



Guided by the light: Roost choice and behaviour of urban Rainbow Lorikeets (*Trichoglossus haematodus*)

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ABSTRACT

1. The formation of large communal roosts is a conspicuous phenomenon associated with a wide range of bird species successfully exploiting urban environments. In many Australian cities, the abundance of the Rainbow Lorikeet (*Trichoglossus haematodus*), a native parrot, has increased markedly in recent decades, with the species roosting in very large numbers within suburban sites. These roosting locations are noisy and cause significant fouling of the land beneath, resulting in conflict with humans.

2. We investigated the selection of roosting sites in this species in Brisbane, Australia, by comparing characteristics of both the general sites of these roosts as well as individual trees used within roosting sites and trees that were avoided.

3. Lorikeets used a wide variety of tree types for roosting but demonstrated a clear preference for clumped trees within sparsely treed areas that received significantly more artificial light at night than otherwise suitable sites and trees nearby.

4. These features of roosting sites may enhance the detection of nocturnal predators by Rainbow Lorikeets, suggesting a potential positive impact of anthropogenic lighting. Our findings provide valuable insights into the management of roost-related conflicts in urban areas. We encourage further investigations into the possible benefits of artificial light.

KEYWORDS

Communal roosts, Urban birds, Roost choice, Rainbow Lorikeet (*Trichoglossus haematodus*)

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INTRODUCTION

Urbanisation is now regarded as a globally disruptive phenomenon (McKinney 2006) with the multiplicity of associated impacts and influences increasingly being the focus of sustained scientific attention (McDonnell et al. 2009; Roberts et al. 2009). The responses of animals to urban landscapes and conditions have been found to be remarkably complex (Chase & Walsh 2006), with a wide range of biological and behavioural traits exhibited by urban species, often operating at different scales and intensities (McCaffrey & Mannan 2012). Introduced bird species, typically a predominant component of avian homogenisation (Blair 2001), are frequently associated with issues such as impacts on native species and amenity values as well as human health and safety concerns (Kark et al. 2007). Similar concerns also result from large concentrations of certain native birds, with geese, corvids, starlings and pigeons being associated

with significant conflicts in many cities throughout the world (Chase & Walsh 2006).

In Australia, a relatively large number of native avian species have managed to thrive in urban areas with numerous recent studies (Sewell & Catterall 1998; Davis et al. 2011), indicating that the process of homogenisation is far from universal, especially in non-temperate cities (Garden et al. 2006). Some native species are also associated with important conflicts, often related to concentrations of large assemblages at foraging sites and roosts (Everding & Jones 2006; Davis et al. 2011; Martin et al. 2011). Amongst the most successful of native birds species in cities and towns throughout Australia is the Rainbow Lorikeet (*Trichoglossus haematodus*) (Shukuroglou & McCarthy 2006; Lowry & Lill 2007; Davis et al. 2011). Traditionally found in the eucalypt forests and woodlands of the continent, this species was an early coloniser of urban environments, though typically in modest numbers (Veerman 1991; Woodall 1995).

Over the past few decades, however, lorikeets populations have increased dramatically in many cities, fuelled in part by the superabundance of nectar-bearing plants favoured by gardeners (Smith & Lill 2008; Lill 2009) and the provision of seed by householders (Rollinson et al. 2003).

One of the most conspicuous traits of Rainbow Lorikeet presence in urban areas is the formation of large roosting colonies, often comprising many thousands of birds (Higgins 1999). Remarkably, these persistent roosts are often situated in trees in highly developed sites such as the intersections of major roads, shopping centre car parks and adjacent to sporting arenas. Despite high levels of human disturbance, traffic noise and prominent lighting present in these areas, numerous roosts in such areas have been in existence for many years (Jaggard et al. 2015). With vast numbers of birds congregating in such sites at nights, concerns and conflicts over noise, soiling and possible health issues are increasing, as are demands for control and management (Temby 2007).

Despite the spectacular growth in urban populations of Rainbow Lorikeets throughout Australia (Fitzsimons et al. 2003; Lill 2009), little is known about most aspects of their roosting behaviour. An important exception is a recent study conducted in Sydney, Australia (Jaggard et al. 2015). This detailed study found that Rainbow Lorikeets preferred to roost in taller non-native roost trees with thick trunks and confirmed the tendency to use highly disturbed locations that were often close to lights. The roosts investigated in this study were, however, occupied by relatively small numbers of birds, with the largest roosts being classed as 'greater than 20' (Jaggard et al. 2015).

