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Impacts of urbanisation on the native avifauna of Perth, Western Australia.

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Abstract

Urban development either eliminates, or severely fragments, native vegetation, and therefore alters the distribution and abundance of species that depend on it for habitat. We assessed the impact of urban development on bird communities at 121 sites in and around Perth, Western Australia. Based on data from community surveys, at least 83% of 65 landbirds were found to be dependent, in some way, on the presence of native vegetation.

For three groups of species defined by specific patterns of habitat use (bushland birds), there were sufficient data to show that species occurrences declined as the landscape changed from variegated to fragmented to relictual, according to the percentage of vegetation cover remaining. For three other groups (urban birds) species occurrences were either unrelated to the amount of vegetation cover, or increased as vegetation cover declined. In order to maximise the chances of retaining avian diversity when planning for broad-scale changes in land-use (i.e. clearing native vegetation for housing or industrial development), land planners should aim for a mosaic of variegated urban landscapes (> 60% vegetation retention) set amongst the fragmented and relictual urban landscapes (< 60% vegetation retention) that are characteristic of most cities and their suburbs. Management actions for conserving remnant biota within fragmented urban landscapes should concentrate on maintaining the integrity and quality of remnant native vegetation, and aim at building awareness among the general public of the conservation value of remnant native vegetation.

Introduction

During the past 180 years, the impact of urbanisation on the Swan Coastal Plain, Western Australia has been profound. From first settlement by Europeans in 1829 to the present day, the native vegetation has been and continues to be cleared for housing, industry and agriculture, and much of what remains has been modified in some way by, and, for human activities. The detrimental impacts of this type of habitat destruction and modification on flora and fauna populations may include reduced breeding success and fecundity (Stephens *et al.* 2003; Temple and Cary 1988), changes in the demographic composition of populations (Major *et al.* 1999), increased dispersal mortality (Brooker *et al.* 1999), increased competitive and aggressive interactions (Grey *et al.* 1997; Grey *et al.* 1998), increased rates of nest predation (Major *et al.* 1996), reduced gene flow (Cunningham and Moritz 1998) and inbreeding depression (Lacy and Lindenmayer 1995). However, much of the discussion of habitat loss and modification has been in the context of island biogeography (MacArthur and Wilson 1967), focussing on fragmentation, patch size, interpatch distances and edge effects (Watson *et al.* 2005). In Western Australia, such studies have been concentrated in the wheatbelt region, that provides a classically fragmented landscape of remnant habitat patches surrounded by a largely un-vegetated, homogenous, hostile matrix (Brooker and Brooker 2003; Fortin and Arnold 1997; Kitchener and How 1982; Sarre *et al.* 1995; Saunders 1989).

In an effort to provide a broader framework for the study of human modified landscapes, McIntyre and Hobbs (1999) proposed four landscape alteration states ("intact", "variegated", "fragmented" and "relictual") where the remaining habitat has undergone varying degrees of modification. They defined intact landscapes as those with less than 10% of the habitat removed, variegated landscapes with between 60% and 90% remaining, fragmented landscapes with between 10% and 40% remaining, and relictual landscapes with less than 10% remaining, but stressed that different species have different habitat preferences and therefore respond to these different alteration states in different ways.

McIntyre and Hobbs' approach provides a suitable framework for the study of urban and peri-urban environments surrounding Perth. To the east of Perth lies the Darling Range, an intact landscape of largely uncleared, though considerably modified, native forest. At the foot of the range lies the Swan Coastal Plain, with partially cleared grazing land, horticultural areas, pine forests, hobby farms, semi-industrial areas, airfields, leafy suburbs with planted gardens and wooded streets, urban parks and new housing developments with minimal backyard gardens − a mosaic of variegated and fragmented landscapes; while inner city and industrial areas are relictual.

Increasingly, the importance of different habitat states in understanding a species' sensitivity to urbanisation is being recognised (e.g. Catterall *et al.* 1998; Garden *et al*. 2006; Hodgson *et al.* 2006; Parsons *et al.* 2003; White *et al.* 2005). In this context, the overall objective of our study was to determine how the bird fauna of the Perth region has responded to the highly modified landscapes on the Swan Coastal Plain. Second, we aimed to identify those bird species that were most at risk from urbanisation. Finally, we aimed to investigate the primary factors influencing bird species occurrences at both broad-scale and fine-scale resolutions, and determine their primary requirements with a view to informing landscape-scale conservation planning and local-scale conservation management.

