC)	01/02/2005		
	Female	No obvious tail barring				
	Juvenile	Yellow spots on wing				
4	Male		Southport (GUGC)	02/03/2005		
	Female	No obvious tail barring, but lots of yellow face feathers				
	Juvenile					

* The yellow face feathers on females are the most distinguishing feature identifying a group, therefore only a picture of the female has been included. Due to difficulty of height, foliage and time of day, photos are not available for all females

6 — *Appendices*

Group	Sex	Distinguishing features	Locations	Dates observed	Female markings *
5	Male		Nerang (NSF1) Gilston (GIL1)	25/08/2003	 
	Female	No obvious tail barring. Noticeably different yellow pattern of left and right side of face		07/07/2004	
	Juvenile	Observed on 25/08/03, not 07/07/04. Very large, healthy-looking bird. Some begging			
6	Male		Natural Bridge	2003	
	Female				
7	Male	Unbarred	Nerang (NSF3)	05/10/2004	
	Female				
8	Male		Natural Bridge (NUM1)	21/11/2003	
	Female	Looks quite young: distinct yellow only on left side of face			

Group	Sex	Distinguishing features	Locations	Dates observed	Female markings *
9	Male		Clagiraba (CLA2)	25/03/2005	n/a – males only
	Juvenile	Male? no yellow face feathers, no obvious spotting			
10	Male		Nerang (NSF5)	17/09/2004	
	Female				
	Juvenile	Begging for food			
11	Male		Pimpama (PIMP1)	14/09/2004	-
	Female				
12	Male	Unbarred	Gilston (GIL2)		
	Female				
13	Male	Unbarred	Bonogin (BON1)	15/12/2004	-
	Female	No obvious barring			
14	Male		Clagiraba (CLAG1)	24/02/2005	-
	Female	No obvious tail barring			
	Juvenile	Begging, some yellow face feathers			
15	Male		Guanaba Nerang (NSF6)	29/01/2003	
	Female	Obvious red tail barring. Single medium yellow patch on each side of face		12/10/2004	

6.5 APPENDIX 5**Raw data for *A. littoralis* (Chapter 3)****General site data for *A. littoralis***

Site	Feeding status	Grass understorey: % Cover	Fire	# Females	# Males	# Juveniles	# Unsexed adults	# <i>A. torulosa</i>	# Total casuarina	# Feed trees	# Apparently suitable feed trees	Total cones	Total chewings	# Pre-feeding cones
NSF1a	Foraged	100	yes	5	1	12	2	0	20	3	3	634	5042	2315
Gil1	Foraged	5	yes	37	0	0	29	0	66	12	22	3109	13825	7717
Pimp	Foraged	2	yes	2	0	5	0	0	7	2	2	740	23223	8481
AJ63	Foraged	50	yes	3	0	21	2	5	31	1	2	1470	66	1492
AC93a	Foraged	80	yes	76	0	109	79	12	276	1	5	1159	2134	1870
BG106	Foraged	20	No	26	12	6	21	0	65	3	7	822	3610	2025
AY103	Non-foraged	95	yes	4	0	1	3	1	9	0	3	390	0	390
BC68c	Non-foraged	10	yes	12	1	126	5	0	144	0	3	507	0	507
AQ34	Non-foraged	80	yes	6	2	3	1	0	12	0	3	524	0	524
BC68a	Non-foraged	40	yes	30	2	86	37	0	155	0	4	1006	0	1006
AA11a	Non-foraged	10	No	11	0	2	6	0	19	0	5	443	0	443
AA11c	Non-foraged	95	No	8	10	9	6	0	33	0	5	1584	0	1584
BC68b	Non-foraged	10	No	17	3	6	15	0	41	0	10	1845	0	1845
P42	Non-foraged	90	No	5	0	0	2	0	7	0	1	866	0	866
AH68a	Non-foraged	60	Yes	5	0	5	9	0	19	0	1	259	0	259
AH68B	Non-foraged	80	Yes	1	0	0	1	0	2	0	1	100	0	100
AJ63	Non-foraged	50	Yes	10	0	0	1	0	11	0	1	163	0	163

Horizon A soil data for *A. littoralis*

Site	Status	Sample	Field texture grade*	% Clay	Clay rank	Soil Colour			pH
						Hue	Value	Chrome	
BG106	Foraged	1	SL	15	3	10 yr	3	2	4.5
BG106	Foraged	2	SL	15	3	10 yr	3	2	4.5
BG106	Foraged	3	SL	15	3	10 yr	3	2	4.5
AC93	Foraged	1	SL	15	3	10 yr	4	2	4.5
AC93	Foraged	2	SL	15	3	10 yr	4	3	5
AJ63	Foraged	1	ZL	25	6	10 yr	4	2	4.5
AJ63	Foraged	2	CL	32.5	8	10 yr	3	2	5
AJ63	Foraged	3	CL	32.5	8	10 yr	3	1	4.5
NSF	Foraged	1	FSL	15	4	10 yr	2	2	4.5
NSF	Foraged	2	ZL	25	6	10 yr	3	2	5
NSF	Foraged	3	ZL	25	6	10 yr	3	2	5
Gil1	Foraged	1	L	25	5	10 yr	3	2	4.5
Gil1	Foraged	2	L	25	5	10 yr	3	2	5
Gil1	Foraged	3	L	25	5	10 yr	3	2	5
Pimp	Foraged	1	LS	5	2	10 yr	2	1	5
Pimp	Foraged	2	LS	5	2	10 yr	2	1	5
Pimp	Foraged	3	LS	5	2	10 yr	2	1	5
BC68b	Non-foraged	1	FSCL	32.5	7	10 yr	4	2	5
BC68b	Non-foraged	2	FSCL	32.5	7	10 yr	3	1	5
BC68b	Non-foraged	3	FSCL	32.5	7	10 yr	4	2	5.5
AA11a	Non-foraged	1	CL	32.5	8	7.5 yr	2.5	2	4.5
AA11a	Non-foraged	2	CL	32.5	8	7.5 yr	3	2	4.75
AA11a	Non-foraged	3	CL	32.5	8	7.5 yr	3	2	4.75
AA11c	Non-foraged	1	SL	15	3	7.5 yr	2.5	2	4.5
AA11c	Non-foraged	2	LC	37.5	10	7.5 yr	2.5	2	4.5
AA11c	Non-foraged	3	LC	37.5	10	10 yr	3	3	4.5
BC68a	Non-foraged	1	CL	32.5	8	10 yr	3	6	4.5
BC68a	Non-foraged	2	FSCL	32.5	7	10 yr	4	2	4.5
BC68a	Non-foraged	3	LC	37.5	10	10 yr	4	3	4.5
BC68c	Non-foraged	1	CL	32.5	8	10 yr	2	1	5
BC68c	Non-foraged	2	FSCL	32.5	7	7.5 yr	3	1	5.5
BC68c	Non-foraged	3	FSCL	32.5	7	10 yr	4	2	5.5
AQ34	Non-foraged	1	ZCL	32.5	9	10 yr	3	2	4.5
AQ34	Non-foraged	2	LC	37.5	10	7.5 yr	2.5	2	5
AQ34	Non-foraged	3	SL	15	3	10 yr	2	2	5
AY103	Non-foraged	1	SL	15	3	10 yr	2	1	4.5
AY103	Non-foraged	2	SL	15	3	10 yr	2	2	5
AY103	Non-foraged	3	SL	15	3	10 yr	2	2	4.5
AH68	Non-foraged	1	FSL	15	4	10 yr	4	2	5
AH68	Non-foraged	2	ZCL	32.5	9	10 yr	4	4	5
AC93	Non-foraged	1	SL	15	3	10 yr	4	2	4.5
AC93	Non-foraged	2	SL	15	3	10 yr	4	3	5
AC93	Non-foraged	1	CL	32.5	8	2.5 y	5	3	4.5

* where SL = sandy loam, FSL = fine sandy loam, FSCL = fine sandy day loam, L = loam, CL = clay loam, ZCL = silty clay loam, LC = light clay, ZL = silty loam

Horizon B soil data for *A. littoralis*

Site	Status	Sample	Depth	Field Texture Grade	% Clay	Clay rank	Soil Colour			pH
							Hue	Value	Chrome	
BG106	Foraged	1	30	MC	75	14	10 yr	4	3	5
BG106	Foraged	2								
BG106	Foraged	3								
AC93	Foraged	1	25	LC	37.5	10	10 YR	5	4	4.5
AC93	Foraged	2	20	HC	75	14	10 YR	5	4	5
AJ63	Foraged	1	20	ZCL	32.5	9	2.5y	5	4	4.5
AJ63	Foraged	2	25	LC	37.5	10	10 yr	4	3	5
AJ63	Foraged	3	25	ZCL	32.5	9	10 yr	3	2	5
NSF	Foraged	1	25	fsd	15	7	10 yr	4	2	4.5
NSF	Foraged	2	30	zcl	32.5	9	10 yr	4	3	5
NSF	Foraged	3	15	zcl	32.5	9	10 yr	4	2	5
Gil1	Foraged	1	25	CL	32.5	8	10 yr	4	2	5
Gil1	Foraged	2	20	MC	47.5	12	10 yr	4	2	5
Gil1	Foraged	3	25	CL	32.5	8	10 yr	4	2	5
Pi mp	Foraged	1	35	LS	5	2	10 yr	3	2	5
Pi mp	Foraged	2	35	LS	5	2	10 yr	3	2	5
Pi mp	Foraged	3	35	LS	5	2	10 yr	3	2	5
BC68b	Non-foraged	1	50	CL	32.5	8	2.5Y	4	2	5
BC68b	Non-foraged	2	30	CL	32.5	8	2.5Y	4	2	5
BC68b	Non-foraged	3	30	ZCL	32.5	9	2.5Y	4	2	5
AA11a	Non-foraged	1	35	ZCL	32.5	9	10 yr	3	2	5
AA11a	Non-foraged	2	25	CL	32.5	8	10 yr	4	2	5
AA11a	Non-foraged	3	25	ZCL	32.5	9	10 yr	4	3	5
AA11c	Non-foraged	1	35	FSL	15	4	10 yr	4	2	5
AA11c	Non-foraged	2	35	CL	32.5	8	10 yr	3	2	5
AA11c	Non-foraged	3	30	CL	32.5	8	10 yr	3	2	5
BC68a	Non-foraged	1	30	LC	37.5	10	2.5Y	4	1	5
BC68a	Non-foraged	2	30	CL	32.5	8	10 yr	4	1	5
BC68a	Non-foraged	3	30	LC	37.5	10	10 yr	4	2	5
BC68c	Non-foraged	1	30	FSCL	32.5	7	10 yr	4	2	5.5
BC68c	Non-foraged	2	30	FSCL	32.5	7	10 yr	4	2	5
BC68c	Non-foraged	3	30	ZCL	32.5	9	10 yr	4	3	5.5
AQ34	Non-foraged	1	20	LC	37.5	10	10 yr	3	3	4.75
AQ34	Non-foraged	2	20	MC	47.5	12	7.5yr	2.5	3	5
AQ34	Non-foraged	3	20	MC	47.5	12	10 yr	3	3	4.5
AY103	Non-foraged	1								
AY103	Non-foraged	2								
AY103	Non-foraged	3	20	SL	15	3	10 yr	4	2	5
AH68	Non-foraged	1	15	ZCL	32.5	9	2.5 Y	5	4	5
AH68	Non-foraged	2	35	SL	15	3	10 yr	5	6	5
AC93	Non-foraged	1	25	LC	37.5	10	10 yr	5	4	4.5
AC93	Non-foraged	2	20	HC	75	14	10 yr	5	4	5
AC93	Non-foraged	1	25	HC	75	14	2.5 Y	6	4	4.5

* where SL = sandy loam, FSL = fine sandy loam, FSCL = fine sandy day loam, L=loam, CL = day loam, ZCL = silty day loam, LC = light day, ZL = silty loam, MC = medium day, HC = heavy day

Female *A. littoralis* tree data

Site	Quadrat	Site feeding status	Tree feeding status	Height (m)	DBH (cm)	# Cones	# Female flowers	# Chewings	# Pre-feeding cones
Pimp	a	Foraged	Feed	14	26.8	40	0	23086	6830
Pimp	a	Foraged	Feed	12	29	700	0	137.3	740
NSF1	a	Foraged	Feed	10	14.4	160	2	3599	1219
NSF1	a	Foraged	Feed	10	21.8	400	0	1398	811
NSF1	a	Foraged	Feed	8	7.6	60	0	45	73.2
Gil1	a	Foraged	Feed	12	13.2	50	0	4297	1314
Gil1	a	Foraged	Feed	12	16.7	150	0	3515	1184
Gil1	a	Foraged	Feed	13	14.2	80	0	2494	814
Gil1	a	Foraged	Feed		11	20	0	1185	369
Gil1	a	Foraged	Feed	12	7.6	50	0	801	286
Gil1	a	Foraged	Feed	15	14.5	100	0	521	253
Gil1	a	Foraged	Feed	13	18.7	120	0	457	254
Gil1	a	Foraged	Feed	12	15.3	4	0	345	106
Gil1	a	Foraged	Feed	12	9	80	0	44	93
Gil1	a	Foraged	Feed	12	10.2	20	0	132	59
Gil1	a	Foraged	Feed	12	10.8	50	0	28	58
Gil1	a	Foraged	Feed	12	8.6	50	0	7	52
BG106	a	Foraged	Feed	10	16	100	200	2552	851
BG106	a	Foraged	Feed	11	10	0	0	1022	301
BG106	a	Foraged	Feed	8	11.5	100	200	33	110
AJ63	b	Foraged	Feed	14	23	1200	0	66	1219
AC93	a	Foraged	Feed	12	16	400	0	2134	1028
Gil1	a	Foraged	Non-feed	11	12.4	400	0	0	400
Gil1	a	Foraged	Non-feed	14	21.1	400	0	0	400
Gil1	a	Foraged	Non-feed	15	12.5	400	0	0	400
Gil1	a	Foraged	Non-feed	16	19.1	300	0	0	300
BG106	a	Foraged	Non-feed	12	10	250	1000	0	250
AJ63	b	Foraged	Non-feed	13	19.5	250	0	0	250
Gil1	a	Foraged	Non-feed	13	10.5	150	0	0	150
Gil1	a	Foraged	Non-feed	14	13.5	140	0	0	140
Gil1	a	Foraged	Non-feed	13	8.7	120	0	0	120
AC93	a	Foraged	Non-feed	6	3.8	105	6	0	105
BG106	a	Foraged	Non-feed	12	8.5	100	0	0	100
Gil1	a	Foraged	Non-feed	15	19	70	0	0	70
Gil1	a	Foraged	Non-feed	12	14.3	60	0	0	60
Gil1	a	Foraged	Non-feed	12	12.4	60	0	0	60
BG106	a	Foraged	Non-feed	9	4	60	100	0	60
AC93	a	Foraged	Non-feed	9	6.2	60	0	0	60
AC93	a	Foraged	Non-feed	7	3.5	55	0	0	55
BG106	a	Foraged	Non-feed	13	8	50	0	0	50
AC93	a	Foraged	Non-feed	7	4.7	50	0	0	50
Gil1	a	Foraged	Non-feed	13	11.8	40	0	0	40
BG106	a	Foraged	Non-feed	10	9	40	50	0	40
Gil1	a	Foraged	Non-feed	14	22.5	30	0	0	30
BG106	a	Foraged	Non-feed	12	10.2	30	100	2	31