The present study is one component of a larger exploration of the possible functionality of communal roosting in this successful urban species, the primary focus here being on the possible anti-predation benefits of communal roosting. In contrast to Jaggard et al. (2015), this study focussed on roosts occupied by large numbers of lorikeets, ranging from hundreds to an estimated 35,000 birds (Daoud-Opit 2011). Rainbow lorikeet roosts in urban areas are typically characterised by high levels of anthropogenic disturbance such as artificial light and proximity to heavy traffic levels (Jaggard et al. 2015). Here, we predict that Rainbow Lorikeets prefer to roost in sites with features that enhance the detection of potential predators. Specifically, we assess whether the trees selected as roosts differ from otherwise similar trees with regard to variables such as artificial light levels, canopy shape, the extent to which trees are clumped and other relevant ecological characteristics.

1. MATERIALS AND METHODS

1.1. Study species

The Rainbow Lorikeet is a moderately sized (112–136 g) colourful and gregarious psittacine found across northern and eastern Australia as well as South-East Asia and the South Pacific (Higgins 1999). They inhabit many habitat types but are

especially abundant in areas dominated by eucalypts and melaleuca (Higgins 1999). Their movements are generally nomadic and somewhat seasonal, responding to the flowering patterns of the native trees in which they forage (Lill 2009). They feed primarily on nectar and pollen, although they will often feed on a wide variety of fruits, seeds and some insects (Higgins 1999; Lill 2009). In urban areas, they have benefitted greatly from the super-abundance of nectar-bearing plants now present in gardens throughout the country (Fitzsimons et al. 2003).

1.2. Study area

This study was conducted in the Greater Brisbane region, a major metropolitan area of approximately 2.3 million people (Australian Bureau of Statistics 2016) on the coast of South-East Queensland. The region has a humid, subtropical climate with average annual temperatures of 16–26° C and 981.4 mm annual rainfall (Australian Bureau of Meteorology 2011). The suburban area Brisbane has an estimated 46% tree canopy cover across its 1,330 km² extent (Brisbane City Council 2012).

1.3. Study sites

Fieldwork focussed on Rainbow Lorikeet roosting aggregations located primarily in the southern suburbs of Brisbane. Because of the large number of birds involved (hundreds to 10,000+ individuals), roost sites are highly conspicuous and easily located. Roost sites were typically large areas occupied by many trees, some of which were used regularly by the birds for roosting throughout the night although some were never used in this way. The 14 roost sites investigated in detail were selected for ease of access and were at least 4 km from other roost sites. The portion of the roosting site investigated was determined by the bird's behaviour and focussed on two classes of trees: those in which the birds settled for the night (roost trees) and those not used for this purpose (non-roost trees), within a radius of approximately 100–300 m of the geographical centre of the overall roost site. This area varied considerably because of the number of birds present and the distribution and number of trees used; the average size of study sites was 43,199 m² (range: 2,880–110,750 m²).

An additional 28 control ('non-roosts') sites were selected for comparison with roost tree sites (i.e. not the overall roosting site), with two each randomly chosen from within 1 km of the 14 roosting sites. Control sites were defined as treed areas potentially suitable for roosting by lorikeets but not used. As such, control sites contained suitable species of trees, most of which were at least 4 m in height. Control sites were randomly selected using satellite photographic maps of the area obtained through the NearMap tool HyperTiles (www.nearmap.com). Random points were plotted onto maps and the control site chosen as the closest group of trees in any direction conforming to the above criteria. All control sites were approximately 2,500 m² in size, similar to that occupied by areas of roost trees. To ensure physical independence between roost and non-roost sites, a buffer zone was created around roost

sites using ArcMap in ArcGIS for Desktop 10 (adapted from Clergeau & Quenot 2007).

1.4. Tree and site characteristics

The selection of trees for the assessment within roost sites was determined by observations of the behaviour of the birds themselves as they moved through the urban environment to settle in specific trees to roost for the night. Because many trees were used as temporary gathering stations en route to roosting trees, it was important to distinguish between trees used for roosting and those not used for this purpose. This discrimination required detailed observations of the behaviour of lorikeets as they moved through the site and were undertaken by researchers equipped with high-resolution aerial photographs of the areas being surveyed, upon which all trees, both roost and non-roost, were identified and numbered. Observers arrived at least one hour before sunset and were positioned throughout the likely area to be used by the incoming birds. Observations continued until all incoming birds had settled down for the night and all trees in the area had been classed as either non-roost (pre-roosts or not used at all) or roost (trees in which multiple birds spend the night).

