Species richness and community composition of passerine birds in suburban Perth: is predation by pet cats the most important factor?

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ABSTRACT

Using data from 57 sites across suburban Perth we tested the influence of Cat Density on species richness and community composition of passerine birds as well as on the presence/absence of 15 common passerine species. Cat Density was not a significant predictor of any of the dependent variables. Instead, passerine species richness declined with increasing Distance to Bushland and with increasing Housing Density, but increased proportionately with the Size of, Nearest Bushland > 5ha. Together, these predictors explained approximately half the variability in bird species richness (adjusted R^2 for the complete data set = 0.414). Passerine community composition was significantly affected by Housing Density, Distance to, and Size of, Nearest Bushland >5ha. These environmental variables, especially Housing Density, appeared to act principally by their effect on the number of small and medium sized insectivores. Attempts to predict the presence/absence of 15 common passerines did not yield clear results, although Housing Density appeared the most likely predictor. While cat predation might be significant adjacent to remnant bushland or other areas of conservation significance, blaming cats for bird conservation issues in long-established suburbs may be a scapegoat for high residential densities, inappropriate landscaping at a range of scales or poor conservation of remnant bushland.

Key words: Suburban wildlife, domestic cats, housing density, remnant bushland

Introduction

In the hyperpredation hypothesis, predation by an introduced predator sustained by a large population of an introduced prey species adapted to high predation pressure threatens populations of native animals (Courchamp *et al.* 2000). Woods *et al.* (2003) suggested that predation by pet cats *Felis catus* (Mammalia: Felidae) in suburbia was analogous to hyperpredation because domestication maintains cats at much higher populations than would otherwise be supported, leading to very high predation pressures on wildlife. Many Australian and international studies confirm that pet cats kill large numbers of wildlife (e.g. Paton 1994; Churcher & Lawton 1987; Barratt 1998; Gillies & Clout 2003; Woods *et al.* 2004; Lepczyk *et al.* 2003a, b). However, other authors query the methodologies used to estimate predation rates, suggest that cats might simply take a 'doomed surplus' of prey or point out that few studies demonstrate a decline in prey populations unequivocally linked to predation by pet cats (e.g. Patronek 1998; Chaseling 2001). These views have substantial practical implications. If predation by pet cats is a problem, it should be a focus in conservation management, whereas if the issue is overstated it may deflect attention from habitat destruction, road mortality, pollution or other critical factors (e.g. Fitzgerald 1990; Nattrass 1992; Chaseling 2001, see also evaluations of community attitudes in Grayson *et al.* 2002, Lilith *et al.* 2006).

Conserving passerine birds in Australian suburbia illustrates the difficulty of resolving the respective impacts of habitat destruction and cat predation. Worldwide, habitat destruction associated with urbanization is proceeding rapidly (Marzluff *et al.* 2001) and Australian cities are also increasing in size and area (van der Ree 2004). The Australian pet cat population is also substantial. In 2002, there were approximately 2.5 million pet cats in Australia spread across 23% of households (www.petnet.com.au/statistics.html) and it is undeniable that many (but not all) of these cats hunt and kill wildlife in suburbia, including birds (see review by Grayson and Calver 2004). However, testing the impact of pet cats on prey populations via controlled experiments in which prey populations are monitored following predator removal/exclusion (e.g. Risbey *et al.* 2000), is logistically and ethically difficult in suburbia. Alternative approaches include regressing prey numbers against predator numbers or relating local extinctions of prey to presence of predators (following the model of the island studies of Burbidge and Manly 2002). There is an extensive precedent for using such approaches to determine the influence of habitat variables on bird species richness or abundance in suburbia (e.g. Sewell and Catterall 1998; Fernandez-Juricic 2000; Thorington and Bowman 2003; Melles *et al.* 2003; Crooks *et al.* 2004).

This study investigated if pet cat density is a significant predictor of passerine species richness (the number of species occurring), passerine community composition (the relative abundances of different bird species) and the presence/absence of common passerine species in suburban Perth, Western Australia, or if other factors such as dog density, housing density, garden composition and proximity and size of remnant habitat (bushland) were stronger predictors.

Pp 195 - 207 in *Pest or Guest: the zoology of overabundance,* edited by Daniel Lunney, Peggy Eby, Pat Hutchings and Shelley Burgin. 2007. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

Methods

Study area

Perth, the capital of Western Australia, is a coastal city of *c.* 1.4 million people founded in 1829. It covers an area of *c.* 35km east-west and 70km north-south along the Swan Coastal Plain in the lower south-west corner of the Australian continent (Thackway and Cresswell 1995). This study was restricted to 25km south and 15km north of the Perth Central Business District (31.955° south and 115.8° east) and 30km inland from the Indian Ocean. Agricultural clearing and urbanisation have removed *c.* 78% of the vegetation from the Swan Coastal Plain and two species of vascular plant, 15 bird species and nine mammal species are believed extinct in the bioregion (Armstrong and Abbott 1995). Significant areas of remnant bushland remain within the Perth city environs (How and Dell 2000) and a long-term study in one of these demonstrated considerable changes in the species composition of bird communities over time, although overall bird abundance remained high (Recher 2004).

Collection of bird data

Members of Birds Australia, formerly the Royal Australasian Ornithologists' Union, collected the bird data used in this study. Since August 1st, 1996, members contributed to a Suburban Bird Survey. Observers chose a particular day of the week as an observation day and recorded all birds seen in and around their gardens (within 100m) on that day (Nealon 1996).

The records of 57 Birds Australia members who contributed bird records for 25 or more weeks from 1st August 1998 to 31st July 1999 were included in this study because this could account for seasonal trends. Each member's contribution constituted one site. These 57 sites were spread over the Perth metropolitan area ranging from Cottesloe in the west to Parkerville in the east (a distance of *c.* 30km) and from Wanneroo in the north to Warnbro in the south (a distance of *c.* 65km). We restricted our analysis to passerines, which excluded a range of itinerant sea birds and parrots as well as exotic doves.