Methods

Bird data

The bird observations used in the analyses were collected by volunteers as part of the Perth Biodiversity Project, a local government conservation initiative involving a number of community groups and organisations. The bird survey methodology and project management was undertaken by Birds Australia (WA). Survey sites were selected by local councils on the Swan Coastal Plain and Darling Range as being of importance in their local context, and therefore may provide a biased sample of remnant native vegetation in the Perth region. However, sites had a wide geographic coverage, ranging across the Swan Coastal Plain and western Darling Range from north (Wanneroo) to south (Rockingham) and from west (Cottesloe) to east (Mundaring). The sites encompassed a range of remnant sizes and included all types of urban landscape from the city, through suburban, semi-rural, and rural to largely uncleared native vegetation in the Darling Range. The great majority of sites included remnant stands of native vegetation, but a small number were urban parks containing only/largely exotic plant species.

Monthly bird surveys were undertaken from July 2002 to May 2003 and from October 2003 to September 2004 (78 sites surveyed between four and 17 times, median number of surveys per site, 12) (Gole 2003; 2004); and from January 2005 to February 2006 (39 sites surveyed between 10 and 13 times, median number of surveys per site, 12) (Gole 2006). At each site, on each survey, a record was made of all birds seen or heard during a search of the entire site including records of birds flying over the site. Presence/absence records were collected for all species. Abundance data were only collected for waterbirds, which are not the focus of this study. Observers were instructed to take as much time as was necessary to survey all habitat types, and so survey time varied with the size of the site. Survey methods are reported in detail in Gole (2003; 2004; 2006). The data are considered reliable as volunteers were selected by a project coordinator based on their knowledge of birds. All sightings were vetted by a project co-ordinator, and queries were made about unusual records. In total, data were available for 1400 site-surveys obtained from 121 sites, with an average of 12 surveys each (range 6-17 surveys).

Our analyses excluded all waterbirds, nocturnal and exotic species; the former because their habitat requirements differ from those of terrestrial species, nocturnal birds because no specific night-time surveys were undertaken and exotic species because the subject of this study was the native avifauna of the Perth region. A list of bird species with scientific nomenclature is provided in the Appendix.

Broad-scale environmental variables

Within the computer program ArcGIS (ESRI), using high resolution air photography and an existing digital map of remnant vegetation as background, the area within a two kilometre radius of each survey site was hand digitised into five different land use types: native vegetation, other vegetation, urban, water and ocean. "Native vegetation" was that area defined by the existing remnant vegetation data map, "other vegetation" included urban parks and playing fields, pine plantations, market gardens, farmland, and hobby farms. Much of the "other vegetation" was modified native vegetation – farmland with scattered patches of native vegetation, parks and playing fields surrounded by a line of native trees, hobby farms with native vegetation minus understorey; "urban" included the central business district and areas of suburbia (including houses and average backyard gardens); "water" referred to large expanses of water other than ocean, such as the Swan River, permanent natural and artificial lakes; and "ocean" was the Indian Ocean.

In order to provide broad-scale variables that described the landscape surrounding each of the survey sites, circles of one kilometre and two kilometre radius were drawn from the site centroids. Given the wide spread of sites, there were few cases where circles from two different survey sites overlapped. The proportion of the circle covered by each land use type was calculated (1 km circle = 314 ha, 2 km circle = 1257 ha) and the resulting ten values and two composite values (all vegetation = native plus other vegetation) were used as environmental variables. In addition, the area of each survey site was obtained and the shortest straight-line distance from each site to the coast (distance inland) and from each site to the Perth general post office (distance from city centre), were calculated. During a preliminary analysis, the vegetation complex of each survey site was also tested as a variable but was subsequently discarded because these units were unevenly sampled, and were geographically confounded (e.g. Pinjar Complex occurs only in the Wanneroo area of the north coastal plain; Forrestfield Complex occurs only in a north-south line along the foot of the Darling Range etc.).

Fine-scale environmental variables

All data on fine-scale variables were recorded by one of us on a standardised form during a visit to each of the sites on the Swan Coastal Plain (104 of 121 sites). Primary data collected included: dominant canopy species; the identity of understorey and weed species; percent cover of leaf litter, bare ground, understorey, trees, canopy and understorey; average height of trees and understorey, the presence of tree hollows suitable for hollow-nesting birds; leaf litter depth; the presence of logs or coarse woody debris; evidence of recent fire; degree of weed invasion and the presence of water or wetlands.