A total of 11 variables were measured or estimated for every tree identified as a roost or non-roost tree. These included the heights of total tree, bole, canopy and perch (exposed leafless vertical limbs that extended beyond the top of the canopy); canopy spread; diameter of the bole; classification of the canopy shape and identification to species (Table 1). Trees were identified to family, genus and species where possible. In addition to tree characteristics, a number of site-related distance and light variables were obtained for all trees within all sites. Distance measurements involved recording the distance (m) from each tree to the closest: tree (D2T), roost tree (D2R), pre-roost tree (D2P), artificial light source (D2L) and building (D2B). Within control sites, as no actual roost trees were present, distance measurements between roost and other features were excluded.

During preliminary surveys, it was noted that many roost trees were close to or directly adjacent to light sources. Direct measurements of light levels at the height of the roosting birds and within the trees were not possible. Instead, we developed the Composite Light Index (CLI), comprised of three main factors contributing to the light environment associated with roost trees: (1) the proportion of the tree receiving light

from the source/s (coverage), (2) a rating of the intensity of the light impacting the tree (strength) and (3) the relative distance between the tree and the light source (distance).

In cases where more than one light source impacted the tree, distance and strength measurements were repeated for all sources to a maximum of 6. These three factors were all categorical approximations. Coverage was determined to be the proportion illuminated directly of 8 sectors centred on the tree, with 1/8 being the least amount of coverage and 8/8 being the maximum; trees not impacted by anthropogenic light were given a value of 0. The strength of each light was measured on a scale of 1–5, 1 being weakest and 5 the strongest. Distance was similarly classified on a 1–10 scale with the lower the value, the further the light source was from the tree, up to a maximum of 50 m. Light sources greater than 50 m distance were all given a distance value of 1 if they impacted the tree.

1.5. Analyses

Data collected across all 14 roost sites was pooled into one dataset of roost site trees, as was similarly done with the data from the 28 non-roost sites. Two main comparisons were made: between actual tree use (roost tree or non-roost tree) within the 14 roost sites, thus primarily assessing tree choice within roost sites (i.e. which trees are selected for roosting); and between roosting trees from the roost sites and trees from the control sites, allowing for the possible factors being used by lorikeets when choosing of overall roost sites (i.e. which sites within the landscape are selected for roosting).

Probability plots produced in SAS 9.1 determined a general lack of normality amongst the variables, with log10 transformations subsequently applied. The selection of roost tree types was assessed by chi-square test, and non-parametric Kruskal–Wallis tests were performed in SAS 9.1 to determine differences in the means of the variables between roost and non-roost trees. Discriminant function analysis (DFA) was used to explore the specific influence of each of the variables in discriminating between the groups. Standardised data was input into IBM SPSS (version 17.0), and a two-tailed partial cross-correlation was performed so that highly correlated (greater than 0.6) variables could be removed. Once completed, DFA were performed to compare Roost (R) trees with Non-Roost (NR) trees within roosting sites and Roost (R) trees from roosting sites with all trees (C) from control sites.

DFA was also used to predict categorically dependent variables by a multitude of continuous independent variables. This procedure uses appropriate canonical discriminant functions to determine the significance level of the comparisons overall, as well as to determine the variables that are most important in discriminating between groups. Additionally, using the information from the variables, the DFA attempts to correctly reclassify the trees by the group types. This assesses how useful the variables that have been collected may be in predicting group membership (or tree use). The DFA was then used to perform a stepwise comparison for the calculation of the canonical function. This method selects the best predictor vari-

$$CLI = [\sum_{i=1}^n (D_i \times S_i)] \times C$$

Where:

CLI is the Composite Light Index for the selected tree

D_i is the Distance of the *i*th light to the selected tree

S_i is the Strength of the *i*th light

C is the estimated Coverage of the selected tree

i = 1, ..., *n*

able or variables from all the original possibilities. The output indicates how many (and which) of the variables were used in a model to obtain the best possible prediction of group types, and how good a fit to the data those models would be with any particular number of said variables.