Environmental variables

For all 57 study sites, data were collected on eight environmental variables suggested by Thomas *et al.* (1977), Green (1984) and Munyenyembe *et al.* (1989) as potential influences on bird distributions in suburbia:

- Dog Density;
- Cat Density;
- Housing Density;
- Age of Suburb;
- Distance to Nearest Bushland less than five hectares;
- Size of Nearest Bushland less than five hectares;
- Distance to Nearest Bushland greater than five hectares

and,

- Size of Nearest Bushland greater than five hectares.

Cat and Dog Density

The pet cat and pet dog densities for each site including and surrounding the residential block where an observer resided were determined by a mailed survey to 27 households (four either side of, and including the observer's block, the nine directly opposite and the nine behind). Surveys were accompanied by a covering letter, a self addressed envelope and a tea bag (to be enjoyed while completing the survey). Residents were asked to include only their pet cats or dogs that spent the majority of time outside the house during the period of the bird survey. A reminder survey was sent within two weeks if no reply was received.

Geographical Information Systems (GIS) were used to create a map of the area for each site, which included the block size of each dwelling (in square metres) issued with a survey. Cat and Dog Density calculations were based upon the number of cats or dogs as reported by those who responded to the survey and the sum of the area of respondents' house blocks.

Housing Density

Housing Density was calculated by dividing the number of dwellings by the sum of the block sizes of the residents asked to participate in the survey.

Suburb Age

Information to determine the age of each suburb included in this study came from a variety of sources, such as Yarrow (1980) and personal communication with officers of the Department of Land Administration and the Department of Local Government and Regional Development. The age of the suburb in years was taken to be the number of years elapsed from the date of the initial sub-division to 1998.

Distance to Nearest Bushland and Area of Nearest Bushland

The Department for Planning and Infrastructure provided a map for each site which showed the Distance to Nearest Bushland as well as the Size of the Bushland. Two sources were used to identify bushland. Firstly, we included bushland designated as such in the maps of *Bushplan Native Vegetation* and secondly, we included bushland designated in *Bush Forever* sites (Western Australian Department for Planning and Infrastructure 2000). The maps and data (such as distances to nearest bushland) were viewed and generated using the software *GRAPE* (Geographical Retrieval and Analysis for the Planning Environment) (www.esri.com/software/arcgis/arcinfo).

Garden vegetation variables

In 1999, 17 observers from the full 57 consented to have their gardens surveyed for vegetation structure and composition. These 17 gardens are referred to as the 'primary gardens'. Neighbours either side and those opposite the primary gardens were also invited to participate in this study. In total, 77 gardens were surveyed over 17 sites. If an area of bushland or parkland was present rather than a homesite at a location that would normally be surveyed, then an area 20m x 60m from the kerb was surveyed. Each primary garden and those gardens immediately surrounding the primary garden will be referred to as a 'site'.

Each garden was measured initially for the area covered by bare ground, paving, lawn and other vegetation. Vegetation was further categorised depending on whether it was: bird pollinated; flowering; deciduous, or could bear fruit that birds eat. These groupings were then recorded in the appropriate height category (<1m, 1≥3m, 3≥5m and >5m) giving 20 categories in all. Finally, each category was recorded as a function of area (m^2) covered.

Vegetation species richness, defined as the number of different species found in all gardens at the site divided by garden area (m^2), was also collected for each garden surveyed. The other vegetation variables were not standardised for area because it is their relative proportions, rather than absolute area, that were considered most important.

Data analysis

In all analyses reported below, data were screened for fundamental assumptions of the statistical test used before analysis and any transformations applied are indicated. The significance level adopted for all tests was 0.05. In cases where multiple tests of dependent data were used, the modified Bonferroni correction (Quinn and Keough 2002) was used to ensure an experiment-wide error rate of 0.05.

Tests for redundancy in the environmental variables

A correlation matrix was established for the eight environmental variables across all 57 sites. R^2 for all but one of the comparisons involving environmental variables ranged from 0.00 to 0.20, indicating only weak relationships between each pair of variables. The last correlation, between Distance to Nearest Bushland less than 5km and Distance to Nearest Bushland greater than 5km, was somewhat higher (R^2=0.72). We decided to keep both variables because the correlation between them still left 28% of the variability unexplained.

Predicting bird species richness across 57 sites

Sites with more weekly records submitted are likely to record greater bird species richness because of the increased chance of observing rarer species. Therefore, the data across all sites were standardised for the number of weekly records using rarefaction, in which a common sample size (in this case, the number of individual birds seen) equal to or less than the smallest data set available was chosen for all sites and the species richness of each site corrected to what would be expected in the common sample size (Krebs 1999, p 330). The minimum number of birds recorded for 25 weekly records was 132, so when calculating the rarefaction (using EcoMeth 6.1; Exeter Software http://www.ExeterSoftware.com) all sites were set to a sample size of n=130.

Setwise regression was used to relate the eight environmental variables (Cat Density, Dog Density, Housing Density, Age of Suburb, Distance to Nearest Bushland <5ha, Distance to Nearest Bushland >5ha, Size of Bushland <5ha, Size of Bushland >5ha) to bird species richness. Setwise regression is an alternative to multiple regression in exploratory studies such as this where the ratio of cases observed to independent variables studied is low (Tabachnick and Fidell 1996). It regresses the dependent variable against all possible permutations of the independent variables and the regression giving the best fit is accepted as the most appropriate model. Cross-validation of the sample is important to ensure that the data are not over fitting. Dividing the whole data set randomly into two equal subsets, each of which is analysed separately, achieves this. Ideally, each analysis should yield the same best set of predictors that also agree with those determined from the full data set (Tabachnick and Fidell 1996).

Analysis was carried out using Mintab 14 'Best Subset Regression' (Minitab Release 14.1, http://www.minitab.com/products/Minitab/14/). Prior to analysis, Dog Density, Housing Density, Distance to Nearest Bushland < 5ha, Distance to Nearest Bushland > 5ha and Size of Bushland > 5ha were log transformed to improve their fit to the normal distribution. For purposes of comparison, the results of simple linear regression for each predictor variable independently were also determined, with the p-values in significance testing adjusted using the modified Bonferroni correction (Quinn and Keough 2002). Given that the predictor variable of Cat Density was of particular interest in this study, the power of a simple regression to detect a range of R values at the sample size of 57 was determined using the Power Analysis module of the Statistica package (Statsoft 1999).