Percentage cover of understorey, trees, bare ground and leaf litter were estimated for the whole site based on the Natural Area Initial Assessment Templates devised by Greening Australia for the Perth Biodiversity Project. This involved assessing cover within a 10 m x10 m area at several points on the site and averaging the results. Fire was noted only if there was evidence of it occurring in recent years (e.g. blackened trunks, lack of leaf litter and burnt logs). The degree of weed invasion was based on the assessment templates and all plants were identified to species level whenever possible.

Statistical analyses

For the first stage of the analysis, the survey data were formatted as a sites-by-species matrix of the observational frequencies with which each species (n=79 species) was recorded on each site (n=121 sites). As the number of surveys per site varied between six and 17, the observational frequency was defined as the total number of sightings divided by the number of surveys for that site. The matrix was analysed using the pattern analysis computer program PATN (Belbin and Collins 2006), in order to identify patterns among bird species in their use of survey sites. It involved a classification of sites and species, where the association measure was the Gower Metric, the classification strategy Agglomerative Hierarchical Fusion, and the clustering technique Flexible UPGMA with a β-value of -0.1. After a first run, infrequently-recorded species with little influence on the analysis (with maximum observational frequency lower than 0.18 or with fewer than six records in total) (Painted Button-quail, Brush Bronzewing, White-fronted Chat, Restless Flycatcher, Rufous Treecreeper, White-breasted Robin, Red-winged Fairy-wren, Red-eared Firetail, Brown Falcon, Brown-headed Honeyeater, Wedge-tailed Eagle, Square-tailed Kite, Peregrine Falcon, Richard's Pipit) were omitted and a second run performed using an identical strategy (65 species, 121 sites). The retention of migrant species (present for only part of the year) in this and subsequent analyses did not affect the results (Table 2). The sites were then assigned to five groups and the species to six groups based on their respective dendrograms and a two-way table was produced in order to display the sites and species re-ordered according to cluster membership.

For the second stage of the analysis, we searched for broad-scale and fine-scale environmental variables that might elucidate the patterns of bird occurrence described by the pattern analysis. We analysed these effects for both species groups and for selected individual species. To begin with, for each of the six groups of bird species identified, we modelled the group species richness of sites using generalised linear models using the computer program Genstat (Payne *et al.* 2006). The group species richness of a site was defined as the sum of the observational frequencies of that group of species. Thus, if every species in the group was recorded on every survey, the group species richness of the site would be equal to the total number of species in the group.

Individual stepwise logistic regression models were built for each of the 6 groups of species, using the group species richness of birds as the dependent variable, with the total number of species in the group as the binomial denominator. In a logistic GLM (generalised linear model), the error structure is assumed to be binomial and the test statistic is the "change in deviance", which is distributed as Chi-squared (Baker and Nelder 1978). The models were checked for over-parameterization using a plot of the standardised Pearson's residuals against the index order of the data.

Seventeen of the sites were omitted from this stage of the analysis (n = 104 sites), because fine-scale environmental data were not collected for them. Each of the broad-scale and fine-scale environmental variables was first fitted independently to the model, then in most cases, the one with highest significant change in deviance was added to the model, and the procedure repeated in a forward stepwise fashion, adding further significant variables, mindful that some variables were mutually confounded. Size of the survey site (i.e. area surveyed) was always added as the first significant variable in the model, even if it was not the most significant, to control for the possible effect of differently sized survey sites, where larger sites might be expected to have more species recorded in them simply because more effort had been expended there. Given the choice of two highly significant variables, one with a positive effect and one with a negative effect, the one with the positive effect was chosen, as this better explained the presence of birds. All variables with a positive effect that were significant when fitted independently (i.e. during the first run of each model) are listed in Table 1.

For the second part of the analysis we constructed individual species models. The dependent variable was the total number of sightings and the binomial denominator the number of surveys (i.e. equivalent to the sum of the observational frequencies, with binomial denominator equal to the number of species in the group, as used in the group models).

Threshold values for variables of interest were determined using cumulative distribution functions (CDFs). The non-parametric Kolmogorov-Smirnov test was used to determine whether there was a significant difference between those sites on which a species occurred (presence) and those on which the species was not recorded (absence). Where there is a significant difference, the threshold value of the variable lies just above the test statistic (point of maximum difference between CDFs). This procedure is described more fully by Brooker and Brooker (2003).