For comparisons between roost and non-roost trees within roosting sites, a partial cross-correlation analyses performed resulted in the variables such as canopy spread, canopy volume, canopy surface area, canopy height, perch height and bole height being removed from further analysis because of high cross-correlations with other variables. Thus nine variables were used: total height, canopy cover, diameter of bole, Composite Light Index, D2R, D2P, D2B, D2L and D2T (see Table 1).

A DFA was used again to determine the variables that are most important in driving the significant differences between roost trees from roost sites and trees from control sites. A partial cross-correlation analysis lead to the removal of several highly correlated variables leaving six variables for the DFA: distance to nearest tree, composite light index, diameter at breast height, distance to nearest building, total height and canopy cover.

2. RESULTS

2.1. Comparison of trees types within roosting sites

A total of 1,781 trees were surveyed across 42 sites throughout the suburbs of Brisbane, with 1,364 (17–181 per site) trees coming from the 14 surveyed roost sites. Control sites contained a total of 417 (6–31 per site) trees none of which were used by Rainbow Lorikeets as roosts at any time during the study. Most trees (1,139 or 83.5%) within roost sites were not used for roosting by Rainbow Lorikeets, although 237 (17.37%) were used as temporary pre-roost staging stations. For analyses, pre-roost trees were combined with non-roost trees and classified as non-roost trees. In total, 16.49% (or 225) of the trees present within roost sites were used by roosting birds (mean of 16.07 per site).

Roost tree taxa were predominantly *Eucalyptus* (93 trees), palms (68 trees) and *Pinales* (25 trees), which together accounted for 81.5% of the 225 roost trees combined. A contingency test of tree taxa used by roosting lorikeets indicated that both *Eucalyptus* and *Roystonea* were used more than expected ($X^2 = 213.34$, $df = 23$, $p < 0.0001$).

Non-parametric Kruskal-Wallis tests comparing mean differences in the 15 variables between roost and non-roost trees found clear differences with all but two variables (perch height and distance to pre-roost tree) to be highly significantly different between these groups (Tables 2 and 3).

Table 1. Variables and descriptions for tree characteristics measured across all sites.

Variables (units)	Mnemonics	Description
Total tree height (m)	TH	Base to canopy top
Bole height (m)	BH	Base to bole definition
Perch height* (m)	PH	From canopy top to perch tip
Canopy height (m)	CH	Bottom of canopy to top of canopy
Average canopy spread (m)	CS	Average of two crown spread measurements taken at right angles
Canopy surface area (m ²)	CSA	Various formulas used [^]
Canopy volume (m ³)	CV	Various formulas used [^]
Average canopy cover (%)	CC	Estimation made through canopy using sighting tube; average taken from four estimations
Bole diameter at breast height (cm)	DBH	Measured at breast height (approximately 150 cm)
Canopy shape type	ST	6 defined shapes
Tree species	N/A	Identification with appropriate guides

*: Perch height refers to the length of leafless or mostly leafless branches that are raised above the top of the canopy, providing a perch-like structure where birds are highly visible. [^] Canopy surface area formulas adapted from McPherson and Rowntree (1988). Canopy volume formulas and crown form factors used were adapted from Coder (2000).

Table 2. Group means, standard deviations and non-parametric Kruskal–Wallis test and significance values for comparisons between roost (R) trees and non-roost (NR) trees from within roosting sites.

Variables	Group Means (\pm SD)		Roost vs Non-Roost	
	Roost	Non-Roost	Chi-Square	P
BH	3.77 \pm 2.57	2.32 \pm 1.85	83.45	<.0001
CH	7.28 \pm 4.34	5.82 \pm 3.16	4.60	<.0001
PH	0.08 \pm 0.32	0.04 \pm 0.25	~	~
TH	11.89 \pm 5.25	8.82 \pm 3.88	93.03	<.0001
D2T	4.34 \pm 2.69	3.85 \pm 2.83	9.10	.00026
D2R	11.47 \pm 16.03	54.71 \pm 39.35	340.98	<.0001
D2P	40.26 \pm 34.74	28.53 \pm 26.88	~	~
D2B	33.48 \pm 22.42	25.65 \pm 19.34	28.76	<.0001
D2L	9.18 \pm 5.75	11.57 \pm 7.98	14.68	.0001
CC	67.92 \pm 14.79	68.95 \pm 19.37	5.27	.0217
DBH	36.82 \pm 27.48	42.14 \pm 36.74	30.19	<.0001
CS	6.69 \pm 3.25	6.14 \pm 2.63	2.33	N.S.
CSA	41.45 \pm 44.45	29.57 \pm 30.18	18.33	<.0001
CV	277.62 \pm 565.9	168.34 \pm 318.9	8.70	.0032
CLI	206.03 \pm 177.3	164.2 \pm 140.33	7.47	.0063