Predicting bird community composition across 57 sites

A matrix of similarities in bird community composition among sites was estimated from square-root transformed bird count data using the Bray-Curtis coefficient (Bray and Curtis 1957). This similarity matrix was then correlated with similarity matrices based on Euclidean distance estimates between sites for each environmental variable and for all environmental variables combined. Preliminary analysis found that standardisation of environmental variables had no effect on the similarity matrices, so the results reported here are for unstandardised variables. Matrix correlations used the permutation procedure RELATE in PRIMER 5.0 (Clarke and Gorley 2001).

Prediction of functional groups and individual bird species across 57 sites

Those environmental variables which significantly affected species diversity or species composition (Distance to Nearest Bushland <5ha, Distance to Nearest Bushland >5ha, Size of Nearest Bushland >5ha and Housing Density) were regressed against combined species counts for five different functional groups of birds, and against the presence/absence of particular bird species. Functional groups were formed based on bird size and feeding behaviour: small insectivores (wingspan < 60mm, diet predominantly arthropods); medium insectivores (wingspan 60 – 150mm, diet predominantly arthropods); large predators/omnivores (wingspan > 150mm, diet predominantly arthropods and small vertebrates); nectarivores (various sizes, diet includes a substantial proportion of nectar and varying proportions of arthropod material); frugivores/granivores (various sizes, diet includes a substantial proportion of fruit or grain and varying proportions of arthropod material). Sizes were estimated from Schodde and Mason (1999) and diet was confirmed by reference to

Barker and Vestjens (1990). There is inevitably some overlap between these groups, necessitating arbitrary decisions about placement for a number of species. The significance of individual environmental variables in forward stepwise multiple regressions against each functional group were determined using a modified Bonferroni correction (Quinn and Keough 2002). Stepwise multiple regression rather than setwise regression was possible in this case because of the smaller number of predictor variables.

Bird species that occurred in at least 20% of sites, but no more than 80% of sites were selected for specific analysis to determine if their presence/absence could be predicted in a logistic regression using the eight environmental variables. It was unlikely that strong predictions could be determined for birds occurring in very few (<20%) or nearly all (>80%) sites. Although the Willie Wagtail occurred in 81% of gardens, it was included in the analysis group because of its status as a suburban icon. Once a logistic regression is fitted, Wald's χ^2 is commonly used for testing the significance of individual independent variables. However, it may be conservative when the absolute value of the regression coefficient is large and standard errors may be over-estimated, increasing the possibility of Type II errors (Tabachnick and Fidell 1996). Therefore, we tested the significance of individual variables in fitted logistic regressions by removing them and noting the change in χ^2.

Influence of vegetation characteristics in 17 sites

The problem in analysing these sites was the large number of predictor variables (20 vegetation variables plus the eight other environmental variables) in relation to the 17 study sites available. Accordingly, factor analysis followed by varimax rotation was used to reduce the vegetation variables to five factors which explained 87.5% of the variance:

Factor one – fruiting vegetation that occurred in all the four height categories (Fruiting)

Factor two – vegetation that was greater than five metres, bird pollinated, flowering and deciduous (Tall bird-pollinated deciduous)

Factor three – deciduous vegetation greater than two metres in height, grassed and paved areas (Medium deciduous and open areas)

Table 1. Birds observed during the census period, the proportion of sites where they were seen and the functional group in which they were placed. Birds occuring in 20-80% of sites were used in analysis as 'selected species'. The Willie Wagtail was also included in this group because of its status as an iconic suburban species. Functional groups are indicated by superscripts: [1]small insectivore;[2]medium insectivore; [3]large predator/omnivore; [4]nectarivore; [5]frugivore/granivore.

0-19% (% occurrence)	0-19% (% occurrence)	20-80% (% occurrence)	>80% (% occurrence)
Black-faced Woodswallow[2] *Artamus cinereus* (3.45)	Splendid Fairy Wren[1] *Malurus splendens* (12.07)	Grey Butcherbird[3] *Cracticus torquatus* (65.52)	Australian Magpie[3] *Gymnorhina tibicen* (100)
Clamorous Reed-warbler[1] *Acrocephalus stentorius* (1.72)	Spotted Pardalote[5] *Pardalotus punctatus* (15.52)	Grey Fantail[1] *Rhipidura fuliginosa* (39.66)	Australian Raven[3] *Corvus coronoides* (100)
Golden Whistler[2] *Pachycephala pectoralis* (3.45)	Tawny-crowned Honeyeater[4] *Phylidonyris melanops* (6.90)	Little Wattlebird[4] *Anthochaera chrysoptera* (53.45)	Black-faced Cuckoo-shrike[2] *Coracina novaehollandiae* (84.48)
Grey Currawong[3] *Strepera versicolor* (3.45)	Varied Sittella[1] *Daphoenositta chrysoptera* (5.17)	Mistletoebird[5] *Dicaeum hirundinaceum* (32.76)	Brown Honeyeater[4] *Lichmera indistincta* (91.38)
Grey Shrike-thrush[2] *Colluricincla harmonica* (12.07)	Weebill[2] *Smicrornis breviostris* (12.07)	New Holland Honeyeater[4] *Phylidonyris novaehollandiae* (67.24)	Magpie-lark[3] *Grallina cyanoleuca* (84.48)
Inland Thornbill[1] *Acanthiza apicalis* (10.34)	Western Thornbill[1] *Acanthiza inorata* (3.45)	Rufous Whistler[2] *Pachycephala rufiventris* (34.48)	Red Wattlebird[4] *Anthochaera carunculata* (94.83)
Little Grassbird[1] *Megalurus gramineus* (1.72)	White–browed Babbler[2] *Pomatostomus superciliosus* (1.72)	Silvereye[5] *Zosterops lateralis* (79.31)	Singing Honeyeater[4] *Lichenostomus virescens* (94.83)
Masked Woodswallow[2] *Artamus personatus* (3.45)	White-browed Scrubwren[1] *Sericornis frontalis* (3.45)	Striated Pardalote[5] *Pardalotus striatus* (55.17)	Willie Wagtail[2] *Rhipidura leucophrys* (81.03)
Pied Butcherbird[3] *Cracticus nigrogularis* (1.72)	White-fronted Chat[1] *Epthianura albifrons* (1.72)	Tree Martin[2] *Hirundo nigricans* (68.97)	
Red-capped Robin[2] *Petroica goddenovii* (5.17)	White-naped Honeyeater[4] *Melithreptus lunatus* (13.79)	Welcome Swallow[2] *Hirundo neoxena* (68.91)	
Red-winged Fairy Wren[1] *Malurus elegans* (1.72)	White-winged Triller[2] *Lalage suereurii* (1.72)	Western Gerygone[1] *Gerygone fusca* (32.76)	
Richard's Pipit[1] *Anthus novaeseelandiae* (5.17)	Yellow-plumed Honeyeater[4] *Lichenostomus ornatus* (1.72)	Western Spinebill[4] *Acanthorynchus superciliosus* (39.66)	
Rufous Songlark[1] *Cincloramphus mathewsi* (1.72)	Zebra Finch[5] *Taenopygia guttata* (3.45)	White-cheeked Honeyeater[4] *Phylidonyris nigra* (37.93)	
Scarlet Robin[2] *Petrica multicolor* (12.07)		Yellow-rumped Thornbill[1] *Acanthiza chrysorrhoa* (22.41)	