6 — Appendices

Site	Quadrat	Site feeding status	Tree feeding status	Height (m)	DBH (cm)	# Cones	# Female flowers	# Chewings	# Pre-feeding cones
AC93	a	Foraged	Non-feed	8	4.8	30	0	0	30
AC93	a	Foraged	Non-feed	7	4.3	30	0	0	30
AC93	a	Foraged	Non-feed	5.5	2.5	30	1	0	30
Gil1	a	Foraged	Non-feed	11	10	25	0	0	25
AC93	a	Foraged	Non-feed	7	3.2	25	3	0	25
AC93	a	Foraged	Non-feed	7	3.7	25	0	0	25
AC93	a	Foraged	Non-feed	7	3	23	0	0	23
AC93	a	Foraged	Non-feed	3.5	1.3	22	1	0	22
AC93	a	Foraged	Non-feed	7	3.8	21	0	0	21
Gil1	a	Foraged	Non-feed	12	7.1	20	0	0	20
Gil1	a	Foraged	Non-feed	12	8.9	20	0	0	20
Gil1	a	Foraged	Non-feed	11	8.1	20	0	0	20
AJ63	b	Foraged	Non-feed	8	5	20	0	0	20
BG106	a	Foraged	Non-feed	11	8.5	19	50	0	19
Gil1	a	Foraged	Non-feed	14	12	15	0	0	15
Gil1	a	Foraged	Non-feed	13	9.7	15	0	0	15
BG106	a	Foraged	Non-feed	10	9.5	15	50	0	15
AC93	a	Foraged	Non-feed	9	4.2	15	0	0	15
AC93	a	Foraged	Non-feed	8	5.2	15	0	0	15
AC93	a	Foraged	Non-feed	6	2.5	15	1	0	15
AC93	a	Foraged	Non-feed	6	3.8	15	0	0	15
Gil1	a	Foraged	Non-feed	8	3.9	14	0	0	14
AC93	a	Foraged	Non-feed	7	3.2	14	0	0	14
NSF1a	a	Foraged	Non-feed	8	10.2	13	0	0	13
BG106	a	Foraged	Non-feed	9	6.5	12	10	0	12
AC93	a	Foraged	Non-feed	6	4.3	12	0	0	12
AC93	a	Foraged	Non-feed	6	3	11	0	0	11
Gil1	a	Foraged	Non-feed	12	10.2	10	0	0	10
Gil1	a	Foraged	Non-feed	13	10.3	10	0	0	10
AC93	a	Foraged	Non-feed	9	4.3	10	0	0	10
AC93	a	Foraged	Non-feed	6	2.3	10	0	0	10
AC93	a	Foraged	Non-feed	6	2.8	10	1	0	10
AC93	a	Foraged	Non-feed	6	2.5	8	0	0	8
AC93	a	Foraged	Non-feed	6	2.3	8	0	0	8
AC93	a	Foraged	Non-feed	6	2.5	7	0	0	7
AC93	a	Foraged	Non-feed	6	3.5	7	0	0	7
AC93	a	Foraged	Non-feed	5	2.5	7	0	0	7
AC93	a	Foraged	Non-feed	6	3	7	0	0	7
AC93	a	Foraged	Non-feed	6	2.5	7	0	0	7
AC93	a	Foraged	Non-feed	6	2.5	7	0	0	7
AC93	a	Foraged	Non-feed	2.5	1	7	1	0	7
BG106	a	Foraged	Non-feed	10	7	6	0	0	6
BG106	a	Foraged	Non-feed	8	9.5	6	1000	0	6
AC93	a	Foraged	Non-feed	7	3.5	6	0	0	6
Gil1	a	Foraged	Non-feed	10	7	5	0	0	5
Gil1	a	Foraged	Non-feed	13	10	5	0	0	5
Gil1	a	Foraged	Non-feed	12	8.8	5	0	0	5
BG106	a	Foraged	Non-feed	12	12.5	5	0	0	5

Site	Quadrat	Site feeding status	Tree feeding status	Height (m)	DBH (cm)	# Cones	# Female flowers	# Chewings	# Pre-feeding cones
BG106	a	Foraged	Non-feed	12	12	5	500	0	5
AC93	a	Foraged	Non-feed	4.5	1.6	5	0	0	5
AC93	a	Foraged	Non-feed	4	1.8	5	0	0	5
BG106	a	Foraged	Non-feed	9	6	4	0	1	4.3
BG106	a	Foraged	Non-feed	8	8	4	0	0	4
BG106	a	Foraged	Non-feed	12	9	4	200	0	4
BG106	a	Foraged	Non-feed	4	2	4	60	0	4
AC93	a	Foraged	Non-feed	7	3.2	4	0	0	4
AC93	a	Foraged	Non-feed	5	2.3	4	0	0	4
AC93	a	Foraged	Non-feed	5	2	4	0	0	4
AC93	a	Foraged	Non-feed	4.5	1.8	4	0	0	4
AC93	a	Foraged	Non-feed	4.5	2.5	4	4	0	4
BG106	a	Foraged	Non-feed	12	12	3	0	0	3
AC93	a	Foraged	Non-feed	3	1.5	3	0	0	3
AC93	a	Foraged	Non-feed	8	3.8	3	0	0	3
AC93	a	Foraged	Non-feed	6	2.3	3	0	0	3
AC93	a	Foraged	Non-feed	6	3	3	0	0	3
AC93	a	Foraged	Non-feed	5.5	2.3	3	0	0	3
BG106	a	Foraged	Non-feed	4	2.5	2	22	0	2
AC93	a	Foraged	Non-feed	6	2	2	0	0	2
AC93	a	Foraged	Non-feed	8	3	2	0	0	2
AC93	a	Foraged	Non-feed	7	2.8	2	0	0	2
AC93	a	Foraged	Non-feed	6	2.5	2	0	0	2
AC93	a	Foraged	Non-feed	3.5	1.5	2	1	0	2
AC93	a	Foraged	Non-feed	5	2	2	0	0	2
AC93	a	Foraged	Non-feed	6	2.7	2	0	0	2
AC93	a	Foraged	Non-feed	3	2	2	0	0	2
AC93	a	Foraged	Non-feed	4	2.5	2	0	0	2
AC93	a	Foraged	Non-feed	3	1.8	2	0	0	2
NSF1a	a	Foraged	Non-feed	1	0.2	1	0	0	1
Gil1	a	Foraged	Non-feed	14	10	1	0	0	1
BG106	a	Foraged	Non-feed	3	1.5	1	12	0	1
BG106	a	Foraged	Non-feed	7	5.5	1	0	0	1
BG106	a	Foraged	Non-feed	12	7.5	1	300	0	1
AC93	a	Foraged	Non-feed	6	3	1	0	0	1
AC93	a	Foraged	Non-feed	3	1.5	1	0	0	1
AC93	a	Foraged	Non-feed	4	1.7	1	0	0	1
AC93	a	Foraged	Non-feed	10	4.8	1	0	0	1
AC93	a	Foraged	Non-feed	8	3.8	1	0	0	1
AC93	a	Foraged	Non-feed	3.5	1.3	1	1	0	1
AC93	a	Foraged	Non-feed	6	2	1	0	0	1
AC93	a	Foraged	Non-feed	3	1.4	1	0	0	1
AC93	a	Foraged	Non-feed	4	2	1	0	0	1
AC93	a	Foraged	Non-feed	3	1.2	1	1	0	1
AC93	a	Foraged	Non-feed	6	3.3	1	0	0	1
AC93	a	Foraged	Non-feed	6	2	1	0	0	1
AC93	a	Foraged	Non-feed	4.5	2.5	1	0	0	1
AC93	a	Foraged	Non-feed	6	2.8	1	0	0	1

Site	Quadrat	Site feeding status	Tree feeding status	Height (m)	DBH (cm)	# Cones	# Female flowers	# Chewings	# Pre-feeding cones
AC93	a	Foraged	Non-feed	7	2.5	1	0	0	1
AC93	a	Foraged	Non-feed	4	2	1	0	0	1
AC93	a	Foraged	Non-feed	1.5	1.1	1	0	0	1
AC93	a	Foraged	Non-feed	2.5	1.5	1	0	0	1
AC93	a	Foraged	Non-feed	3	1.3	1	0	0	1
BG106	a	Foraged	Non-feed	10	5	0	3	0	0
AC93	a	Foraged	Non-feed	2.5	1	0	0	0	0
AC93	a	Foraged	Non-feed	4	1.5	0	1	0	0
AA11	c	Non-foraged	Non-feed	16	30.5	500	200	0	500
BC68	a	Non-foraged	Non-feed	15	29	300	100	0	300
BC68	b	Non-foraged	Non-feed	14	13	300	0	0	300
BC68	b	Non-foraged	Non-feed	12	10	300	0	0	300
BC68	b	Non-foraged	Non-feed	11	13	300	0	0	300
BC68	c	Non-foraged	Non-feed	10	16	300	0	0	300
AQ34	a	Non-foraged	Non-feed	13	30.5	300	200	0	300
AA11	c	Non-foraged	Non-feed	13	5.5	300	50	0	300
AA11	c	Non-foraged	Non-feed	14	15.5	300	0	0	300
AA11	c	Non-foraged	Non-feed	11	13	300	100	0	300
BC68	a	Non-foraged	Non-feed	11	17.5	250	0	0	250
BC68	b	Non-foraged	Non-feed	12	10.5	200	0	0	200
BC68	b	Non-foraged	Non-feed	12	11.2	200	0	0	200
AY103	a	Non-foraged	Non-feed	12	21	200	200	0	200
AQ34	a	Non-foraged	Non-feed	14	27.5	160	50	0	160
BC68	b	Non-foraged	Non-feed	9	9.8	150	100	0	150
AA11	c	Non-foraged	Non-feed	13	14.8	150	100	0	150
BC68	b	Non-foraged	Non-feed	12	10.5	100	0	0	100
BC68	b	Non-foraged	Non-feed	11	14.5	100	0	0	100
AY103	a	Non-foraged	Non-feed	12	18	100	0	0	100
AA11	a	Non-foraged	Non-feed	13	17.2	100	20	0	100
AA11	a	Non-foraged	Non-feed	6	4.5	90	60	0	90
BC68	b	Non-foraged	Non-feed	11	12.5	80	0	0	80
BC68	c	Non-foraged	Non-feed	11	7.5	70	0	0	70
AA11	a	Non-foraged	Non-feed	9	6.8	70	10	0	70
BC68	b	Non-foraged	Non-feed	11	19.2	60	0	0	60
AY103	a	Non-foraged	Non-feed	11	18.5	60	0	0	60
AA11	a	Non-foraged	Non-feed	12	17.3	60	200	0	60
AA11	a	Non-foraged	Non-feed	14	15.5	60	200	0	60
BC68	a	Non-foraged	Non-feed	6	5	55	50	0	55
BC68	a	Non-foraged	Non-feed	12	10	50	0	0	50
BC68	c	Non-foraged	Non-feed	9	10.5	50	0	0	50
AQ34	a	Non-foraged	Non-feed	15	19.5	50	30	0	50
BC68	a	Non-foraged	Non-feed	12	6.3	40	0	0	40
BC68	c	Non-foraged	Non-feed	11	6	40	0	0	40
BC68	a	Non-foraged	Non-feed	4	1	38	0	0	38
BC68	a	Non-foraged	Non-feed	8	4.3	35	30	0	35
AQ34	b	Non-foraged	Non-feed	5	5	33	35	0	33
BC68	a	Non-foraged	Non-feed	10	10.2	30	0	0	30
AY103	a	Non-foraged	Non-feed	13	14.5	30	0	0	30