Note: ~: Variable not used in this comparison so no value available. N.S.: Not Significant.

Table 3. Group means, standard deviations and non-parametric Kruskal–Wallace test and significance values for comparisons between roost (R) trees and control (C) trees.

Variables	Group Means (\pm SD)		Roost vs Control	
	Roost	Control	Chi square	P
BH	3.77 \pm 2.57	2.45 \pm 2.13	58.10	<0.0001
CH	7.28 \pm 4.34	6.87 \pm 3.81	0.39	N.S.
PH	0.08 \pm 0.32	0.004 \pm 0.06	~	~
TH	11.89 \pm 5.25	10.42 \pm 5.16	454.16	<0.0001
D2T	4.34 \pm 2.69	3.14 \pm 3.08	48.57	<0.0001
D2R	11.47 \pm 16.03	~	~	~
D2P	40.26 \pm 34.74	~	~	~
D2B	33.48 \pm 22.42	44.80 \pm 37.16	265.50	<0.0001
D2L	9.18 \pm 5.75	37.89 \pm 33.63	1.60	N.S.
CC	67.92 \pm 14.79	68.23 \pm 15.66	270.57	<0.0001
DBH	36.82 \pm 27.48	39.28 \pm 30.31	287.34	<0.0001
CS	6.69 \pm 3.25	6.76 \pm 3.76	33.99	<0.0001
CSA	41.45 \pm 44.45	40.15 \pm 46.37	187.28	<0.0001
CV	277.62 \pm 565.9	285.6 \pm 553.3	98.35	<0.0001
CLI	206.03 \pm 177.3	26.1 \pm 46.37	12.53	0.0004

Note: ~: Variable not used in this comparison so no value available. N.S.: Not Significant.

2.2. Choosing a roost tree: Comparison of roosting and non-roosting trees

DFA was used to discern whether roost and non-roost trees within roost sites could be separated reliably on the basis of the variables measured. The nine variables used in the step-wise DFA showed that distance to nearest roost tree, total height, distance to nearest pre-roost tree, composite light index and distance to nearest light source contributed most to the discrimination between roost and non-roost trees (Table 4). These five variables produced a single highly significant canonical function that accounted for 100% of the variation found in the samples. The standardised canonical discrimination function coefficients (SCDFC) indicated that distance to nearest roost tree and total height of the tree were the most important variables in discriminating between tree use (SCDFC $> \pm 0.4$). The DFA predicted group membership with an accuracy of 82.0%.

2.3. Choosing a roost site: Comparison of trees in roosting sites and control sites

Comparisons of variables of trees used for roosting in roosting sites and those from control trees found almost all variables to be significant ($df = 1$, $p < 0.05$) except for canopy height and distance to nearest light source. The DFA produced a single canonical function to account for 100% of the variability in the data with high eigenvalue and chi-square and highly significant p-value (Table 5). Standardised discriminant function coefficients indicate that distance to nearest tree and the Composite Light Index were the most important variables in this model. The DFA predicted group membership with an accuracy of 96.1%.

Table 4. Summary of standardised discriminant function coefficients produced by the DFA of environmental variables for roost and non-roost trees ($n = 1364$ trees) within lorikeet roosting sites. (Eigenvalue = 0.354; $X^2 = 412.144$; $df = 5$; $P < 0.0001$). (Variables are listed in order of importance. ~: Variable not included in DFA).

Variable	Standardised Discriminant Function Coefficients
D2R	-0.794
TH	0.576
D2P	0.309
D2L	-0.153
CLI	0.205
D2B	~
DBH	~
D2T	~
CC	~

3. DISCUSSION

Rainbow lorikeets are one of the most successful native bird species to have exploited urban environments throughout Australia (Catterall et al. 2010; Davis et al. 2011). Although the formation of roosting aggregations is typical of the species in all habitats (Higgins 1999), the size and especially the location of these formations in highly disturbed areas within cities are intriguing. The primary aim of the present study was to investigate the selection of roosting trees by Rainbow Lorikeets in an urban environment and to discuss the possible functionality of this apparent choice.