Results

The results of the first stage of the analysis, a re-ordering of sites and species based on a row and column classification of bird species frequencies with respect to sites is shown in Figure 1. Note that the sites (y-axis) were allocated five groups and the species (x-axis) six groups based on their respective dendrograms (Figure 2).

Site groups

A cursory examination suggests that the sites (y-axis of Figure 1) have been re-ordered from the least species-diverse (Site Group 1 at top of Figure 1) to the most species-diverse (Site Groups 2 – 5, at the bottom of the table). Sites in Group 1 (n = 98) were small (mean size 11.2 ha, range 0.8 – 75.8 ha), tended to occur in inner-city and suburban areas (mean distance from Perth GPO 15.9 km, range 1.6 – 56.1 km) (Figure 3), and occurred in landscapes with low percentage vegetation cover (mean percentage all vegetation within 2 kilometres 31.5%, range 5.4 – 89.4%). By contrast, the most species-rich sites (in Site Groups 2 – 5, n = 17) were larger (mean size 31.5 ha, range 4.5 – 83.5 ha), occurred mainly outside the metropolitan area (mean distance from Perth GPO 34.5 km, range 18.8 – 47.1 km) (Figure 3) and tended to occur in landscapes with more than 70% vegetation cover (mean percentage all vegetation within 2 kilometres 77.2%, range 56.7 – 90.3%).

Two examples of urban landscapes are shown in Figure 4. The first (Figure 4a) is typical of sites in Site Group 1 (total vegetation cover 37%); while the second (Figure 4b) is more typical of the sites in Groups 2 – 5 (total vegetation cover 80%).

Species Groups

The bird species (x-axis of Figure 1) formed six distinct groups based on their different patterns of occurrence in terms of their relative commonness or rarity. Group 5 species were the most common, followed by Group 6 (Singing Honeyeater), Group 3, Group 2, Group 1 and Group 4 species, which were relatively rare on the Swan Coastal Plain.

Species Group 1 (on left of the two-way table), comprised 14 species including the Common Bronzewing, Red-capped Parrot, Rainbow Bee-eater, Tree Martin, Western Wattlebird, Scarlet Robin, Grey Shrike-thrush, Western Thornbill, Western Spinebill, Inland Thornbill, White-browed Scrubwren, Yellow-rumped Thornbill, Splendid Fairy-wren and New Holland Honeyeater. Nine of these species are insectivores that feed in shrub, canopy or aerially; three are nectarivores and two are granivores that feed on the ground (Recher and Serventy, 1991) (see Appendix). These species were moderately common on sites in vegetated landscapes (Site Groups 2-5) but uncommon on suburban sites (Site Group1).

Species richness of the group was positively related to the proportion of native vegetation, the proportion of other vegetation, the distance from the coast, tree cover, canopy cover, the presence of hollows, litter and logs, the presence of wetlands (but not large bodies of water), and the presence of Teatree *Melaleuca* spp. (Table 1); and negatively related to the proportion of urban land cover and the presence of bare areas. However, many of the variables were inter-correlated. After controlling for the size of the area searched (AREA), the final, most parsimonious model, included only the proportions of native (PNV2) and other vegetation (POV2) within two kilometres. This model accounted for 57% of the total deviance in species richness. (Model equation: logit [group species richness] = -3.085 + 0.017 AREA + 3.276 PNV2 + 1.952 POV2).

The model indicates that, as the proportion of native and other vegetation in the landscape decreased, the species richness of the group declined (Figure 5a); in other words this group was highly sensitive to loss and fragmentation of habitat due to urbanisation.

Species Group 2 (second group from left in Figure 1) comprised eight species – Galah, Black-faced Cuckoo-shrike, Grey Butcherbird, Grey Fantail, Western Gerygone, Rufous Whistler, Striated Pardalote and Weebill. These species were common in vegetated landscapes (Site Groups 2-5) and moderately common on suburban sites (Site Group1). They all require trees, either for feeding, nesting or perching – seven are either insectivores or predators that feed in the canopy (see Appendix) and one, the Galah, is an obligate tree hollow nester that feeds on seeds on the ground.

Species richness of the group was positively related to the proportions of native and other vegetation, the distances from the coast and from Perth GPO, tree cover, canopy cover, the presence of hollows, litter and logs, the presence of weeds, and the presence of Marri *Corymbia calophylla*, Flooded Gum *Eucalyptus rudis* and Tuart *E. gomphocephala*

(Table 1); and negatively related to the proportion of large water bodies, ocean, and urban cover. After controlling for the size of the survey site (AREA), the final, most parsimonious model included only the proportion of other vegetation within one kilometre (POV1), and the presence of logs (LOGS). This model explained 44% of the total deviance in species richness of the Tree Group. (Model equation: logit [group species richness] = - 2.281 + 0.027 AREA + 2.318 POV1 + 0.678 LOGS).