Site	Quadrat	Site feeding status	Tree feeding status	Height (m)	DBH (cm)	# Cones	# Female flowers	# Chewings	# Pre-feeding cones
AA11	a	Non-foraged	Non-feed	14	18.5	30	150	0	30
AQ34	b	Non-foraged	Non-feed	6	7.7	28	25	0	28
BC68	a	Non-foraged	Non-feed	10	15	25	0	0	25
AA11	c	Non-foraged	Non-feed	11	10.5	25	0	0	25
BC68	a	Non-foraged	Non-feed	11	8	24	0	0	24
BC68	a	Non-foraged	Non-feed	6	2.5	24	20	0	24
AQ34	b	Non-foraged	Non-feed	8	6	22	100	0	22
BC68	a	Non-foraged	Non-feed	10	4	20	0	0	20
BC68	a	Non-foraged	Non-feed	7	69	20	0	0	20
BC68	b	Non-foraged	Non-feed	10	16	20	0	0	20
AA11	a	Non-foraged	Non-feed	11	12	20	200	0	20
AQ34	b	Non-foraged	Non-feed	3	2.5	17	20	0	17
BC68	c	Non-foraged	Non-feed	14	7	15	0	0	15
AA11	b	Non-foraged	Non-feed	8	5.5	14	40	0	14
BC68	a	Non-foraged	Non-feed	9	5	13	0	0	13
BC68	a	Non-foraged	Non-feed	6	2	13	35	0	13
BC68	a	Non-foraged	Non-feed	11	8.3	10	0	0	10
BC68	a	Non-foraged	Non-feed	10	5.3	10	0	0	10
BC68	b	Non-foraged	Non-feed	10	13.5	10	100	0	10
AQ34	c	Non-foraged	Non-feed	9	11.5	10	10	0	10
BC68	a	Non-foraged	Non-feed	7	6.2	9	0	0	9
BC68	b	Non-foraged	Non-feed	4	1.4	9	20	0	9
BC68	b	Non-foraged	Non-feed	13	11	8	100	0	8
AQ34	a	Non-foraged	Non-feed	13	19.8	8	100	0	8
AA11	a	Non-foraged	Non-feed	11	6.6	8	6	0	8
BC68	a	Non-foraged	Non-feed	7	4.5	7	20	0	7
BC68	a	Non-foraged	Non-feed	4.5	2.2	6	54	0	6
BC68	a	Non-foraged	Non-feed	3	2.8	6	2	0	6
BC68	b	Non-foraged	Non-feed	3	1	6	0	0	6
BC68	c	Non-foraged	Non-feed	7	8	6	30	0	6
BC68	c	Non-foraged	Non-feed	5	2.5	6	20	0	6
AA11	c	Non-foraged	Non-feed	4	3	6	4	0	6
AA11	b	Non-foraged	Non-feed	9	8	6	100	0	6
BC68	a	Non-foraged	Non-feed	9	6.5	5	0	0	5
BC68	a	Non-foraged	Non-feed	6	2.5	5	0	0	5
BC68	c	Non-foraged	Non-feed	11	5	5	0	0	5
BC68	c	Non-foraged	Non-feed	3	1.5	5	20	0	5
AQ34	a	Non-foraged	Non-feed	12	10.5	5	0	0	5
AA11	a	Non-foraged	Non-feed	7	6.3	5	0	0	5
BC68	a	Non-foraged	Non-feed	4	1.3	4	0	0	4
BC68	c	Non-foraged	Non-feed	14	4.5	4	0	0	4
BC68	c	Non-foraged	Non-feed	2	1.2	4	20	0	4
BC68	a	Non-foraged	Non-feed	2.5	2	3	0	0	3
AQ34	b	Non-foraged	Non-feed	7	4.5	3	10	0	3
AA11	c	Non-foraged	Non-feed	7	4.8	3	0	0	3
AA11	b	Non-foraged	Non-feed	9	6.5	3	0	0	3
BC68	a	Non-foraged	Non-feed	5	4	2	4	0	2
BC68	b	Non-foraged	Non-feed	7	4.5	2	0	0	2

Site	Quadrat	Site feeding status	Tree feeding status	Height (m)	DBH (cm)	# Cones	# Female flowers	# Chewings	# Pre-feeding cones
BC68	c	Non-foraged	Non-feed	14	6.5	2	0	0	2
BC68	a	Non-foraged	Non-feed	9	3.2	1	0	0	1
BC68	a	Non-foraged	Non-feed	2	0.3	1	2	0	1
AQ34	a	Non-foraged	Non-feed	4	3	1	11	0	1
AQ34	b	Non-foraged	Non-feed	6	5.6	1	2	0	1
AQ34	b	Non-foraged	Non-feed	4	1.5	1	5	0	1
AQ34	b	Non-foraged	Non-feed	6	4.5	1	10	0	1
BC68	a	Non-foraged	Non-feed	4	2	0	50	0	0
BC68	a	Non-foraged	Non-feed	2	1	0	1	0	0
BC68	b	Non-foraged	Non-feed	4	1.4	0	100	0	0
AQ34	b	Non-foraged	Non-feed	4	2	0	2	0	0
AQ34	c	Non-foraged	Non-feed	5	4.2	0	30	0	0
AA11	a	Non-foraged	Non-feed	4	3	0	30	0	0
AA11	a	Non-foraged	Non-feed	12	10.8	0	200	0	0
P42	b	Non-foraged	Non-feed	9	20	15	20	0	15
P42	b	Non-foraged	Non-feed	13	44	800	500	0	800
P42	b	Non-foraged	Non-feed	7	15.4	12	120	0	12
P42	b	Non-foraged	Non-feed	2	1.2	4	0	0	4
P42	b	Non-foraged	Non-feed	2.5	6	35	0	0	35
AJ63	a	Non-foraged	Non-feed	8	18	5	0	0	5
AJ63	a	Non-foraged	Non-feed	10	14	4	0	0	4
AJ63	a	Non-foraged	Non-feed	8	22	2	0	0	2
AJ63	a	Non-foraged	Non-feed	8	18.5	25	0	0	25
AJ63	a	Non-foraged	Non-feed	8	16	80	0	0	80
AJ63	a	Non-foraged	Non-feed	8	11	6	0	0	6
AJ63	a	Non-foraged	Non-feed	8	19	8	0	0	8
AJ63	a	Non-foraged	Non-feed	9	19	25	0	0	25
AJ63	a	Non-foraged	Non-feed	4.5	6	7	0	0	7
AJ63	a	Non-foraged	Non-feed	9	25	1	0	0	1
AH68	b	Non-foraged	Non-feed	7	25	17	0	0	17
AH68	b	Non-foraged	Non-feed	10	24.4	200	200	0	200
AH68	b	Non-foraged	Non-feed	8	21	1	20	0	1
AH68	b	Non-foraged	Non-feed	7	17.5	36	20	0	36
AH68	b	Non-foraged	Non-feed	5	8.5	5	0	0	5
AH68	c	Non-foraged	Non-feed	10	29	100	200	0	100

Male *A. littoralis* trees data

Site	Quadrat	Site Feeding Status	Sex	Height (m)	DBH (cm)	# Cones	# ♂ Flowers
BG106	a	Foraged	m	10	7.5	0	300
BG106	a	Foraged	m	10	15	0	150
BG106	a	Foraged	m	9	13	0	1000
BG106	a	Foraged	m	10	12.5	0	1000
BG106	a	Foraged	m	9	8	0	1000
BG106	a	Foraged	m	8	10	0	300
BG106	a	Foraged	m	6	5	0	200
BG106	a	Foraged	m	9	6	0	500
BG106	a	Foraged	m	8	7.5	0	1000
BG106	a	Foraged	m	8	5	0	500
BG106	a	Foraged	mf	10	9.5	2	1000
BG106	a	Foraged	mf	5	2.5	1	60
NSF1	a	Foraged	m	9	9.2	0	500
AA11	b	Non-foraged	m	7	6.5	0	100
AA11	b	Non-foraged	m	6	6.5	0	400
AA11	b	Non-foraged	m	12	14.5	0	100
AA11	b	Non-foraged	m	5	4.8	0	500
AA11	b	Non-foraged	m	6	6	0	100
AA11	b	Non-foraged	m	8	6.5	0	100
AA11	b	Non-foraged	m	5	4.5	0	100
AA11	c	Non-foraged	m	7	8	0	200
AA11	c	Non-foraged	m	5	3.5	0	30
AA11	c	Non-foraged	m	8	4.8	0	100
AA11	c	Non-foraged	m	14	16	0	1000
AA11	c	Non-foraged	m	8	8	0	200
AA11	c	Non-foraged	m	14	10	0	200
AA11	c	Non-foraged	m	5	4	0	200
AA11	c	Non-foraged	m	6	7	0	100
AA11	c	Non-foraged	m	6	4	0	50
AA11	c	Non-foraged	m	10	7.5	0	500
AQ34	a	Non-foraged	m	12	13.5	0	500
AQ34	a	Non-foraged	m	11	11	0	1000
AQ34	b	Non-foraged	m	6	4	0	100
AQ34	b	Non-foraged	m	10	13.5	0	500
AQ34	b	Non-foraged	m	7	5	0	50
AQ34	b	Non-foraged	mf	6	4.5	1	100
AQ34	c	Non-foraged	m	12	29.5	0	500
AQ34	c	Non-foraged	m	11	15	0	1000
BC68	a	Non-foraged	m	2	0.3	0	5
BC68	a	Non-foraged	m	4.5	2	0	50
BC68	b	Non-foraged	m	11	24.5	0	30
BC68	b	Non-foraged	m	12	7.5	0	50
BC68	b	Non-foraged	m	11	18.5	0	20
BC68	c	Non-foraged	m	8	21	0	60

6.6 APPENDIX 6

Raw data for *A. torulosa* (Chapter 2)General site data for *A. torulosa*

Site	Feeding Status	# Juveniles	# Adult Trees		# Total Trees	# Total Cones	# Chewings	# Pre-feeding cones	# Apparently suitable feed Trees	# Feed Trees
			Without cones	With cones						
S124c	Foraged	3	1	3	7	1140	6	1142	2	1
AR101b	Foraged	1	14	3	18	192	73	212	2	1
AA93b	Foraged	3	7	5	15	2421	326	2509	3	1
AC93a	Foraged	5	5	5	15	521	501	656	1	1
X104b	Foraged	0	4	4	8	342	719	536	3	1
AI64c	Foraged	0	2	4	6	408	1337	769	4	2
W49a	Foraged	1	5	4	10	576	2892	1358	2	2
AA56c	Foraged	13	13	7	33	3237	4138	4355	5	3
S124a	Foraged	9	5	2	16	1001	7632	3064	2	2
AA56b	Non-foraged	9	7	7	23	618	0	618	4	0
AA93c	Non-foraged	1	21	3	25	1201	0	1201	2	0
AC87a	Non-foraged	6	2	3	11	165	0	165	2	0
AJ71b	Non-foraged	7	13	8	28	1066	0	1066	2	0
AJ71c	Non-foraged	2	16	5	23	1803	0	1803	4	0
AN112a	Non-foraged	2	14	2	18	1200	0	1200	2	0
AN112c	Non-foraged	3	11	5	19	640	0	640	4	0
AP109c	Non-foraged	3	10	8	21	1184	0	1184	5	0
S124b	Non-foraged	0	7	2	9	130	0	130	2	0
T123b	Non-foraged	0	10	5	15	2210	0	2210	4	0
T123a	Non-foraged	0	7	3	10	2150	1	2150	3	0
AJ71a	Non-foraged	4	7	5	16	834	3	835	2	0
AA93a	Non-foraged	0	18	6	24	138	0	138	1	0
AC93c	Non-foraged	0	5	2	7	190	0	190	1	0
AE98b	Non-foraged	0	2	1	3	200	0	200	1	0
AI64b	Non-foraged	0	4	2	6	75	0	75	1	0
AN112b	Non-foraged	0	5	1	6	100	0	100	1	0
AP105a	Non-foraged	4	19	3	26	268	0	268	1	0
AP109a	Non-foraged	1	19	2	22	316	0	316	1	0
AR101a	Non-foraged	3	9	7	19	160	0	160	1	0
AR110c	Non-foraged	9	3	1	13	300	0	300	1	0
AT110a	Non-foraged	28	4	2	34	1010	0	1010	1	0
AT110b	Non-foraged	20	14	2	36	75	0	75	1	0
V69	Non-foraged	0	9	1	10	150	0	150	1	0
W49b	Non-foraged	1	3	1	5	300	0	300	1	0
X104c	Non-foraged	24	0	1	25	900	0	900	1	0

Female *A. torulosa* tree data

Site	Quadrat	Site Feeding Status	Tree Feeding Status	# Cones	Height (m)	# Chewings	# Pre-feeding Chewings
AA56	c	Foraged	Feed	1000	17	1927	1521
AA56	c	Foraged	Feed	1000	13	1218	1329
AA56	c	Foraged	Feed	500	13	994	769
AA93	b	Foraged	Feed	1000	15	326	1088
AC93	a	Foraged	Feed	500	14	501	635
AI64	c	Foraged	Feed	8	11	200	62
AI64	c	Foraged	Feed	250	11	1137	557
AR101	b	Foraged	Feed	80	12	73	100
S124	a	Foraged	Feed	1000	20	7365	2991
S124	a	Foraged	Feed	0	10	267	72
S124	c	Foraged	Feed	1000	19	6	1002
W49	a	Foraged	Feed	500	13	990	768
W49	a	Foraged	Feed	500	13	1902	1014
X104	b	Foraged	Feed	100	13	719	294
AA56	c	Foraged	Non-feed	400	12	0	400
AA56	c	Foraged	Non-feed	30	6	0	30
AA56	c	Foraged	Non-feed	300	13	0	300
AA56	c	Foraged	Non-feed	7	7	0	7
AA93	b	Foraged	Non-feed	17	7	0	17
AA93	b	Foraged	Non-feed	4	9	0	4
AA93	b	Foraged	Non-feed	1000	14	0	1000
AA93	b	Foraged	Non-feed	400	9	2	401
AC93	a	Foraged	Non-feed	1	8	0	1
AC93	a	Foraged	Non-feed	10	9	0	10
AC93	a	Foraged	Non-feed	5	7	0	5
AC93	a	Foraged	Non-feed	5	10	0	5
AI64	c	Foraged	Non-feed	80	13	1	80
AI64	c	Foraged	Non-feed	70	13	0	70
AR101	b	Foraged	Non-feed	12	11	0	12
AR101	b	Foraged	Non-feed	100	13	0	100
S124	a	Foraged	Non-feed	1	9	0	1
S124	c	Foraged	Non-feed	100	14	0	100
S124	c	Foraged	Non-feed	40	20	0	40
W49	a	Foraged	Non-feed	6	9	0	6
W49	a	Foraged	Non-feed	30	11	0	30
W49	a	Foraged	Non-feed	40	10	0	40
X104	b	Foraged	Non-feed	12	7	0	12
X104	b	Foraged	Non-feed	150	8	0	150
X104	b	Foraged	Non-feed	80	12	0	80
AA56	b	Non-foraged	Non-feed	17	6	0	17
AA56	b	Non-foraged	Non-feed	200	8	0	200
AA56	b	Non-foraged	Non-feed	150	7	0	150
AA56	b	Non-foraged	Non-feed	4	5	0	4
AA56	b	Non-foraged	Non-feed	80	8	0	80
AA56	b	Non-foraged	Non-feed	150	8	0	150
AA56	b	Non-foraged	Non-feed	17	7	0	17