3.1. Characteristics of trees selected for roosting

In accord with reports from non-urban areas (Serpell 1982), *Eucalyptus* species were the most common tree type used by Rainbow Lorikeets for roosting, an unsurprising finding given the general predominance of this taxa throughout Australia including suburban areas. However, many palm tree species, especially of the genera *Roystonea* and *Arecaceae*, were also used as roosts significantly more than all other tree types apart from the Eucalypts. Nonetheless, a remarkably broad collection of tree types (including various *Pinales*, *Ficus* and *Caesalpinia* species) of vastly different growth forms were also used as roosts in the Brisbane region. A wide diversity of roost trees used by Rainbow Lorikeets has also been reported from other Australian cities (Box 2001). In contrast to the most detailed study by Jaggard et al. (2015) from Sydney, however, the majority of roosts used in Brisbane were natives. These observations strongly suggest that both tree species and general growth form are not the major criteria used in the selection of trees for roosting by Rainbow Lorikeets.

To examine the apparent preferences Rainbow Lorikeets exhibited for roosting trees within urban roost sites, trees used as roosts were compared to trees readily available in the same immediate area yet not used. A clear discrimination between these two classes was found, with the distance to nearest roost tree being the most important variable; Rainbow Lorikeets chose to roost in trees relatively closer to other roost trees (a mean of about 11 m from the centre of the trunk),

Table 5. Summary of standardised discriminant function coefficients produced by the DFA of environmental variables for roost and non-roost trees ($n = 642$ trees) within lorikeet roosting sites. (Eigenvalue = 2.671; $X^2 = 829.078$; $df = 5$; $P < 0.0001$). (Variables are listed in order of importance. ~: Variable not included in DFA)

Variable	Standardised Discriminant Function Coefficients
D2T	0.686
CLI	0.506
DBH	-0.503
D2B	-0.350
TH	0.127
CC	~

often forming clumps of roosting trees within roost sites. In addition, these roosting trees were significantly taller on average than other trees within the site that were not used for roosting (total height of approximately 11 m compared to 8.9 m for non-roost trees). These findings accord closely with Jaggard et al. (2015) who also found a clear tendency for lorikeets to roost in trees close together, as well as relatively taller than others nearby. In addition, the study conducted in Sydney found that roosts were significantly close to light sources, as did the present study. The DFA procedure used here provides further details on these features, identifying three variables – distance to nearest pre-roost, distance to nearest light source and Composite Light Index – as significant components of the selection of roosting trees. Thus, the taller, clumped roost trees also tended to be closer to light sources than were non-roost trees, with greater amounts of light impacting them, whilst also being further from trees not used for roosting.

Comparisons were also made between trees used for roosting and those not used although otherwise suitable (control sites) within the same environment by roosting Rainbow Lorikeets. The DFA identified that roosts trees were significantly more illuminated by anthropogenic light (higher Composite Light Indices) and relatively spread out (using the distance to nearest tree variable) in comparison with control trees.

3.2. Possible functionality of roost tree characteristics

The roosting aggregations formed by Rainbow Lorikeets in many urban areas are extremely conspicuous, frequently comprised of thousands of birds and accompanied by spectacular pre-roost flights and exceptionally loud communal vocalisations (Higgins 1999). In the present study, several of the roosts investigated were estimated to consist of more than 10,000 birds (Daoud-Opit 2011). As has been well established (Calf et al. 2002), the risk associated with predation to an individual is significantly diluted by roosting within such aggregations, with the risks further reduced by greater numbers, the enhanced vigilance of the larger group and being situated centrally within the aggregation (Beauchamp 1999; Davis et al. 2011). These benefits relate primarily to behavioural adaptations and strategies; here we explore whether similar predation-related benefits may relate to characteristics of the roost trees themselves.

There is limited information on the predators that prey on roosting Rainbow Lorikeets. In large urban areas such as Brisbane, anecdotal evidence suggest that large owls, snakes and cats are the most likely nocturnal predators (Higgins 1999), whilst some raptors such as Peregrine Falcons (*Falco peregrinus*) have been observed harassing lorikeets settling into roosts at dusk (Serpell 1982; D. Jones, unpubl. data).