Factor four – flowering plants across the two middle height groups, 1-3m and 3-5m and bare areas (Medium bird-pollinated and open areas)

Factor five – plants that are <1m, bird pollinated and flowering (Low bird-pollinated).

No correlation matrix was produced to check for redundancy in the vegetation factors, because factor analysis had already reduced the number of variables.

The five vegetation factors were then analysed both as a separate group and together with the eight environmental variables using setwise regression and similarity matrices in PRIMER 5.0 in the same manner as the environmental variables were analysed for the full 57 sites. Simple linear regressions were also run for each vegetation factor. Finally, logistic regression was used in an attempt to predict the presence/absence of specific bird species on the basis of the five garden vegetation factors.

Results

Bird species observed

Forty-nine passerine species were observed during the census period at one or more of the 57 sites. Twenty-seven species (55%) occurred in fewer than 20% of sites, 14 species (29%) occurred at between 20% and 80% of sites and eight species (16%) occurred at more than 80% of sites (Table 1).

Distribution of environmental variables

Survey responses for determination of cat and dog densities across the 57 sites varied between 27% and 100% ($\bar{x}$ = 63.61, SE ± 2.26). In this study, cat and dog ownership were 19% and 28% of households respectively. Table 2 displays means and standard errors for all environmental variables for each site.

Effects of eight environmental variables across 57 sites

Bird species richness

Results of all three setwise and simple linear regression analyses (full data set, half data set one and half data set two) are shown in Table 3. Cat Density was not significant in a simple linear regression, nor was it included in the best fitting setwise regression. The best setwise regressions included Distance to Nearest Bushland >5 ha and Housing Density and Size of Nearest Bushland >5ha as components of the regression model, although Size of Nearest Bushland >5ha was not significant. Bird species richness declined with increasing Distance to Bushland > 5ha and with increasing Housing Density (Figure 1). Together, these predictors explain almost half of the variability in bird species richness (adjusted R^2 for the complete data set = 0.414).

Table 2. Means, standard errors (in parentheses) and ranges for eight independent variables in the study.

	Response rate (%) of number dwellings surveyed	Cat density[1]	Dog density[2]	Housing density[3]	Distance (km)* (and size [ha] to nearest bushland** <5ha[4])	Distance (km)* (and size [ha] to nearest bushland** >5ha)	Age at 1998
Mean (std error)	63.63(2.26)	3.30(0.35)	4.01(0.42)	15.78(3.52)	*0.82(0.1)**1.97(0.16)	*1.71(0.83) **102.17(69.23)	55.54 (3.10)
Range	27-100	0-10.8	0-14.84	0.02-192.31	*0-4.07 **0.5-4.99	*0.00 – 3.47 **5.0-3941	0-80

[1] number of cats/total block size of respondents in hectares (cats/ha)
[2] number of dogs/total block size of respondents in hectares (dogs/ha)
[3] number of dwellings/sum of block sizes in hectares (dwellings/ha)

Table 3. Results of setwise regression and simple linear regression for predicting bird species richness from the eight core predictor variables. The setwise columns show all independent variables included in the best fitting multiple regression and the results of separate t-tests for the significance of each variable.

Independent variable	Simple linear regression	Setwise regression ** (total data set)	Setwise regression Split one Split two
Cat density	$F_{(1,55)}$ = 1.01, p = 0.319, R = 0.018		
Dog density	$F_{(1,55)}$ = 0.733, p = 0.733, R = 0.002		
Distance to nearest bushland <5ha	$F_{(1,55)}$ = 6.05, p = 0.017, R = 0.09		
Size of nearest bushland <5ha	$F_{(1,55)}$ = 0.20, p = 0.658, R = 0.005		
Distance to nearest bushland >5ha	$F_{(1,55)}$ = 10.48, p = 0.002*, R = 0.16	t = -3.45, p = 0.001	t = -1.73, p = 0.098 t = -3.68, p = 0.001
Size of nearest bushland >5ha	$F_{(1,55)}$ = 2.92, p = 0.093, R = 5	t = -1.27, p = 0.210	
Housing density	$F_{(1,55)}$ = 25.83, p = 0.0001*, R = 0.32	t = -5.11, p = 0.000	t = -2.98, p = 0.007 t = -5.07, p = 0.000
Age of suburb	$F_{(1,55)}$ = 4.83, p = 0.032, R = 0.081		

Only p values marked with (*) are significant after modified Bonferroni.
**Only variables included in the best subset are displayed. Test statistics for best subset: R^2 (adj)=0.41, Mallows Cp= -0.3, S=3.68, ANOVA: $F_{3,53}$=14.17, p<0.00.