Site	Quadrat	Site Feeding Status	Tree Feeding Status	# Cones	Height (m)	# Chewings	# Pre-feeding Chewings
AA93	a	Non-foraged	Non-feed	90	13	0	90
AA93	a	Non-foraged	Non-feed	1	8	0	1
AA93	a	Non-foraged	Non-feed	20	12	0	20
AA93	a	Non-foraged	Non-feed	16	11	0	16
AA93	a	Non-foraged	Non-feed	6	14	0	6
AA93	A	Non-foraged	Non-feed	5	9	0	5
AA93	C	Non-foraged	Non-feed	1	12	0	1
AA93	c	Non-foraged	Non-feed	1000	16	0	1000
AA93	c	Non-foraged	Non-feed	200	13	0	200
AC87	a	Non-foraged	Non-feed	80	11	0	80
AC87	a	Non-foraged	Non-feed	15	8	0	15
AC87	a	Non-foraged	Non-feed	70	6	0	70
AC93	c	Non-foraged	Non-feed	40	11	0	40
AC93	c	Non-foraged	Non-feed	150	10	0	150
AE98	b	Non-foraged	Non-feed	200	14	0	200
AI64	b	Non-foraged	Non-feed	20	11	0	20
AI64	b	Non-foraged	Non-feed	55	7	0	55
AJ71	a	Non-foraged	Non-feed	700	12	3	701
AJ71	a	Non-foraged	Non-feed	35	9	0	35
AJ71	a	Non-foraged	Non-feed	6	7	0	6
AJ71	a	Non-foraged	Non-feed	3	6	0	3
AJ71	a	Non-foraged	Non-feed	90	17	0	90
AJ71	b	Non-foraged	Non-feed	900	11	0	900
AJ71	b	Non-foraged	Non-feed	6	8	0	6
AJ71	b	Non-foraged	Non-feed	8	7	0	8
AJ71	b	Non-foraged	Non-feed	9	7	0	9
AJ71	b	Non-foraged	Non-feed	3	10	0	3
AJ71	b	Non-foraged	Non-feed	70	7	0	70
AJ71	b	Non-foraged	Non-feed	45	9	0	45
AJ71	b	Non-foraged	Non-feed	25	8	0	25
AJ71	c	Non-foraged	Non-feed	3	9	0	3
AJ71	c	Non-foraged	Non-feed	550	17	0	550
AJ71	c	Non-foraged	Non-feed	600	12	0	600
AJ71	c	Non-foraged	Non-feed	500	12	0	500
AJ71	c	Non-foraged	Non-feed	150	10	0	150
AN112	a	Non-foraged	Non-feed	1000	16	0	1000
AN112	a	Non-foraged	Non-feed	200	16	0	200
AN112	b	Non-foraged	Non-feed	100	20	0	100
AN112	c	Non-foraged	Non-feed	50	17	0	50
AN112	c	Non-foraged	Non-feed	40	15	0	40
AN112	c	Non-foraged	Non-feed	300	17	0	300
AN112	c	Non-foraged	Non-feed	100	20	0	100
AN112	c	Non-foraged	Non-feed	150	19	0	150
AP105	a	Non-foraged	Non-feed	16	7	0	16
AP105	a	Non-foraged	Non-feed	250	12	0	250
AP105	a	Non-foraged	Non-feed	2	5	0	2
AP109	a	Non-foraged	Non-feed	300	9	0	300
AP109	a	Non-foraged	Non-feed	16	7	0	16
AP109	c	Non-foraged	Non-feed	350	13	0	350

Site	Quadrat	Site Feeding Status	Tree Feeding Status	# Cones	Height (m)	# Chewings	# Pre-feeding Chewings
AP109	c	Non-foraged	Non-feed	29	8	0	29
AP109	c	Non-foraged	Non-feed	90	7	0	90
AP109	c	Non-foraged	Non-feed	3	7	0	3
AP109	c	Non-foraged	Non-feed	2	6	0	2
AP109	c	Non-foraged	Non-feed	350	10	0	350
AP109	c	Non-foraged	Non-feed	300	10	0	300
AP109	c	Non-foraged	Non-feed	60	12	0	60
AR101	a	Non-foraged	Non-feed	35	8	0	35
AR101	a	Non-foraged	Non-feed	1	13	0	1
AR101	a	Non-foraged	Non-feed	9	10	0	9
AR101	a	Non-foraged	Non-feed	25	9	0	25
AR101	a	Non-foraged	Non-feed	50	9	0	50
AR101	a	Non-foraged	Non-feed	20	11	0	20
AR101	a	Non-foraged	Non-feed	20	12	0	20
AR110	c	Non-foraged	Non-feed	300	8	0	300
AT110	a	Non-foraged	Non-feed	1000	15	0	1000
AT110	a	Non-foraged	Non-feed	10	13	0	10
AT110	b	Non-foraged	Non-feed	70	16	0	70
AT110	b	Non-foraged	Non-feed	5	15	0	5
S124	b	Non-foraged	Non-feed	70	12	0	70
S124	b	Non-foraged	Non-feed	60	22	0	60
T123	a	Non-foraged	Non-feed	1000	19	1	1000.27
T123	a	Non-foraged	Non-feed	1000	15	0	1000
T123	a	Non-foraged	Non-feed	150	15	0	150
T123	b	Non-foraged	Non-feed	10	12	0	10
T123	b	Non-foraged	Non-feed	700	18	0	700
T123	b	Non-foraged	Non-feed	150	20	0	150
T123	b	Non-foraged	Non-feed	700	15	0	700
T123	b	Non-foraged	Non-feed	650	15	0	650
V69		Non-foraged	Non-feed	150	12	0	150
W49	b	Non-foraged	Non-feed	300	12	0	300
X104	c	Non-foraged	Non-feed	900	11	0	900

6.7 APPENDIX 7

Raw data for *A. littoralis* cone softness and colour (Chapter 3)

Tree Details

Site	Height (m)	# Cones	DBH (cm)	# Chewings	# Pre-feeding cones	Cone Colour			Average Cone Softness (mm)	Average Cone Greyness
						Hue	Value	Chroma		
CG1	17	800	57	0	819				27.5	2.2
CG2	11	100	23.5	0	100				23.4	2.2
CG3	3.5	12	5	0	12				28.4	0
CG4	13	400	62	2480	1227	7.5 yr	5	8	25.3	2.5
CG5	9	80	14	0	80				25.9	3
G1	5	42	8	0	42				24.0	1.9
G2	8	250	19	0	250				27.4	0
G3	12	150	35.5	0	150				24.6	1
G4	8	180	15	17	186	7.5 yr	5	6	26.3	0
G5	10	500	40	3	501	7.5 yr	5	6	24.2	0
GSW1	12	60	50	10789	3656	7.5 yr	5	6	31.2	2.8
GSW2	13	130	49	0	130				29.0	3.4
GSW3	10	500	37	0	500				26.7	2
GSW4	3.5	19	6	0	19				25.8	3.6
GSW5	9	200	30	0	200				25.5	2.5
NSF1	11	300	50	0	300				23.5	3.3
NSF2	9	400	29	0	400				28.8	2.3
NSF3	14	200	49.5	0	200				26.0	2.4
NSF4	16	1100	58	0	1100				27.7	2.2
NSF5	7	42	24.5	0	42				28.9	2
W1	14	2000	125	25533	10511	7.5 yr	5	8	29.8	2
W2	14	1100	130	282	1194	7.5 yr	5	6	28.5	2
W3	14	600	101	0	600				24.7	2.1
W4	8	5	13	0	5				29.2	1
W5	10	1000	128	0	1000				27.2	2.3
W6	7.5	65	12	0	65				25.5	1
HD1	7.5	250	17	9	253	7.5 yr	4	6	24.9	4
HD2	11	150	31	0	150				29.1	2.9
HD3	4	18	6	0	18				29.3	3.7
HD4	9	250	21	0	250				25.3	2
HD5	15	150	43.5	18	156	7.5 yr	4	6	28.8	3.2
HDa1	15	600	61	15	605	7.5 yr	5	6	24.8	2.3
HDa2	10	120	17	0	120				28.8	2.7
HDa3	11	250	22	21	257	7.5 yr	5	6	26.4	2.2
HDa4	4	13	6	0	13				25.1	2.9
HDa5	6	100	7	0	100				24.7	3.7
NSFa1	8	60	7.6	45	75	5 yr	5	8	27.8	4
NSFa2	7	300	13	0	300				27.7	3.1
NSFa3	10	400	21.8	398	533	5 yr	5	8	26.5	3
NSFa4	5.5	60	3.5	0	60				26.2	3.6
NSFa5	14	180	13	0	180				26.2	3.3
NSFa6	10	200	14.5	0	200				23.9	3.8

Cone Details

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
CG1	1	Feed	38	2	7.5 yr	3	2
	2	Feed	34	4	10 yr	3	1
	3	Feed	30	4	10 yr	3	1
	4	Feed	24	2	7.5 yr	3	2
	5	Feed	28	4	10 yr	3	1
	6	Feed	24	1	7.5 yr	3	2
	7	Feed	27	2	7.5 yr	3	2
	8	Feed	22	1	7.5 yr	3	2
	9	Feed	21	1	7.5 yr	3	1
	10	Feed	27	1	7.5 yr	3	1
CG2	1	Non-feed	21	2	7.5 yr	3	2
	2	Non-feed	25	3	7.5 yr	3	2
	3	Non-feed	23	2	7.5 yr	3	2
	4	Non-feed	25	1	7.5 yr	3	2
	5	Non-feed	23	2	7.5 yr	3	4
	6	Non-feed	24	2	7.5 yr	3	2
	7	Non-feed	23	3	10 yr	3	1
	8	Non-feed	22	3	10 yr	3	1
	9	Non-feed	26	2	7.5 yr	4	4
	10	Non-feed	22	2	7.5 yr	3	4
CG3	1	Non-feed	20	0	5 yr	3	2
	2	Non-feed	31	0	5 yr	3	2
	3	Non-feed	29	0	5 yr	3	2
	4	Non-feed	29	0	5 yr	3	2
	5	Non-feed	33	0	5 yr	3	2
	6	Non-feed	32	0	5 yr	3	2
	7	Non-feed	31	0	5 yr	3	2
	8	Non-feed	25	0	5 yr	3	2
	9	Non-feed	27	0	5 yr	3	2
	10	Non-feed	27	0	5 yr	3	2
CG4	1	Feed	26	4	10 yr	4	1
	2	Feed	26	2	7.5 yr	3	2
	3	Feed	25	2	7.5 yr	3	3
	4	Feed	24	2	7.5 yr	3	2
	5	Feed	26	3	7.5 yr	3	2
	6	Feed	25	2	7.5 yr	3	1
CG5	1	Feed	27	4	10 yr	3	1
	2	Feed	29	2	7.5 yr	3	3
	3	Feed	24	2	7.5 yr	3	3
	4	Feed	24	2	7.5 yr	3	2
	5	Non-feed	24	4	10 yr	3	1
	6	Non-feed	22	4	10 yr	3	1
	7	Non-feed	28	2	7.5 yr	3	3
	8	Non-feed	28	4	10 yr	3	1
	9	Non-feed	22	4	10 yr	3	1
	10	Non-feed	31	2	7.5 yr	4	3

Cone Details 2 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
G1	1	Non-feed	26	2	7.5 yr	3	2
	2	Non-feed	23	2	7.5 yr	3	2
	3	Non-feed	25	3	7.5 yr	3	2
	4	Non-feed	23	2	7.5 yr	3	3
	5	Non-feed	23	2	7.5 yr	3	3
	6	Non-feed	27	2	7.5 yr	3	1
	7	Non-feed	22	2	7.5 yr	3	2
	8	Non-feed	22	1	7.5 yr	3	2
	9	Non-feed	24	2	7.5 yr	3	3
	10	Non-feed	25	1	7.5 yr	3	3
G2	1	Non-feed	28	0	7.5 yr	3	2
	2	Non-feed	27	0	7.5 yr	3	4
	3	Non-feed	29	0	7.5 yr	3	4
	4	Non-feed	28	0	7.5 yr	3	3
	5	Non-feed	26	0	7.5 yr	3	3
	6	Non-feed	26	0	7.5 yr	4	1
	7	Non-feed	33	0	7.5 yr	3	4
	8	Non-feed	30	0	7.5 yr	4	4
	9	Non-feed	21	0	7.5 yr	4	2
	10	Non-feed	26	0	7.5 yr	3	3
G3	1	Non-feed	21	1	7.5 yr	4	4
	2	Non-feed	25	1	7.5 yr	4	3
	3	Non-feed	23	1	7.5 yr	3	2
	4	Non-feed	28	1	7.5 yr	3	4
	5	Non-feed	24	1	7.5 yr	3	4
	6	Non-feed	24	1	7.5 yr	4	4
	7	Non-feed	20	1	7.5 yr	3	4
	8	Non-feed	28	1	7.5 yr	4	3
	9	Non-feed	29	1	7.5 yr	4	3
	10	Non-feed	24	1	7.5 yr	4	4
G4	1	Feed	26	0	7.5 yr	3	4
	2	Feed	29	0	7.5 yr	3	3
	3	Feed	26	0	7.5 yr	3	3
	4	Feed	30	0	7.5 yr	3	3
	5	Feed	26	0	7.5 yr	3	4
	6	Feed	27	0	7.5 yr	3	2
	7	Feed	16	0	7.5 yr	3	4
	8	Feed	30	0	7.5 yr	4	4
	9	Feed	30	0	7.5 yr	3	3
	10	Feed	23	0	7.5 yr	3	2