Roost trees within roosting sites were found to be taller and more tightly clumped than local trees not used by the birds. These features may facilitate the greatest possible concentration of roosting birds in closely grouped trees whilst providing optimal surveillance of the surroundings, both with possible predator-detection benefits. Furthermore, taller trees

would increase the difficulty for a terrestrial predator to reach roosting lorikeets undetected.

Other than these characteristics of the roosting trees themselves, a key feature discriminating roost trees from both non-roost trees and control sites was the significantly higher levels of ambient light. The Psittaciformes, which include the lorikeets, have relatively poor vision in low-light conditions (Birkhead 2011). This trait suggests that roosting aggregations of these birds in roosts would be especially vulnerable to nocturnal predators, with the loss of ambient light following sundown greatly diminishing the ability of the birds to detect approaching danger. The strong anthropogenic light environment so typical of virtually all of the roosts investigated here, which typically lasts throughout the night, would likely significantly aid predator detection. Such a claim requires, however, experimental verification. We believe that the implications of this prominent feature of all urban environments requires further attention.

3.3. Anthropogenic light

As a direct consequence of urban development, many areas around the world are now almost continuously illuminated by anthropogenic light sources (Longcore & Rich 2004). There are a multitude of sources of such light, including street lights, security lights and vehicle lights (Navara & Nelson 2007). Anthropogenic light sources are exceptionally bright in comparison with natural light sources, with even simple security or street lights being up to one million times brighter than that of natural light (Perry et al. 2008). As light influences the ecological processes and impacts the life histories of many animal species (Longcore & Rich 2004), the phenomenon of anthropogenic night light and its impacts on animal species has recently become the subject of investigation (Gauthreaux & Beler 2006). Whilst current research implies that increased levels of anthropogenic light around the world may be detrimental to many species (Gauthreaux & Beler 2006), the results of this study suggest that for some species, anthropogenic light potentially has certain benefits. The fact that Rainbow Lorikeets may choose more illuminated areas as roost sites, rather than areas with suitable roosting trees but less anthropogenic light, as well as more often choosing trees with greater light levels within a site, suggests light may be an important beneficial factor.

4. CONCLUSION

The growth of urban populations of Rainbow Lorikeets has the potential for creating management problems, especially in areas where the lorikeet is an invasive species (Higgins 1999). They are extremely noisy, especially immediately prior and soon after entering their roosting tress, and in some locations, they are known to vocalise very loudly throughout the night (D. Jones, unpubl. data). Additionally, their preference for well-illuminated areas and tall trees has attracted them to high-use human areas, such as the car parks of shopping malls and along main streets. Their faecal contamination and damage to trees

is a problem for many urban authorities and is likely to increase as their population continues to grow (Temby 2007). Research into roost preferences of Rainbow Lorikeets may aid in the provision of management strategies to deal with problems created by roosts and populations as well as prevent future roosts from occurring in certain areas. Current means of dealing with problems created by populations of these and other species, such as the removal of trees or attempts to scare birds away, are increasingly met with opposition (Temby 2007). If Rainbow Lorikeets have a preference for taller tree species, it may be beneficial for councils and authorities to explore the use of different tree species in areas where lorikeets roost (Jaggard et al. 2015). Additionally, a decrease in the use of bright lights along main roads or throughout car parks at night may also deter communal lorikeet roosts.

The possible influence of anthropogenic light discussed in this study suggests that this is a significant new area of investigation. It would be interesting to conduct experimen-

tal studies involving the manipulation of anthropogenic light and observing the behaviours of the lorikeets or other species in relation to changed light conditions – would a roosting population remove themselves from a permanent roost if light conditions were dramatically reduced? This is especially important as the impact of light is an ever-increasing problem around the world and is likely to continue to, and increasingly impact, an increasing amount of species.

Acknowledgements: We thank the many volunteers who dedicated time to the field research involved in this study, especially Mitch McCarthy, Matt Brown, David Black, Renee Chapman and Stephanie East. We are grateful to the Environmental Futures Research Institute, Griffith University, for the support and funding. The research was conducted with the permission of the Griffith School of Environment, Griffith University and Brisbane City Council.

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