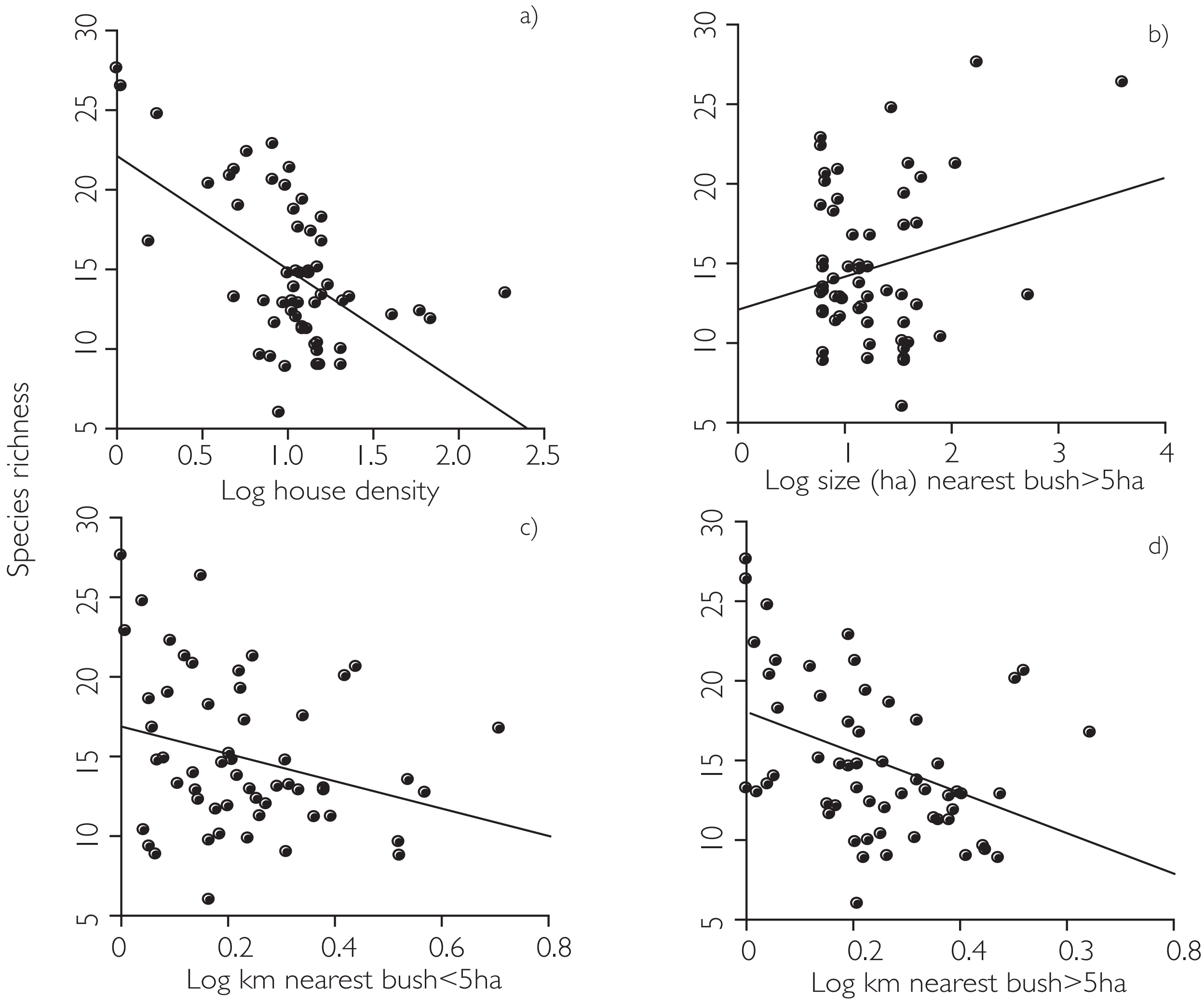

Figure 1. Relationship between bird species richness (x) and four significant predictor variables (y) over 57 sites (a) Log Housing Density, b) Log (ha) Size of Nearest Bushland >5ha, c) Log Distance (km) to Nearest Bushland <5ha and d) Log distance (km) to Nearest Bushland >5ha).

There was 80% power for a simple regression to detect even a modest R of 0.38 given the sample size of 57 and this increased rapidly with larger R values. Therefore the simple linear regressions were highly likely to detect even weak relationships between bird species richness and an individual predictor variable.

Bird community composition

There was no significant relationship between the similarity of sites based on their bird community composition and the similarity of sites based on all the environmental variables combined (Rho = 0.076, p = 0.12). However, when sites were grouped by each individual environmental variable, the similarity in bird community composition was significantly related to the similarity in Distance to Nearest Bushland <5ha, Distance to Nearest Bushland >5ha, Size of Nearest Bushland >5ha and Housing Density after modified Bonferroni correction (Table 4).

Analysis of functional groups

Stepwise multiple regression analyses of bird counts for different functional groups against Distance to Nearest Bushland <5ha, Distance to Nearest Bushland >5ha, Size of Nearest Bushland >5ha and Housing Density were strongest for small insectivores ($R^2 = 0.42$) and medium insectivores ($R^2 = 0.21$), with significant relationships (after a Bonferroni correction) only for Housing Density (for small insectivores $F_{(1,55)} = 27.91$, $p < 0.0001$; for medium insectivores $F_{(1,55)} = 10.35$, $p < 0.001$). The same significant relationships were found when the data file was randomly split into two groups and each group was analysed separately.

Analysis of presence/absence of 15 selected bird species

Logistic regression was used to test if the presence or absence of the selected passerine species over the 57 sites was related to the environmental variables. Each bird species was regressed against the eight environmental variables with modified Bonferroni corrections used to ensure an overall significance level of 0.05. Regressions approached significance for the Grey Fantail, Mistletoe Bird and Western Spinebill, with Size of Nearest Bushland <5ha emerging as a possible predictor. Cat Density was almost a significant predictor for the occurrence of the Western Spinebill (Table 5). Splitting the data file to

Table 4. Results of Primer analysis to assess bird community composition.