Cone Details 3 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
G5	1	Non-feed	26	0	10 yr	3	1
	2	Non-feed	24	0	10 yr	3	2
	3	Non-feed	24	0	10 yr	3	2
	4	Non-feed	25	0	10 yr	3	2
	5	Non-feed	25	0	10 yr	3	2
	6	Non-feed	24	0	10 yr	3	2
	7	Non-feed	25	0	10 yr	3	3
	8	Non-feed	24	0	10 yr	3	3
	9	Non-feed	23	0	10 yr	3	3
	10	Non-feed	22	0	10 yr	3	2
GSW1	1	Feed	30	3	7.5 yr	3	4
	2	Feed	30	2	7.5 yr	3	4
	3	Feed	32	3	7.5 yr	3	4
	4	Feed	33	3	7.5 yr	3	4
	5	Feed	31	3	7.5 yr	3	4
GSW2	1	Non-feed	30	3	7.5 yr	3	3
	2	Non-feed	30	3	7.5 yr	3	3
	3	Non-feed	32	3	7.5 yr	3	3
	4	Non-feed	30	4	7.5 yr	3	1
	5	Non-feed	30	3	7.5 yr	3	2
	6	Non-feed	28	4	10 yr	3	1
	7	Non-feed	28	4	10 yr	3	1
	8	Non-feed	32	2	7.5 yr	3	2
	9	Non-feed	29	4	2.5 y	3	1
	10	Non-feed	28	4	10 yr	3	1
GSW3	1	Non-feed	25	2	7.5 yr	3	3
	2	Non-feed	25	2	7.5 yr	3	4
	3	Non-feed	24	2	7.5 yr	3	3
	4	Non-feed	27	2	7.5 yr	3	2
	5	Non-feed	31	2	7.5 yr	3	3
	6	Non-feed	27	2	7.5 yr	4	3
	7	Non-feed	27	2	7.5 yr	3	3
	8	Non-feed	27	2	7.5 yr	3	4
	9	Non-feed	28	2	7.5 yr	3	4
	10	Non-feed	26	2	7.5 yr	3	3
GSW4	1	Non-feed	28	3	7.5 yr	4	1
	2	Non-feed	28	3	7.5 yr	4	1
	3	Non-feed	25	3	7.5 yr	4	1
	4	Non-feed	28	4	2.5 y	4	1
	5	Non-feed	24	4	2.5 y	3	1
	6	Non-feed	26	4	10 yr	3	1
	7	Non-feed	25	4	10 yr	3	1
	8	Non-feed	27	3	7.5 yr	4	4
	9	Non-feed	24	4	10 yr	3	1
	10	Non-feed	23	4	10 yr	3	1

Cone Details 4 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
GSW5	1	Non-feed	24	3	7.5 yr	3	1
	2	Non-feed	27	4	10 yr	3	1
	3	Non-feed	24	2	7.5 yr	3	1
	4	Non-feed	24	4	2.5 y	3	1
	5	Non-feed	23	2	7.5 yr	3	2
	6	Non-feed	25	2	7.5 yr	3	2
	7	Non-feed	29	2	7.5 yr	3	2
	8	Non-feed	27	2	7.5 yr	3	2
	9	Non-feed	26	2	7.5 yr	3	2
	10	Non-feed	26	2	7.5 yr	3	1
HD1	1	Feed	24	4	10 yr	3	1
	2	Feed	24	4	10 yr	3	1
	3	Feed	27	4	10 yr	3	1
	4	Feed	23	4	10 yr	3	1
	5	Feed	27	4	10 yr	3	1
	6	Feed	24	4	10 yr	3	1
	7	Feed	26	4	10 yr	3	1
	8	Feed	26	4	10 yr	3	1
	9	Feed	24	4	10 yr	3	1
	10	Feed	24	4	10 yr	3	2
HD2	1	Non-feed	28	4	2.5 y	4	1
	2	Non-feed	29	4	2.5 y	4	1
	3	Non-feed	27	3	7.5 yr	4	3
	4	Non-feed	26	2	7.5 yr	4	4
	5	Non-feed	26	2	7.5 yr	4	4
	6	Non-feed	21	2	7.5 yr	3	4
	7	Non-feed	29	4	2.5 y	4	1
	8	Non-feed	33	4	2.5 y	4	1
	9	Non-feed	25	2	7.5 yr	3	4
	10	Non-feed	47	2	7.5 yr	3	4
HD3	1	Non-feed	33	4	7.5 yr	4	1
	2	Non-feed	27	4	7.5 yr	4	1
	3	Non-feed	27	4	7.5 yr	4	1
	4	Non-feed	28	1	7.5 yr	4	4
	5	Non-feed	31	4	7.5 yr	4	1
	6	Non-feed	30	4	7.5 yr	4	1
	7	Non-feed	28	4	7.5 yr	4	1
	8	Non-feed	29	4	7.5 yr	4	1
	9	Non-feed	30	4	7.5 yr	4	1
	10	Non-feed	30	4	7.5 yr	4	1

Cone Details 5 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
HD4	1	Non-feed	25	2	7.5 yr	4	4
	2	Non-feed	27	2	7.5 yr	4	4
	3	Non-feed	25	2	7.5 yr	4	4
	4	Non-feed	28	2	7.5 yr	4	4
	5	Non-feed	26	2	7.5 yr	4	4
	6	Non-feed	24	2	7.5 yr	4	4
	7	Non-feed	24	2	7.5 yr	4	4
	8	Non-feed	26	2	7.5 yr	4	4
	9	Non-feed	25	2	7.5 yr	4	4
	10	Non-feed	23	2	7.5 yr	4	4
HD5	1	Feed	25	4	2.5 y	3	1
	2	Feed	27	4	2.5 y	3	1
	3	Feed	28	4	2.5 y	3	1
	4	Feed	24	4	2.5 y	3	1
	5	Feed	28	4	2.5 y	3	1
	6	Feed	31	4	2.5 y	3	1
	7	Feed	34	2	5 yr	3	1
	8	Feed	31	2	5 yr	3	1
	9	Feed	25	2	5 yr	3	1
	10	Feed	35	2	5 yr	3	2
HDa1	1	Feed	25	2	7.5 yr	3	3
	2	Feed	24	2	5 yr	3	1
	3	Feed	26	4	10 yr	3	1
	4	Feed	24	3	5 yr	3	1
	5	Feed	24	2	5 yr	3	1
	6	Feed	26	2	5 yr	3	2
	7	Feed	25	2	5 yr	3	1
	8	Feed	25	2	5 yr	3	3
	9	Feed	26	2	5 yr	3	2
	10	Feed	23	2	5 yr	3	3
HDa2	1	Non-feed	30	2	5 yr	3	1
	2	Non-feed	36	1	5 yr	3	3
	3	Non-feed	27	2	5 yr	3	1
	4	Non-feed	32	2	5 yr	3	1
	5	Non-feed	28	1	5 yr	3	3
	6	Non-feed	26	4	10 yr	3	1
	7	Non-feed	26	4	10 yr	3	1
	8	Non-feed	28	3	5 yr	3	1
	9	Non-feed	27	4	2.5 y	4	1
	10	Non-feed	28	4	7.5 yr	3	1

Cone Details 6 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
HDa3	1	Feed	26	2	7.5 yr	4	4
	2	Feed	25	2	7.5 yr	3	4
	3	Feed	25	2	7.5 yr	4	4
	4	Feed	27	2	5 yr	3	1
	5	Feed	24	2	7.5 yr	3	4
	6	Feed	25	2	7.5 yr	3	4
	7	Feed	29	2	7.5 yr	3	4
	8	Feed	27	2	7.5 yr	4	4
	9	Feed	31	2	7.5 yr	4	4
	10	Feed	25	4	7.5 yr	3	1
HDa4	1	Non-feed	27	1	7.5 yr	3	3
	2	Non-feed	31	1	2.5 yr	3	1
	3	Non-feed	22	1	5 yr	3	3
	4	Non-feed	28	2	2.5 y	3	1
	5	Non-feed	27	4	10 yr	3	1
	6	Non-feed	26	4	10 yr	3	1
	7	Non-feed	28	4	10 yr	3	1
	8	Non-feed	22	4	10 yr	3	1
	9	Non-feed	17	4	10 yr	3	1
	10	Non-feed	23	4	10 yr	3	1
HDa5	1	Non-feed	24	3	7.5 yr	3	4
	2	Non-feed	27	4	10 yr	3	1
	3	Non-feed	24	4	10 yr	3	1
	4	Non-feed	23	4	10 yr	3	1
	5	Non-feed	24	4	10 yr	3	1
	6	Non-feed	19	4	10 yr	3	1
	7	Non-feed	29	4	10 yr	3	1
	8	Non-feed	30	4	10 yr	3	1
	9	Non-feed	23	3	7.5 yr	4	4
	10	Non-feed	24	3	5 yr	3	2
NSF1	1	Non-feed	23	4	10 yr	3	1
	2	Non-feed	20	4	2.5 y	3	1
	3	Non-feed	25	4	2.5 y	3	1
	4	Non-feed	23	4	2.5 y	3	1
	5	Non-feed	23	4	10 yr	3	1
	6	Non-feed	23	3	7.5 yr	2.5	2
	7	Non-feed	25	3	7.5 yr	2.5	1
	8	Non-feed	23	3	7.5 yr	3	1
	9	Non-feed	24	3	7.5 yr	3	1
	10	Non-feed	26	1	7.5 yr	3	3

Cone Details 7 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
NSF2	1	Non-feed	36	2	7.5 yr	4	4
	2	Non-feed	27	3	7.5 yr	4	3
	3	Non-feed	29	1	7.5 yr	3	2
	4	Non-feed	34	1	7.5 yr	3	4
	5	Non-feed	29	3	7.5 yr	3	2
	6	Non-feed	26	3	7.5 yr	4	3
	7	Non-feed	28	3	7.5 yr	3	3
	8	Non-feed	24	4	10 yr	3	1
	9	Non-feed	31	1	7.5 yr	3	2
NSF3	1	Non-feed	28	1	7.5 yr	4	4
	2	Non-feed	27	1	7.5 yr	4	4
	3	Non-feed	28	2	7.5 yr	4	4
	4	Non-feed	27	4	10 yr	4	1
	5	Non-feed	25	4	10 yr	4	1
	6	Non-feed	20	4	10 yr	4	1
	7	Non-feed	22	1	7.5 yr	3	3
	8	Non-feed	34	1	7.5 yr	3	3
	9	Non-feed	26	2	7.5 yr	3	3
	10	Non-feed	23	4	7.5 yr	4	1
NSF4	10	Non-feed	24	4	10 yr	3	1
	1	Non-feed	28	2	7.5 yr	4	4
	2	Non-feed	27	1	7.5 yr	4	4
	3	Non-feed	28	2	7.5 yr	4	4
	4	Non-feed	29	1	7.5 yr	4	4
	5	Non-feed	26	2	7.5 yr	4	4
	6	Non-feed	29	2	7.5 yr	4	4
	7	Non-feed	25	4	10 yr	4	1
	8	Non-feed	29	4	10 yr	4	1
	9	Non-feed	27	2	7.5 yr	4	4
NSF5	10	Non-feed	29	2	7.5 yr	3	4
	1	Non-feed	26	3	7.5 yr	4	4
	2	Non-feed	29	3	7.5 yr	4	4
	3	Non-feed	31	1	7.5 yr	4	4
	4	Non-feed	34	1	7.5 yr	4	3
	5	Non-feed	26	2	7.5 yr	4	4
	6	Non-feed	27	3	7.5 yr	3	2
	7	Non-feed	37	1	7.5 yr	3	2
	8	Non-feed	26	2	7.5 yr	4	3
	9	Non-feed	26	2	7.5 yr	4	3
10	Non-feed	27	2	7.5 yr	3	1	

Cone details 8 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
NSFa1	1	Feed	31	4	5 yr	3	1
	2	Feed	32	4	5 yr	3	1
	3	Feed	30	4	5 yr	3	1
	4	Feed	25	4	5 yr	3	1
	5	Feed	31	4	5 yr	3	1
	6	Feed	28	4	5 yr	3	1
	7	Feed	27	4	5 yr	3	1
	8	Feed	28	4	5 yr	3	1
	9	Feed	21	4	5 yr	3	1
	10	Feed	25	4	5 yr	3	1
NSFa2	1	Non-feed	32	3	5 yr	4	3
	2	Non-feed	30	3	5 yr	4	3
	3	Non-feed	32	4	10 yr	4	1
	4	Non-feed	25	3	7.5 yr	4	3
	5	Non-feed	27	3	7.5 yr	4	3
	6	Non-feed	26	3	7.5 yr	4	3
	7	Non-feed	27	3	7.5 yr	4	3
	8	Non-feed	28	3	7.5 yr	4	3
	9	Non-feed	28	3	7.5 yr	4	2
	10	Non-feed	22	3	7.5 yr	4	3
NSFa3	1	Feed	26	3	7.5 yr	4	2
	2	Feed	23	3	7.5 yr	4	3
	3	Feed	27	3	7.5 yr	4	4
	4	Feed	25	3	7.5 yr	4	2
	5	Feed	29	3	7.5 yr	4	3
	6	Feed	26	3	7.5 yr	4	4
	7	Feed	26	3	7.5 yr	4	1
	8	Feed	30	3	7.5 yr	3	2
	9	Feed	26	3	7.5 yr	3	2
	10	Feed	27	3	7.5 yr	4	1
NSFa4	1	Non-feed	28	4	7.5 yr	3	2
	2	Non-feed	26	4	10 yr	3	1
	3	Non-feed	28	3	7.5 yr	3	2
	4	Non-feed	28	4	7.5 yr	3	2
	5	Non-feed	23	4	10 yr	3	1
	6	Non-feed	27	3	7.5 yr	3	2
	7	Non-feed	23	4	10 yr	3	1
	8	Non-feed	24	3	7.5 yr	3	2
	9	Non-feed	28	4	7.5 yr	3	1
	10	Non-feed	27	3	7.5 yr	3	1

Cone Details 9 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
NSFa5	1	Non-feed	26	4	10 yr	3	1
	2	Non-feed	22	3	7.5 yr	3	2
	3	Non-feed	37	4	10 yr	3	1
	4	Non-feed	28	3	7.5 yr	3	2
	5	Non-feed	27	4	10 yr	3	1
	6	Non-feed	27	3	5 yr	3	1
	7	Non-feed	24	3	5 yr	3	1
	8	Non-feed	25	3	5 yr	3	1
	9	Non-feed	23	3	5 yr	3	1
	10	Non-feed	23	3	5 yr	3	1
NSFa6	1	Non-feed	26	3	5 yr	3	2
	2	Non-feed	27	4	5 yr	4	1
	3	Non-feed	22	3	5 yr	3	2
	4	Non-feed	23	4	5 yr	4	1
	5	Non-feed	21	4	5 yr	3	1
	6	Non-feed	28	4	5 yr	4	1
	7	Non-feed	24	4	5 yr	4	1
	8	Non-feed		4	5 yr	4	1
	9	Non-feed	22	4	5 yr	4	1
	10	Non-feed	22	4	5 yr	4	1
W1	1	Feed	26	2	7.5 yr	4	4
	2	Feed	28	3	7.5 yr	4	4
	3	Feed	30	2	7.5 yr	4	4
	4	Feed	26	2	7.5 yr	4	4
	5	Feed	24	2	7.5 yr	4	4
	6	Feed	26	2	7.5 yr	4	4
	7	Feed	31	2	7.5 yr	4	4
	8	Feed	32	2	7.5 yr	4	4
	9	Feed	37	2	7.5 yr	4	4
	10	Feed	38	1	7.5 yr	4	4
W2	1	Feed	30	2	7.5 yr	3	3
	2	Feed	27	2	7.5 yr	3	4
	3	Feed	28	2	7.5 yr	4	2
	4	Feed	31	2	7.5 yr	4	4
	5	Feed	28	2	7.5 yr	4	4
	6	Feed	31	2	7.5 yr	4	3
	7	Feed	26	2	7.5 yr	4	3
	8	Feed	28	2	7.5 yr	4	2
	9	Feed	30	2	7.5 yr	4	3
	10	Feed	26	2	7.5 yr	4	3

Cone Details 10 – continued

Site	Replicate	Tree Feeding Status	Cone Softness (mm)	Cone Greyness	Cone Colour (redness)		
					Hue	Value	Chroma
W3	1	Non-feed	18	1	7.5 yr	3	4
	2	Non-feed	24	0	7.5 yr	3	3
	3	Non-feed	22	4	2.5 y	3	1
	4	Non-feed	29	2	7.5 yr	3	4
	5	Non-feed	24	2	7.5 yr	3	4
	6	Non-feed	26	1	7.5 yr	3	4
	7	Non-feed	27	4	10 yr	3	1
	8	Non-feed	26	3	10 yr	3	2
	9	Non-feed	24	3	7.5 yr	4	4
	10	Non-feed	27	1	7.5 yr	4	4
W4	1	Non-feed	26	1	10 yr	3	2
	2	Non-feed	31	1	10 yr	3	2
	3	Non-feed	31	1	10 yr	3	2
	4	Non-feed	30	1	10 yr	3	2
	5	Non-feed	28	1	10 yr	3	2
W5	1	Non-feed	26	1	7.5 yr	3	3
	2	Non-feed	31	2	7.5 yr	3	3
	3	Non-feed	28	2	7.5 yr	3	4
	4	Non-feed	27	2	7.5 yr	3	3
	5	Non-feed	30	2	7.5 yr	3	3
	6	Non-feed	27	2	7.5 yr	3	3
	7	Non-feed	28	2	7.5 yr	3	3
	8	Non-feed	25	3	10 yr	4	2
	9	Non-feed	24	4	10 yr	3	1
	10	Non-feed	26	3	7.5 yr	4	3
W6	1	Non-feed	26	1	7.5 yr	3	2
	2	Non-feed	26	1	7.5 yr	3	2
	3	Non-feed	29	1	7.5 yr	3	1
	4	Non-feed	23	1	7.5 yr	3	2
	5	Non-feed	24	1	7.5 yr	3	1
	6	Non-feed	25	1	7.5 yr	3	2
	7	Non-feed	26	1	7.5 yr	3	1
	8	Non-feed	24	1	7.5 yr	3	1
	9	Non-feed	24	1	7.5 yr	3	4
	10	Non-feed	28	1	7.5 yr	3	1

6.8 APPENDIX 8

Raw Data for *C. lathami* Feeding (Chapter 3)Feed Rates for *A. littoralis* cones

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
Bon	Adult	Female	17	1	Pair
Bon	Adult	Female	52	4	Pair
Bon	Adult	Female	35	3	Pair
Bon	Adult	Female	59	4	Pair
Bon	Adult	Female	57	4	Pair
Bon	Adult	Female	55	4	Pair
Bon	Adult	Male	101	3	Pair
Bon	Adult	Male	64	1	Pair
Bon	Adult	Male	16	2	Pair
Bon	Adult	Male	91	4	Pair
Bon	Adult	Male	34	2	Pair
Bon	Adult	Male	50	4	Pair
Bon	Adult	Male	27	2	Pair
Bon	Adult	Male	65	4	Pair
Bon	Adult	Male	46	4	Pair
Bon	Adult	Male	78	8	Pair
Bon	Adult	Male	60	4	Pair
Bon	Adult	Male	91	7	Pair
Bon	Adult	Male	90	7	Pair
Bon	Adult	Male	80	8	Pair
Bon	Adult	Male	121	5	Pair
Bon	Adult	Male	75	4	Pair
Bon	Adult	Male	104	4	Pair
Bon	Adult	Male	103	7	Pair
Bon	Adult	Male	28	2	Pair
Bon	Adult	Male	135	6	Pair
Bon	Adult	Male	87	3	Pair
Bon	Adult	Male	64	4	Pair
Bon	Adult	Male	73	3	Pair
Bon	Adult	Male	96	5	Pair
Bon	Adult	Male	117	4	Pair
Bon	Adult	Male	84	5	Pair
Bon	Adult	Male	80	8	Pair
Bon	Adult	Male	81	4	Pair
F BON 1	Adult	Female	74	3	Pair
F BON 1	Adult	Female	81	4	Pair
F BON 1	Adult	Female	69	5	Pair
F BON 1	Adult	Female	66		Pair
F BON 1	Adult	Female	149		Pair
F BON 1	Adult	Female	88		Pair

Feed Rates for *A. littoralis* cones 2 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F BON 1	Adult	Female	70	2	Pair
F BON 1	Adult	Female	38	1	Pair
F BON 1	Adult	Female	55	2	Pair
F BON 1	Adult	Male	72	4	Pair
F BON 1	Adult	Male	67	4	Pair
F BON 1	Adult	Male	73	3	Pair
F BON 1	Adult	Male	57	1	Pair
F BON 1	Adult	Male	69	2	Pair
F BON 1	Adult	Male	53	2	Pair
F BON 1	Adult	Male	79	2	Pair
F BON 1	Adult	Male	103	2	Pair
F BON 1	Adult	Male	91	1	Pair
F BON 1	Adult	Male	111	4	Pair
F BON 1	Adult	Male	81	3	Pair
F BON 1	Adult	Male	51	1	Pair
F BON 1	Adult	Male	21	1	Pair
F BON 1	Adult	Male	96	4	Pair
F BON 1	Adult	Male	59	2	Pair
F BON 1	Adult	Male	18	1	Pair
F BON 1	Adult	Male	81	4	Pair
F BON 1	Adult	Male	92	4	Pair
F BON 1	Adult	Male	94	5	Pair
F BON 2	Adult	Female	85	3	Pair
F BON 2	Adult	Female	38	2	Pair
F BON 2	Adult	Female	83	4	Pair
F BON 2	Adult	Female	84	7	Pair
F BON 2	Adult	Female	80	2	Pair
F BON 2	Adult	Female	8	1	Pair
F BON 2	Adult	Female	110	4	Pair
F BON 2	Adult	Female	132	4	Pair
F CLAG 1	Adult	Female	35	1	Pair with juvenile
F CLAG 1	Adult	Female	56	4	Pair with juvenile
F CLAG 1	Adult	Female	73	3	Pair with juvenile
F CLAG 1	Adult	Female	4	1	Pair with juvenile
F CLAG 1	Adult	Female	68	6	Pair with juvenile
F CLAG 1	Adult	Female	68	2	Pair with juvenile
F CLAG 1	Adult	Male	103	1	Pair with juvenile
F CLAG 1	Adult	Male	49	5	Pair with juvenile
F CLAG 1	Adult	Male	43	3	Pair with juvenile
F CLAG 1	Adult	Male	46	1	Pair with juvenile
F CLAG 1	Adult	Male	43	3	Pair with juvenile
F CLAG 1	Adult	Male	101	4	Pair with juvenile
F CLAG 1	Adult	Male	76	3	Pair with juvenile
F CLAG 1	Adult	Male	68	4	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	67	2	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	96	2	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	2	1	Pair with juvenile

Feed Rates for *A. littoralis* cones 3 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F CLAG 1	Juvenile	Unsexed	54	3	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	3	1	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	56	4	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	51	3	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	2	1	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	73	4	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	40	5	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	48	7	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	106	5	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	75	2	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	101	3	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	63	1	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	80	4	Pair with juvenile
F CLAG 1	Juvenile	Unsexed	106	5	Pair with juvenile
F Gil 2	Adult	Male	130	2	Pair
F Gil 2	Adult	Male	42	2	Pair
F Gil 2	Adult	Male	131	4	Pair
F Gil 2	Adult	Male	51	2	Pair
F Gil 2	Adult	Male	29	2	Pair
F Gil 2	Adult	Male	102	4	Pair
F Gil 2	Adult	Male	121	4	Pair
F Gil 2	Adult	Male	111	2	Pair
F Gil 2	Adult	Male	38	2	Pair
F Gil 2	Adult	Male	110	2	Pair
F Gil 2	Adult	Male	51	4	Pair
F Gil 2	Adult	Male	24	2	Pair
F Gil 2	Adult	Female	60	3	Pair
F Gil 2	Adult	Female	25	1	Pair
F Gil 2	Adult	Female	39	3	Pair
F Gil 2	Adult	Female	101	2	Pair
F Gil 2	Adult	Female	32	2	Pair
F Gil 2	Adult	Female	111	4	Pair
F Gil 2	Adult	Female	102	2	Pair
F Gil 2	Adult	Female	118	5	Pair
F Gil 2	Adult	Female	117	6	Pair
F Gil 2	Adult	Female	60	4	Pair
F Gil 2	Adult	Female	53	2	Pair
F GUGC 1	Adult	Female	13	4	Pair with juvenile
F GUGC 1	Adult	Female	79	3	Pair with juvenile
F GUGC 1	Adult	Female	74	7	Pair with juvenile
F GUGC 1	Adult	Female	3	1	Pair with juvenile
F GUGC 1	Adult	Female	40	4	Pair with juvenile
F GUGC 1	Adult	Female	97	4	Pair with juvenile
F GUGC 1	Adult	Female	2	1	Pair with juvenile
F GUGC 1	Adult	Female	53		Pair with juvenile
F GUGC 1	Adult	Female	34		Pair with juvenile

Feed Rates for *A. littoralis* cones 4 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F GUGC 1	Adult	Male	19	1	Pair with juvenile
F GUGC 1	Adult	Male	85	5	Pair with juvenile
F GUGC 1	Adult	Male	26	3	Pair with juvenile
F GUGC 1	Adult	Male	81	5	Pair with juvenile
F GUGC 1	Adult	Male	56	2	Pair with juvenile
F GUGC 1	Adult	Male	51	2	Pair with juvenile
F GUGC 1	Adult	Male	91	5	Pair with juvenile
F GUGC 1	Juvenile	Unsexed	138	8	Pair with juvenile
F GUGC 3	Adult	Male	48	2	Pair with juvenile
F GUGC 3	Adult	Male	46	3	Pair with juvenile
F GUGC 3	Adult	Male	50	2	Pair with juvenile
F GUGC 3	Adult	Male	51	3	Pair with juvenile
F GUGC 3	Adult	Male	66	4	Pair with juvenile
F GUGC 3	Adult	Male	43	3	Pair with juvenile
F GUGC 3	Adult	Male	68	4	Pair with juvenile
F GUGC 3	Adult	Male	57	3	Pair with juvenile
F GUGC 3	Adult	Male	51	3	Pair with juvenile
F GUGC 3	Adult	Male	46	3	Pair with juvenile
F GUGC 3	Adult	Male	36	1	Pair with juvenile
F GUGC 3	Adult	Male	48	3	Pair with juvenile
F GUGC 3	Adult	Male	38	2	Pair with juvenile
F NFS 7	Adult	Female	75	3	Pair
F NFS 7	Adult	Female	97	9	Pair
F NFS 7	Adult	Female	79	6	Pair
F NFS 7	Adult	Female	84	10	Pair
F NFS 7	Adult	Female	48	2	Pair
F NFS 7	Adult	Female	79	4	Pair
F NFS 7	Adult	Female	87	7	Pair
F NFS 7	Adult	Female	77	5	Pair
F NFS 7	Adult	Female	31	3	Pair
F NFS 7	Adult	Female	88	9	Pair
F NFS 7	Adult	Female	87	11	Pair
F NFS 7	Adult	Female	81	8	Pair
F NFS 7	Adult	Female	59	5	Pair
F NFS 7	Adult	Female	120	5	Pair
F NFS 7	Adult	Male	11	2	Pair
F NFS 7	Adult	Male	29	3	Pair
F NFS 7	Adult	Male	37	4	Pair
F NFS 7	Adult	Male	41	2	Pair
F NFS 7	Adult	Male	18	2	Pair
F NFS 7	Adult	Male	56	3	Pair
F NFS 7	Adult	Male	97	5	Pair
F NFS 7	Adult	Male	66	4	Pair
F NFS 7	Adult	Male	95	4	Pair
F NFS 7	Adult	Male	45	2	Pair
F NFS 7	Adult	Male	51	4	Pair