Independent variable	Assessment of individual predictors
All variables combined	Rho = 0.076, p = 0.12
Cat density	Rho = 0.103, p = 0.05
Dog density	Rho = 0.032, p = 0.257
Distance to nearest bushland <5ha	Rho = 0.178, p = 0.004*
Size of nearest bushland <5ha	Rho = 0.068, p = 0.86
Distance to nearest bushland >5ha	Rho = 0.266, p = 0.001*
Size of nearest bushland >5ha	Rho = 0.273, p = 0.001*
Housing density	Rho = 0.337, p = 0.001*
Age of suburb	Rho = 0.057, p = 0.172

Only p values marked with (*) are significant after modified Bonferroni.

determine the consistency of the predictions found that one of the two splits for the Grey Fantail, Mistletoe Bird and Western Spinebill data file approached significance (Table 5). Size of Nearest Bushland < 5ha occurred in all these cases, suggesting that of all the predictors investigated, this factor is most likely to be important. Cat Density was only significant in one half of the split for the Western Spinebill and was not reproduced in the other, making it a questionable predictor.

Effects of environmental and vegetation variables at 17 sites

Effect of all variables combined

When all 13 variables (environmental variables and vegetation factors one to five) were analysed the best subset, containing eight independent variables (Dog Density, Housing Density, and Factors one to five), was not significant (R^2 (adj) = 0.43, Mallows Cp = 6.4, S = 4.08, $F_{8,9}$ = 2.45, p = 0.11). The inability to find a significant subset probably occurred because of the small number of cases (n=17) in the vegetation subset. Although 77 gardens were surveyed for vegetation content, only 17 sites were represented. The power of a simple regression to detect a particular value of R given the sample size of 17 is 80% for an R of 0.62 and this increases rapidly with larger R values. However, power is lower for modest R values, being only 40% for an R of 0.4.

There was also no significant relationship between the similarity of sites based on the 13 independent variables (including the vegetation factors) analysed as a group and the similarity of sites based on bird species composition (Rho = 0.06, p = 0.25).

Effect of the five vegetation factors alone

Setwise regression was used to select a best subset using only the five vegetation factors and bird species richness, but no significant best subset was found (result closest to significance was $F_{3,13}$ = 0.75, p = 0.54). Similarly, logistic regression failed to indicate vegetation factors which predicted significantly the presence/absence of any of the 15 bird species tested after application of the modified Bonferroni correction. The Yellow-rumped Thornbill came closest to signficance. Gardens which contained low bird-pollinated plants (Factor 5) may be more likely to contain Yellow-rumped Thornbills, while gardens dominated by fruiting vegetation (Factor 1), tall, bird –pollinated deciduous vegetation (Factor 2) and medium deciduous plants and open areas (Factor 3) may be less likely to contain Yellow-rumped Thornbills (χ^2_5= 14.73, p = 0.02, n.s. after modifed Bonferroni of 0.003).

Discussion

Is Cat Density related to passerine species richness or passerine community composition?

Cat Density was not a predictor of passerine species richness, bird community composition or, with the possible exception of the Western Spinebill, presence/absence of bird species across our study sites. Before considering the implications of these findings, it is important to establish the validity of the study design by rejecting the possibility of bias in the measurements of Cat Density, bird species richness, bird community composition or presence/absence of species, justifying the representativeness of the gardens sampled and confirming that the study had adequate power to detect effects.

Validity of the findings

One indication of bias in estimating cat densities would be if the percentage of households owning cats or the estimated cat densities differed markedly from those reported in other major Australian surveys. In this study, approximately 19% of households surveyed owned cats, compared to *c.* 23 % nationally in a 2002 survey (petnet.com.au/statistics.html). We estimated Cat Density across all sites at 3.30 cats per hectare, close to the density of 3.82 cats per hectare reported by Barratt (1998) for suburban Canberra. These comparisons give no reason to believe that the estimates of densities are biased significantly in this study. While it is possible that cat ownership was under-reported or denied (e.g. Lepczyk *et al.* 2004a, b), this would only be a problem in the unlikely event that the bias was unequal across sites. Otherwise, relativities between sites would be preserved and the effect of relative Cat Density would still be testable. Furthermore, the range in cat densities found across the sites was from 0.00 – 10.80 cats per hectare, eliminating the possible problem that cat densities were too uniform across sites to detect an effect.

Table 5. Logistic regression results of 15 selected bird species versus eight core predictors.

Selected species	Logistic Regression results*	Significant Predictors**	Logistic regression on split data file for significant relationships* (Split 1, Split 2)	Significant predictors in split**
Grey Butcherbird	$\chi^2_8 = 9.15$, $p = 0.329$			
Grey Fantail	$\chi^2_8 = 16.31$, $p = 0.038$ (NS using modified Bonferroni)	Size of nearest bushland <5ha. $\chi^2_8 = 10.40$, $p = 0.001$	$\chi^2_8 = 8.03$, $p = 0.43$ $\chi^2_8 = 13.62$, $p = 0.09$	
Little Wattlebird	$\chi^2_8 = 6.26$, $p = 0.62$			
Mistletoebird	$\chi^2_8 = 15.59$, $p = 0.049$ (NS using modified Bonferroni)	Size of nearest bushland <5ha. $\chi^2_8 = 7.36$, $p = 0.007$	$\chi^2_8 = 20.62$, $p = 0.008$ $\chi^2_8 = 8.01$, $p = 0.43$	Size of nearest bushland <5ha. $\chi^2_8 = 7.00$, $p = 0.008$
New Holland Honeyeater	$\chi^2_8 = 5.77$, $p = 0.67$			
Rufous Whistler	$\chi^2_8 = 7.59$, $p = 0.47$			
Silvereye	$\chi^2_8 = 11.87$, $p = 0.16$			
Striated Pardalote	$\chi^2_8 = 5.07$, $p = 0.75$			
Tree Martin	$\chi^2_8 = 7.69$, $p = 0.46$			
Welcome Swallow	$\chi^2_8 = 14.37$, $p = 0.07$			
Western Gerygone	$\chi^2_8 = 8.87$, $p = 0.35$			
Western Spinebill	$\chi^2_8 = 17.95$, $p = 0.022$ (NS using modified Bonferroni)	Size of nearest bushland <5ha: $\chi^2_8 = 8.84$, $p = 0.003$ Cat Density: $\chi^2_8 = 6.70$, $p = 0.01$	$\chi^2_8 = 9.88$, $p = 0.27$ $\chi^2_8 = 17.97$, $p = 0.02$	No variables significant when model viewed (ie. No variables signifcant with Walds chi square. Dog density is closest $\chi^2_8 = 3.41$, $p = 0.065$
White-cheeked Honeyeater	$\chi^2_8 = 10.68$, $p = 0.22$			
Willie Wagtail	$\chi^2_8 = 11.81$, $p = 0.16$			
Yellow-rumped Thornbill	$\chi^2_8 = 14.71$, $p = 0.06$			