Feed Rates for *A. littoralis* cones 5 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 2	Adult	Female	116	4	Pair
F NSF 2	Adult	Female	100	9	Pair
F NSF 2	Adult	Female	118	9	Pair
F NSF 2	Adult	Female	115	11	Pair
F NSF 2	Adult	Female	109	12	Pair
F NSF 2	Adult	Female	18	1	Pair
F NSF 2	Adult	Female	11	1	Pair
F NSF 2	Adult	Female	128	8	Pair
F NSF 2	Adult	Female	64	4	Pair
F NSF 2	Adult	Female	5	1	Pair
F NSF 2	Adult	Female	59	5	Pair
F NSF 2	Adult	Female	103	6	Pair
F NSF 2	Adult	Female	98	5	Pair
F NSF 2	Adult	Female	82	3	Pair
F NSF 2	Adult	Female	111	9	Pair
F NSF 2	Adult	Female	119	4	Pair
F NSF 2	Adult	Female	12	1	Pair
F NSF 2	Adult	Female	76	5	Pair
F NSF 2	Adult	Female	87	8	Pair
F NSF 2	Adult	Female	104	7	Pair
F NSF 2	Adult	Female	91	7	Pair
F NSF 2	Adult	Female	85	7	Pair
F NSF 2	Adult	Female	76	3	Pair
F NSF 2	Adult	Female	99	6	Pair
F NSF 2	Adult	Female	50	2	Pair
F NSF 2	Adult	Female	123	5	Pair
F NSF 2	Adult	Female	103	7	Pair
F NSF 2	Adult	Female	123	6	Pair
F NSF 2	Adult	Female	98	2	Pair
F NSF 2	Adult	Female	87	4	Pair
F NSF 2	Adult	Female	88	4	Pair
F NSF 2	Adult	Female	69	4	Pair
F NSF 2	Adult	Female	31	2	Pair
F NSF 2	Adult	Female	71	3	Pair
F NSF 2	Adult	Female	90	4	Pair
F NSF 2	Adult	Female	72	6	Pair
F NSF 2	Adult	Female	98	5	Pair
F NSF 2	Adult	Male	143	6	Pair
F NSF 2	Adult	Male	122	7	Pair
F NSF 2	Adult	Male	26	1	Pair
F NSF 2	Adult	Male	90		Pair
F NSF 2	Adult	Male	141	3	Pair
F NSF 2	Adult	Male	34	1	Pair
F NSF 2	Adult	Male	86	3	Pair
F NSF 2	Adult	Male	49	3	Pair
F NSF 2	Adult	Male	70	1	Pair

Feed Rates for *A. littoralis* cones 6 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 2	Adult	Male	42	1	Pair
F NSF 2	Adult	Male	78	1	Pair
F NSF 2	Adult	Male	69	1	Pair
F NSF 2	Adult	Male	57	4	Pair
F NSF 2	Adult	Male	35	1	Pair
F NSF 2	Adult	Male	60	3	Pair
F NSF 2	Adult	Male	56	1	Pair
F NSF 2	Adult	Male	52	1	Pair
F NSF 2	Adult	Male	71	4	Pair
F NSF 2	Adult	Male	45	1	Pair
F NSF 2	Adult	Male	46	4	Pair
F NSF 2	Adult	Male	98	3	Pair
F NSF 3	Adult	Male	46	3	Pair
F NSF 3	Adult	Male	62	2	Pair
F NSF 3	Adult	Male	69	2	Pair
F NSF 3	Adult	Male	63	2	Pair
F NSF 3	Adult	Male	68	2	Pair
F NSF 3	Adult	Male	50	4	Pair
F NSF 3	Adult	Male	60	3	Pair
F NSF 3	Adult	Male	39	1	Pair
F NSF 3	Adult	Male	57	3	Pair
F NSF 3	Adult	Male	56	3	Pair
F NSF 3	Adult	Male	38	3	Pair
F NSF 3	Adult	Male	67	4	Pair
F NSF 3	Adult	Male	69	4	Pair
F NSF 3	Adult	Male	67	5	Pair
F NSF 3	Adult	Male	64	2	Pair
F NSF 3	Adult	Male	47	5	Pair
F NSF 3	Adult	Male	59	2	Pair
F NSF 3	Adult	Male	9	1	Pair
F NSF 3	Adult	Male	23	1	Pair
F NSF 3	Adult	Male	63	4	Pair
F NSF 3	Adult	Male	25	2	Pair
F NSF 3	Adult	Male	38	1	Pair
F NSF 3	Adult	Male	25	1	Pair
F NSF 3	Adult	Male	58	1	Pair
F NSF 3	Adult	Male	48	2	Pair
F NSF 3	Adult	Male	61	1	Pair
F NSF 3	Adult	Male	31	1	Pair
F NSF 3	Adult	Male	29	1	Pair
F NSF 3	Adult	Male	12	1	Pair
F NSF 3	Adult	Male	80	3	Pair
F NSF 3	Adult	Male	57	3	Pair
F NSF 3	Adult	Male	62	3	Pair
F NSF 3	Adult	Male	66	5	Pair
F NSF 3	Adult	Male	56	2	Pair

Feed Rates for *A. littoralis* cones 7 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 3	Adult	Male	60	3	Pair
F NSF 3	Adult	Male	38		Pair
F NSF 3	Adult	Male	45	3	Pair
F NSF 3	Adult	Male	43		Pair
F NSF 3	Adult	Male	46	2	Pair
F NSF 3	Adult	Male	51	3	Pair
F NSF 3	Adult	Male	26	2	Pair
F NSF 3	Adult	Male	57	2	Pair
F NSF 3	Adult	Male	50	1	Pair
F NSF 3	Adult	Male	44	3	Pair
F NSF 3	Adult	Male	76	3	Pair
F NSF 3	Adult	Male	85	2	Pair
F NSF 3	Adult	Male	72	3	Pair
F NSF 3	Adult	Male	55	1	Pair
F NSF 3	Adult	Male	134	7	Pair
F NSF 3	Adult	Male	117	7	Pair
F NSF 3	Adult	Male	95	4	Pair
F NSF 3	Adult	Male	139	5	Pair
F NSF 3	Adult	Male	125	5	Pair
F NSF 3	Adult	Male	82	2	Pair
F NSF 3	Adult	Male	57	4	Pair
F NSF 3	Adult	Male	30	2	Pair
F NSF 3	Adult	Male	42	3	Pair
F NSF 3	Adult	Male	51	3	Pair
F NSF 3	Adult	Male	46	3	Pair
F NSF 3	Adult	Male	29	2	Pair
F NSF 3	Adult	Male	52	3	Pair
F NSF 3	Adult	Male	50	3	Pair
F NSF 3	Adult	Male	62	5	Pair
F NSF 3	Adult	Male	34	2	Pair
F NSF 3	Adult	Male	58	3	Pair
F NSF 3	Adult	Male	61	3	Pair
F NSF 3	Adult	Male	61	4	Pair
F NSF 3	Adult	Male	62	5	Pair
F NSF 3	Adult	Male	21	3	Pair
F NSF 3	Adult	Male	54	4	Pair
F NSF 3	Adult	Male	32	3	Pair
F NSF 3	Adult	Male	74	5	Pair
F NSF 3	Adult	Male	54		Pair
F NSF 3	Adult	Male	44	4	Pair
F NSF 3	Adult	Male	56	1	Pair
F NSF 3	Adult	Male	48	3	Pair
F NSF 3	Adult	Male	49	4	Pair
F NSF 3	Adult	Male	44	3	Pair
F NSF 3	Adult	Male	60	2	Pair
F NSF 3	Adult	Male	57	3	Pair

Feed Rates for *A. littoralis* cones 8 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 3	Adult	Male	104	3	Pair
F NSF 3	Adult	Male	47	2	Pair
F NSF 3	Adult	Male	69	3	Pair
F NSF 3	Adult	Male	82	2	Pair
F NSF 3	Adult	Male	50	4	Pair
F NSF 3	Adult	Female	130	6	Pair
F NSF 3	Adult	Female	81	3	Pair
F NSF 3	Adult	Female	90	4	Pair
F NSF 3	Adult	Female	124		Pair
F NSF 3	Adult	Female	43	2	Pair
F NSF 3	Adult	Female	75	2	Pair
F NSF 3	Adult	Female	100	6	Pair
F NSF 3	Adult	Female	83	5	Pair
F NSF 3	Adult	Female	73	4	Pair
F NSF 3	Adult	Female	105	4	Pair
F NSF 3	Adult	Female	71	2	Pair
F NSF 3	Adult	Female	85	3	Pair
F NSF 3	Adult	Female	107	6	Pair
F NSF 3	Adult	Female	90	7	Pair
F NSF 3	Adult	Female	65	3	Pair
F NSF 3	Adult	Female		2	Pair
F NSF 3	Adult	Female		1	Pair
F NSF 3	Adult	Female	9	3	Pair
F NSF 3	Adult	Female	16	3	Pair
F NSF 3	Adult	Female	55	3	Pair
F NSF 3	Adult	Female	31	1	Pair
F NSF 3	Adult	Female	33	1	Pair
F NSF 3	Adult	Female	128	4	Pair
F NSF 3	Adult	Female	64	5	Pair
F NSF 3	Adult	Female	49	2	Pair
F NSF 3	Adult	Female	71	2	Pair
F NSF 3	Adult	Female	54	1	Pair
F NSF 3	Adult	Female	70	5	Pair
F NSF 3	Adult	Female	73	2	Pair
F NSF 3	Adult	Female	7	1	Pair
F NSF 3	Adult	Female	59	2	Pair
F NSF 3	Adult	Female	93	4	Pair
F NSF 3	Adult	Female	43	5	Pair
F NSF 3	Adult	Female	48	1	Pair
F NSF 3	Adult	Female	76	4	Pair
F NSF 3	Adult	Female	66	3	Pair
F NSF 3	Adult	Female	98	5	Pair
F NSF 3	Adult	Female	84	8	Pair
F NSF 3	Adult	Female	50	3	Pair
F NSF 3	Adult	Female	109	8	Pair
F NSF 3	Adult	Female	12	1	Pair

Feed Rates for *A. littoralis* cones 9 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 3	Adult	Female	57	3	Pair
F NSF 3	Adult	Female	90	5	Pair
F NSF 3	Adult	Female	83	6	Pair
F NSF 3	Adult	Female	50	3	Pair
F NSF 3	Adult	Female	144	8	Pair
F NSF 3	Adult	Female	147	5	Pair
F NSF 3	Adult	Female	70	4	Pair
F NSF 3	Adult	Female	135	3	Pair
F NSF 3	Adult	Female	42	2	Pair
F NSF 3	Adult	Female	32	2	Pair
F NSF 3	Adult	Female	49	2	Pair
F NSF 3	Adult	Female	49	6	Pair
F NSF 3	Adult	Female	56	3	Pair
F NSF 3	Adult	Female	75	3	Pair
F NSF 3	Adult	Female	44	3	Pair
F NSF 3	Adult	Female	60	4	Pair
F NSF 3	Adult	Female	62	4	Pair
F NSF 3	Adult	Female	54	5	Pair
F NSF 3	Adult	Female	73	6	Pair
F NSF 3	Adult	Female	65	3	Pair
F NSF 3	Adult	Female	53	2	Pair
F NSF 3	Adult	Female	47	3	Pair
F NSF 3	Adult	Female	68	3	Pair
F NSF 3	Adult	Female	48	3	Pair
F NSF 3	Adult	Female	52	4	Pair
F NSF 3	Adult	Female	56	3	Pair
F NSF 3	Adult	Female	57	2	Pair
F NSF 3	Adult	Female	62	7	Pair
F NSF 3	Adult	Female	32	2	Pair
F NSF 3	Adult	Female	57	3	Pair
F NSF 3	Adult	Female	15	1	Pair
F NSF 3	Adult	Female	55	3	Pair
F NSF 3	Adult	Female	121	12	Pair
F NSF 3	Adult	Female	78	7	Pair
F NSF 3	Adult	Female	78	5	Pair
F NSF 3	Adult	Female	7	1	Pair
F NSF 3	Adult	Female	56		Pair
F NSF 3	Adult	Female	19	1	Pair
F NSF 3	Adult	Female	88	4	Pair
F NSF 3	Adult	Female	98	4	Pair
F NSF 3	Adult	Female	127	7	Pair
F NSF 4	Adult	Female	32	2	Pair
F NSF 4	Adult	Female	92		Pair
F NSF 4	Adult	Female	24		Pair
F NSF 4	Adult	Female	100	5	Pair
F NSF 4	Adult	Female	1	1	Pair

Feed Rates for *A. littoralis* cones 10 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 4	Adult	Female	68	7	Pair
F NSF 4	Adult	Female	73	6	Pair
F NSF 4	Adult	Female	88	10	Pair
F NSF 4	Adult	Female	42		Pair
F NSF 4	Adult	Female	31	1	Pair
F NSF 4	Adult	Female	68	3	Pair
F NSF 4	Adult	Female	77	3	Pair
F NSF 4	Adult	Female	72	4	Pair
F NSF 4	Adult	Female	35		Pair
F NSF 4	Adult	Female	31	1	Pair
F NSF 4	Adult	Male	42	2	Pair
F NSF 4	Adult	Male	48	2	Pair
F NSF 4	Adult	Male	45	4	Pair
F NSF 4	Adult	Male	52		Pair
F NSF 4	Adult	Male	62		Pair
F NSF 4	Adult	Male	2		Pair
F NSF 4	Adult	Male	62		Pair
F NSF 4	Adult	Male	73		Pair
F NSF 4	Adult	Male	52	3	Pair
F NSF 4	Adult	Male	69		Pair
F NSF 4	Adult	Male	65		Pair
F NSF 4	Adult	Male	82	3	Pair
F NSF 4	Adult	Male	84	3	Pair
F NSF 4	Adult	Male	78	5	Pair
F NSF 4	Adult	Male	62	4	Pair
F NSF 4	Adult	Male	76	3	Pair
F NSF 4	Adult	Male	78	5	Pair
F NSF 4	Adult	Male	22	2	Pair
F NSF 4	Adult	Male	59	2	Pair
F NSF 4	Adult	Male	80		Pair
F NSF 4	Adult	Male	75	5	Pair
F NSF 4	Adult	Male	6	1	Pair
F NSF 4	Adult	Male	63	2	Pair
F NSF 4	Adult	Male	63	7	Pair
F NSF 4	Adult	Male	89	6	Pair
F NSF 4	Adult	Male	84	7	Pair
F NSF 4	Adult	Male	85	6	Pair
F NSF 4	Adult	Male	77	4	Pair
F NSF 4	Adult	Male	42	3	Pair
F NSF 4	Adult	Male	2	1	Pair
F NSF 4	Adult	Male	65	4	Pair
F NSF 4	Adult	Male	53	2	Pair
F NSF 4	Adult	Male	37	1	Pair
F NSF 4	Adult	Male	67	3	Pair
F NSF 4	Adult	Male	64	5	Pair
F NSF 4	Adult	Male	49		Pair

Feed Rates for *A. littoralis* cones 11 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 4	Adult	Male	32	3	Pair
F NSF 5	Adult	Male	66	5	Pair with juvenile
F NSF 5	Adult	Male	52	2	Pair with juvenile
F NSF 5	Adult	Male	34	2	Pair with juvenile
F NSF 5	Adult	Male	44	3	Pair with juvenile
F NSF 5	Adult	Male	13	1	Pair with juvenile
F NSF 5	Adult	Male	6	1	Pair with juvenile
F NSF 5	Adult	Male	59	2	Pair with juvenile
F NSF 5	Adult	Male	86	5	Pair with juvenile
F NSF 5	Adult	Male	58	3	Pair with juvenile
F NSF 5	Adult	Male	64	5	Pair with juvenile
F NSF 5	Adult	Male	7	1	Pair with juvenile
F NSF 5	Adult	Male	65	3	Pair with juvenile
F NSF 5	Adult	Male	76	2	Pair with juvenile
F NSF 5	Adult	Male	46	2	Pair with juvenile
F NSF 5	Adult	Male	53	3	Pair with juvenile
F NSF 5	Adult	Male	86	3	Pair with juvenile
F NSF 5	Adult	Male	61	4	Pair with juvenile
F NSF 5	Adult	Male	25	2	Pair with juvenile
F NSF 5	Adult	Male	34	2	Pair with juvenile
F NSF 5	Adult	Male	10	1	Pair with juvenile
F NSF 5	Juvenile	Unsexed	111	2	Pair with juvenile
F NSF 5	Juvenile	Unsexed	33	1	Pair with juvenile
F NSF 6	Adult	Female	86	2	Pair
F NSF 6	Adult	Female	35	1	Pair
F NSF 6	Adult	Female	126	3	Pair
F NSF 6	Adult	Female	135	6	Pair
F NSF 6	Adult	Female	142	7	Pair
F NSF 6	Adult	Female	56	3	Pair
F NSF 6	Adult	Male	79		Pair
F Pimp 1	Adult	Male	104	5	Pair
F Pimp 1	Adult	Male	88	2	Pair
F Pimp 1	Adult	Male	103	5	Pair
F Pimp 1	Adult	Male	64	3	Pair
F Pimp 1	Adult	Male	32	2	Pair
F Pimp 1	Adult	Male	78	3	Pair
F Pimp 1	Adult	Male	112	4	Pair
F Pimp 1	Adult	Male	64	3	Pair
F Pimp 1	Adult	Male	116	5	Pair
F Pimp 1	Adult	Female	17	1	Pair
F Pimp 1	Adult	Female	50	3	Pair
F Pimp 1	Adult	Female	37	2	Pair
F Pimp 1	Adult	Female	59	4	Pair
F Pimp 1	Adult	Female	57	3	Pair
F Pimp 1	Adult	Female	52	4	Pair
F Pimp 1	Adult	Female	25	2	Pair

Feed Rates for *A. littoralis* cones 12 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F Pimp 1	Adult	Female	64	6	Pair
F Pimp 1	Adult	Female	48	3	Pair
F Pimp 1	Adult	Female	79	7	Pair
F Pimp 1	Adult	Female	58	4	Pair
F Pimp 1	Adult	Female	55	4	Pair
F Pimp 1	Adult	Female	90	4	Pair
F Pimp 1	Adult	Female	89	5	Pair
F Pimp 1	Adult	Female	77	4	Pair
F Pimp 1	Adult	Female	99	5	Pair
F Pimp 1	Adult	Female	24	1	Pair
F Pimp 1	Adult	Female	68	6	Pair
F Pimp 1	Adult	Female	72	5	Pair
F Pimp 1	Adult	Female	91	4	Pair
FGil1	Adult	Female	49	6	Pair
FGil1	Adult	Female	39	2	Pair
FGil1	Adult	Female	60	5	Pair
FGil1	Adult	Female	56		Pair
FGil1	Adult	Female	58	2	Pair
FGil1	Adult	Female	44		Pair
FGil1	Adult	Female	48	1	Pair
FGil1	Adult	Female	62	5	Pair
FGil1	Adult	Female	53	2	Pair
FGil1	Adult	Female	60	3	Pair
FGil1	Adult	Female	35		Pair
FGil1	Adult	Female	38	1	Pair
FGil1	Adult	Female	18	1	Pair
FGil1	Adult	Female	48	4	Pair
FGil1	Adult	Female	36	1	Pair
FGil1	Adult	Female	58	2	Pair
FGil1	Adult	Female	55	2	Pair
FGil1	Adult	Female	57		Pair
FNSF 5	Adult	Female	66	1	Pair with juvenile
FNSF 5	Adult	Female	50	2	Pair with juvenile
FNSF 5	Adult	Female	56	2	Pair with juvenile
FNSF 5	Adult	Female	41	3	Pair with juvenile
FNSF 5	Adult	Female	52	3	Pair with juvenile
FNSF 5	Adult	Female	40	1	Pair with juvenile
FNSF 5	Adult	Female	51	5	Pair with juvenile
FNSF 5	Adult	Female	69	3	Pair with juvenile
FNSF 5	Adult	Female	57	3	Pair with juvenile
FNSF 5	Adult	Female	49	1	Pair with juvenile
FNSF 5	Adult	Female	21	2	Pair with juvenile
FNSF 5	Adult	Female	51	2	Pair with juvenile
FNSF 5	Adult	Female	26	1	Pair with juvenile
FNSF 5	Adult	Female	56	2	Pair with juvenile
FNSF 5	Adult	Female	34		Pair with juvenile

Feed Rates for *A. littoralis* cones 13 – continued

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
FNSF 5	Adult	Female	50	2	Pair with juvenile
FNSF 5	Adult	Female	44	5	Pair with juvenile
FNSF 5	Adult	Female	95	6	Pair with juvenile
FNSF 5	Adult	Female	67	5	Pair with juvenile
FNSF 5	Adult	Female	71	3	Pair with juvenile
FNSF 5	Adult	Female	33	1	Pair with juvenile
FNSF 5	Adult	Female	29	1	Pair with juvenile
FNSF 5	Adult	Female	37	1	Pair with juvenile
FNSF 5	Adult	Female	60	2	Pair with juvenile
FNSF 5	Adult	Female	96	5	Pair with juvenile
	Adult	Male	56	1	
	Adult	Male	51	2	
	Adult	Male	49	3	
	Adult	Male	48	3	
	Adult	Male	61	2	
	Adult	Male	57	3	

Feed Rates for *A. torulosa* cones

Site and bird #	Age	Sex	Time taken to consume one cone (secs)	# Chewings per cone	Family group
F NSF 1	Adult	Male	50	4	Pair with juvenile
F NSF 1	Adult	Male	68	4	Pair with juvenile
F NSF 1	Adult	Male	77	2	Pair with juvenile
F NSF 1	Adult	Male	77	5	Pair with juvenile
F NSF 1	Adult	Male	23	2	Pair with juvenile
F NSF 1	Adult	Male	65	6	Pair with juvenile
F NSF 1	Adult	Male	48	4	Pair with juvenile
F NSF 1	Adult	Male	55	3	Pair with juvenile
F NSF 1	Adult	Male	79	4	Pair with juvenile
F NSF 1	Adult	Male	85	5	Pair with juvenile
F NSF 1	Adult	Male	21	1	Pair with juvenile
F NSF 1	Adult	Male	36	2	Pair with juvenile
F NSF 1	Adult	Male	22	2	Pair with juvenile
F NSF 1	Adult	Male	18	1	Pair with juvenile
F NSF 1	Adult	Male	76	3	Pair with juvenile
F NSF 1	Adult	Male	118	8	Pair with juvenile
F NSF 1	Adult	Male	65	4	Pair with juvenile
F NSF 1	Adult	Male	76	3	Pair with juvenile
F NSF 1	Adult	Male	68	2	Pair with juvenile
F NSF 1	Adult	Male	6	1	Pair with juvenile
F NSF 1	Adult	Male	72	4	Pair with juvenile
F NSF 1	Adult	Male	50	5	Pair with juvenile
F NSF 1	Adult	Male	18	1	Pair with juvenile
F NSF 1	Adult	Male	162	7	Pair with juvenile
F NUM 1	Adult	Male	80	6	Pair
F NUM 1	Adult	Male	13	4	Pair
F NUM 1	Adult	Male	55	7	Pair
F NUM 1	Adult	Male	40	2	Pair
F NUM 1	Adult	Female	56	3	Pair
F NUM 1	Adult	Female	59	6	Pair
F NUM 1	Adult	Female	70	4	Pair
F NUM 1	Adult	Female	10	2	Pair
F NUM 1	Adult	Female	125	3	Pair
F NUM 1	Adult	Female	71	2	Pair
F NUM 1	Adult	Female	55	4	Pair
F NUM 1	Adult	Female	45	5	Pair
F NUM 1	Adult	Female	79	6	Pair
F NUM 1	Adult	Female	70	4	Pair
F NUM 1	Adult	Female	85	7	Pair
F NUM 1	Adult	Female	52	4	Pair
F NUM 1	Adult	Female	113	5	Pair
F NUM 1	Adult	Female	48	5	Pair
F NUM 1	Adult	Female	63	4	Pair
F NUM 1	Adult	Female	1	1	Pair
F NUM 1	Adult	Female	1	1	Pair

6.9 APPENDIX 9

Raw Data for *C. lathami* Daily Activities (Chapter 3)

Date	Time	10 minute blocks					
		10	20	30	40	50	60
Adults							
1/04/2001	1640	f	f	f	flew off	d	
1/04/2001	1640	f	f	f	flew off	d	
27/05/2001	1600	f	f	flew off	d		
27/05/2001	1600	f	f	f	flew off	d	
26/09/2002	1640	f	f	flew off	d		
26/09/2002	1640	f	f	f	flew off	d	
26/09/2002	1700	f	f	flew off	d		
29/01/2003	1730	f	flew off	p	d	d	
29/01/2003	1730	f	f	f	flew off	d	
25/08/2003	1143	f	f	f	f	f	f
20/11/2003	1730	f	f	flew off	d		
20/11/2003	1730	f	f	flew off	d		
20/11/2003	1730	f	f	flew off	d		
21/11/2003	830	f	f	f	f	f	f
7/07/2004	1130	f	f	f	f	f	f
2/08/2004	1110	f	f	f	f	f	f
13/09/2004	1630	f	f	f	f	flew off	d
14/09/2004	930	f	f	f	f	f	f
14/09/2004	1030	f	p	f	f	f	f
14/09/2004	1130	f	f	f	f	f	f
14/09/2004	1230	f	f	f	p	f	f
14/09/2004	1330	f	f	f	f	f	f
14/09/2004	1430	f	f	f	f	f	f
14/09/2004	1530	f	f	f	f	f	f
14/09/2004	1430	f	f	f	flew off	p	p
17/09/2004	1530	f	p	f	f	f	f
17/09/2004	1630	f	f	f	flew off	p	p
17/09/2004	1530	f	f	f	p	p	f
17/09/2004	1630	f	f	f	flew off	d	
23/09/2004	1530	f	f	f	f	f	f
23/09/2004	1630	f	f	f	flew off	p	p
4/10/2004	1233	f	f	p	f	p	f
4/10/2004	1333	f	f	f	f	f	f
4/10/2004	1533	f	f	f	f	f	f
5/10/2004	630	f	f	p	f	f	f
5/10/2004	730	f	f	f	p	p	f
5/10/2004	830	f	f	f	f	f	f
5/10/2004	930	f	f	f	f	f	f
5/10/2004	1030	f	f	f	f	f	f
5/10/2004	1130	f	f	f	f	f	f
5/10/2004	1330	f	f	f	p	p	p
5/10/2004	1430	p	f	p	f	p	p

Date	Time	10 minute blocks					
		10	20	30	40	50	60
Adults (continued)							
5/10/2004	1230	f	f	f	f	f	f
5/10/2004	1530	p	p	f	f	f	f
5/10/2004	1630	f	f	f	flew off	p	p
12/10/2004	1630	f	f	f	f	f	flew off
12/10/2004	1730	p	p	p	p	p	p
13/10/2004	1415	f	f	p	f	f	f
13/10/2004	1515	f	f	f	f	f	f
13/10/2004	1715	f	f	flew off	p	p	p
15/12/2004	1615	f	f	f	f	f	f
15/12/2004	1515	f	flew off	d	p	p	p
1/02/2005	1600	f	f	f	f	f	f
21/02/2005	1800	f	f	f	flew off	d	
24/02/2005	1415	f	f	f	f	f	f
24/02/2005	1515	f	f	f	f	f	f
24/02/2005	1615	f	f	f	f	f	f
24/02/2005	1715	f	f	p	flew off	d	
2/03/2005	1200	f	f	f	f	f	f
25/03/2005	1730	f	f	f	f	f	flew off
25/03/2005	1830	p	p	p	flew off	d	
Juveniles							
24/02/2005	1415	f	f	begging	f	f	f
24/02/2005	1515	f	begging	begging	f	f	begging
24/02/2005	1615	begging	begging	begging	f	f	begging
17/09/2004	1530	F	begging	begging	begging	f	
17/09/2004	1630	begging	begging	begging	flew off		
Legend: f = feeding; d = drinking; p = preening							