*(using Wald's chi-squared), **(chi square and p values obtained using maximum liklihood)

Estimates of passerine species richness, community composition and presence/absence were unlikely to be a problem because members of Birds Australia were responsible for collecting these data. It is fair to assume that members of such a group are passionate about their hobby and more than capable of recognising and recording birds correctly. It may be initially thought that a birdwatcher's garden would bias results but this study included the gardens surrounding each birdwatcher's garden also, totalling 77 gardens from 17 sites. Lastly, Cat Density did not approach significance as a predictor of bird species richness in a simple linear regression even though this had 80% power to detect even a moderate R of 0.38. Overall, we believe that the estimates of Cat Density, bird species richness, bird community composition and presence/absence are robust, so the conclusion of no effect of Cat Density on bird species richness, bird community composition and presence/absence of individual species is sound.

Significance and comparison to other studies

Some other studies have also failed to link cat abundance or density with declines in the abundance of urban or suburban birds. Indeed, in the United States Thomas *et al.* (1977) found a significant positive relationship between cat density and abundance of House Sparrows *Passer domesticus* and Chipping Sparrow *Spizella passerina*. They concluded that these species are reliant upon the presence of humans and that this relationship over-rides any loss of sparrows to cat predation. In Canberra, Australian Capital Territory, Barratt (1995, 1997, 1998) found that Blackbirds *Turdus merula* and House Sparrows were increasing in numbers despite being the favoured prey of cats, while Crimson Rosellas *Platycercus elegans* and Silvereyes were either stable or increasing in numbers despite extensive predation by cats. Barratt (1998) concluded that it was inappropriate to assume that prey populations were endangered because some individuals were killed by cats, although he acknowledged that cat predation might be a more significant influence in native vegetation adjacent to new suburban subdivisions. In contrast, Dickman (2002) found a negative relationship between cat activity (measured by presence of cat faeces) and bird species richness in 24 bushland sites in the Sydney UBD. The bird species most affected by cat activity foraged or nested at or close to the ground. However, in the same study site, increased densities of cats correlated with reduced nest predation by introduced rats and other predators of nests, so a complex of interacting factors could be involved.

Overall, the most conservative interpretation is that in areas where the original vegetation has been removed and replaced with roads, buildings, open grassed areas and canopy trees with minimal coverage of local native foliage, cats do not appear to impact populations of passerine birds. The passerines occurring in these areas have either persisted through the disturbances of subdivision, or recolonised successfully as gardens and trees have established. They have done so in the presence of cats and are robust against the losses caused by cat predation (Mead 1982; Barratt 1998; Fitzgerald and Turner 2000). However, cat density may be negatively related to populations of birds that forage and nest close to the ground in remnant bushland where there is appropriate habitat (Dickman 2002).

What other environmental factors influence passerine species richness and passerine community composition?

Four environmental variables predicted bird species richness or bird community composition for the 57 sites throughout suburban Perth:

1) Housing Density,

2) Distance to Nearest Bushland <5ha,

3) Distance to Nearest Bushland >5ha and

4) Size of Nearest Bushland >5ha.

Housing Density and Distance to Nearest Bushland (both less than and greater than 5 hectares) were negatively related to bird species richness while Size of Nearest Bushland >5ha was positively related to bird species richness. The two groups of birds most affected by these environmental variables seemed to be small and medium sized insectivores, such as fantails, thornbills and whistlers.

Placing these results in an international context is challenging, because much of the published work is North American or European, involving very different species assemblages and city layouts to those occurring in Australia in general and Perth in particular. Even studies within Australia may not be fully comparable because of significant variations in study methodology (see discussion in Catterall 2004). Furthermore, Perth is very unusual in lacking the House Sparrow and the Common Starling *Sturnus vulgaris*, which are important components of many other urban avifaunas. Those cautions should be borne in mind when considering the following discussion.

Housing Density

A strong negative effect of Housing Density on bird species richness was also found in a study in Arizona by Germaine *et al.* (1998). The driving force, which is applicable to a wide range of urban areas, appears to be that as housing density increases, remnant bushland areas generally become fragmented and smaller. In describing the central European situation, Bezzel (1985) noted that gardens also decrease in size and do not provide protection or food sources to replace the native habitat, while pesticides reduce biodiversity and pollute the soil and ground water. By contrast, gardens in the UK are viewed as possible refuges for remaining avifauna, particularly for the declining House Sparrow (Nelson *et al.* 2005). Increased housing density is often associated with more roads, possibly sealed parking lots and often increased traffic. When assessing factors relevant to bird conservation in a large bushland remnant in Perth, Recher (2004) observed that roads and open areas act as barriers to many small insectivores, preventing them from moving between islands of remnant bushland. Even if the birds were able to cross roads that fragmented their habitat, mortality from cars would be high because these birds occupy low canopy and fly at the same level as cars. Forman and Deblinger (2000) and Forman *et al.* (2002), who studied bird communities near Boston, USA, claimed traffic noise to be a greater disturbance to avian community changes than visual disturbance, air pollution or predators, perhaps because it interferes with communication between breeding pairs and their broods.

Clergeau *et al.*'s (2001) major meta-analysis of 18 studies from France, Finland and Canada raised the issue of people's attitudes towards wildlife as perhaps the greatest long-term concern. This may change as housing density increases, influencing an individual's receptivity to any measures proposed to increase the wildlife around properties. For example, in French urban areas, 12% of people surveyed reported never observing birds, 45% didn't intentionally observe birds and 66% only noticed noisy birds. In support of this view, a US survey revealed that 63% of respondents disliked the noise and mess made by birds (Penland 1986). Interestingly, the birds that were observed most frequently were noisy, large birds that were most often associated with wildlife problems.

Size and proximity of native vegetation remnants

The association between size and distance to remnant bushland on the one hand and bird species richness and community composition on the other is not surprising in the light of recent Australian studies. Catterall (2004) described the small and medium sized insectivores most affected in our study as 'neglected foliophiles' because they are uncommon and inconspicuous in suburbia and the general public are often unaware of them. They are commonly found in undisturbed remnants greater than 10-20 hectares in size (Catterall 2004). Populations of sedentary birds such as the Rufous Whistler require territories of one to two hectares per breeding pair (Freudenberger *et al.* 1997; Watson *et al.* 2001) and there are limited numbers of large areas of bushland within suburban Perth to meet this need (How and Dell 1994, 2000). The Western Spinebill is able to utilise suburban native plantings, but still requires small amounts of remnant bushland to supplement its food source and for provision of nesting sites. Similarly, the Grey Fantail forages on the insects that are associated with human occupation, but requires some bushland for nesting and extra food sources. The Mistletoe Bird feeds wherever mistletoe parasitises other plants, which could include suburban gardens adjacent to small amounts of bushland, as well as on small exotic berries found in many gardens. Like the Western Spinebill and Grey Fantail, the Mistletoe Bird will still be dependent upon small amounts of bushland to supplement its food and to provide nesting sites.

The spatial distribution of the vegetation is also crucial for the presence and survival of populations of insectivorous birds, both in terms of habitat structure and the provision of resources (Green *et al.* 1989). For example, the abundance of small insectivores decreases as one moves toward the edge of a continuous habitat (Atkinson 2003). The shape of the remnant bushland is of great importance, particularly when attempting to maximise the usable internal space and minimise any detrimental edge effects. The most efficient way a bird can conserve energy and time is to minimise the perimeter of its territory, using concentric circles radiating from the nest and ending at the furthest range of the bird's territory (Goldstein *et al.* 1981, Figure 12.2 in Recher 1996).

Given the importance of proximity to bushland and the vegetation structures it provides, it is surprising that we found no influence of garden vegetation structure and floristics on bird species richness or bird community composition, although the presence of the Yellow-rumped Thornbill may be associated with gardens which contained low bird-pollinated plants. However, these data were limited severely by sample size and it may be premature to discount them, or the possibility that they correlate with other environmental variables such as Housing Density.

Other possible environmental factors

Environmental factors other than those measured in this study may also influence suburban bird species diversity and community composition. For example, Recher (2004) suggested that small insectivorous birds fair poorly in suburban Perth because of changes in garden composition, high populations of raptors sustained by exotic prey and possibly increased nest predation.

Suburban gardens consist mostly of exotic plants or native cultivars that support few herbivorous arthropods and gardeners may actively discourage the few that occur. For example, Catterall *et al.* (1989) compared the use of Australian native and exotic plants by native birds in a temperate site and found that native birds utilised native plants significantly more than exotic plants. In general, local indigenous plants support a greater diversity and number of insects and spiders than exotic plants (Bhuller and Majer 2000; Majer *et al.* 2000).

The diet, foraging behaviour and breeding requirements of the group of birds recorded in ≥80% of observations in this study reflect the most prevalent types of suburban vegetation. Birds such as Australian Ravens, Australian Magpies, Black-faced Cuckoo-shrikes and Magpie Larks may exploit open grassed areas, while Red Wattlebirds, Brown Honeyeaters and Singing Honeyeaters feed among exotic and native cultivars. Along the east coast of Australia the extremely aggressive Noisy Miner *Manorina melanocephala* occurs in increasingly large numbers throughout mature suburbs with canopy (Catterall 2004). Loyn (1987), Catterall *et al.* (1991, 2002), Low (1994) and Woodall (2002) showed that birds such as the Noisy Miner exclude small foliage feeding birds from suburban areas that they would otherwise be able to inhabit. The Red Wattlebird is the most aggressive of the honeyeaters in suburban Perth (Ford 1989; Low 2002) and may exclude smaller insectivorous birds otherwise able to utilise garden vegetation.

Raptors represent a clear case of hyperpredation (Courchamp *et al.* 2000). They survive well in suburbia because of the constant supply of introduced Laughing Turtle-Doves *Streptopelia senegalensis* and the increased populations of raptors could impact populations of small insectivores, particularly in bushland or park areas (Recher 2004). Australian Ravens were often thought to be the culprit in nest predation, but unpublished work in suburban Perth found they predated only 4% of nests (Stewart 1997). However, if a particular population is already at risk, then a predation rate of 4% may indeed become significant (Recher 2004).

Suggestions for bird conservation in Perth suburbia and the role of pet cats

In summary, this study found no evidence that Cat Density was related to bird species richness and community composition in suburban Perth. Instead, Housing Density and proximity to native bushland of suitable size were the most critical determinants, largely through their effect on insectivorous species. Although some bushland species are restricted to specific habitats because they are specialised in their foraging and nesting behaviours, other species may be more adaptable (Craig 2002). With some encouragement such as appropriate garden plantings and nearby remnant bushlands of reasonable size, shape and quality, these species may be able to use garden corridors connecting remnant bushland (Vale and Vale 1976; Lancaster and Rees 1979; Green 1984; Mills *et al.* 1989; Munyenyumbe *et al.* 1989; Majer *et al.* 2001). Catterall (2004) highlights that the landscaping solutions required are far more complex than simply planting a range of native trees. Instead, they require planning for between-habitat diversity in an urban mosaic incorporating a range of different garden styles interlinked with bushland remnants.

The findings from our study do not exclude the possibilities that cat predation might be significant adjacent to remnant bushland or other areas of conservation significance, that some regulation of predatory pressure might lead to the re-establishment of a greater range of bird species in suburbia or that detrimental predatory impacts occur rapidly after the establishment of new subdivisions. However, they do suggest that blaming cats for bird conservation issues in long-established suburbs may be a scapegoat for high residential densities, inappropriate landscaping at a range of scales or poor conservation of remnant bushland.

Acknowledgements

We thank Clive Nealon for allowing access to the Birds Australia data base, Leonie Howman for preparing surveys and Sarah Plewright for helping in their distribution, Tony Hodge for assistance in vegetation sampling, Laurie Mitchell for his expertise in Excel and to those observers who allowed us access to their gardens. The manuscript benefitted greatly from reviews by Carla Catterall and Harry Recher and editorial guidance from Pat Hutchings, although they may not share all our final opinions. Jacky Grayson was supported by the Robert Hammond Postgraduate Research Studentship.

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