As with the Species Group 1, the species richness of Group 2 declined as the proportion of all vegetation in the landscape decreased, again indicating sensitivity to urbanisation. However, although the general trend was similar to that of Group 1 (Figure 5b), Group 2 was more sensitive to vegetation in the immediate landscape (1 kilometre radius) than the wider landscape (2 kilometres), suggesting that species in this group may not require as large an area of vegetation as those in Group 1. In addition to the landscape variables, the presence of hollows was also significant. Tree hollows, logs and litter are all indicative of mature, well-established trees with undisturbed ground cover, and so the inclusion of any of these variables may simply indicate the quality of vegetation needed for occurrence.

Species Group 3 (third from left in two-way table) comprised the Welcome Swallow, White-cheeked Honeyeater, Willie Wagtail and Magpie-lark (4 species). These are all common species that frequent open spaces and eco-tones, including parks and gardens. They were slightly less common in vegetated landscapes. Three are insectivores and one, the White-cheeked Honeyeater, feeds on nectar (see Appendix).

Species richness of the group was positively related to the proportion of urban cover, the area of the survey site covered by trees, the presence of permanent or ephemeral wetlands, and to the presence of Tea-tree and Sheoak, *Allocasuarina* spp. (Table 1); and negatively related to the proportion of other vegetation. In summary, this group was more common on suburban sites with trees, such as grassed parks and river foreshores, than on sites that were primarily bushland. After controlling for the size of the survey site (AREA), the final model included only the presence of Teatree (MEL) (Table 2). However, as this model explained only 11% of the total deviance in species richness, it was considered a relatively poor predictor for the group as a whole. (Model equation: logit [group species richness] = - 0.853 + 0.011 AREA + 0.448 MEL).

Unlike Groups 1 and 2, the species richness of Group 3 increased as the proportion of urban cover increased and the proportion of vegetation in the landscape decreased, indicating assimilation to urbanisation. For ease of comparison with the other groups, the species richness of Group 3 is plotted as a function of vegetation cover in Figure 5c.

Species Group 4 (third from right in two-way table) was a very large group of 32 miscellaneous species (see Appendix). These birds were rarely recorded on the Swan Coastal Plain during the survey. Six of the species (cuckoos, kingfisher, triller) are migrants and therefore present for only part of the year; seven are raptors with very large home ranges; others are of patchy or limited distribution (e.g. Variegated Fairy-wrens, woodswallows); while some are mobile species (e.g. Mistletoebird, Golden Whistler).

Species richness of the group was positively related to the proportion of native and other vegetation, to the distance from the Perth GPO and the area of tree cover on the survey site (Table 1); and negatively related to the proportion of urban cover. The final most parsimonious model included only the proportion of other vegetation within one kilometre (POV1). This model explained 37% of the total deviance. (Model equation: logit [group species richness] = - 4.560 + 0.026 AREA + 1.693 POV1).

Clearly, the pattern analysis has grouped these species together because there were so few records for them compared to the other species. Had there been more data, these species would most likely have been distributed among Groups 1 and 2, as species richness declined as the proportion of vegetation in the landscape decreased (Figure 5d). Because there were so few data, we were unable to model these species individually and they are not considered further here.

Species Group 5 (second from right in two-way table) comprised the Australian Ringneck, Brown Honeyeater, Red Wattlebird, Australian Magpie, Australian Raven and Silvereye (6 species). These may be classed as very common in both urban and vegetated landscapes. They comprise three omnivores, two nectarivores and one granivore (see Appendix).

Species richness of the group was positively related to the proportion of native and other vegetation, to the area of tree cover on the survey site, the amount of canopy cover, presence of hollows, litter, and logs and to the presence of Marri and Jarrah *Eucalyptus marginata* trees (Table 1); and negatively related to the proportion of urban cover and large bodies of water. However, after the size of the survey site (AREA), the final model included only the presence of litter (LITT) (Table 2). None of the other variables that had been significant when fitted independently, were significant after the inclusion of survey site and litter, although the final model explained 30% of the total deviance in species richness. This indicates that the group was relatively insensitive to the broader landscape configuration but had a higher species richness at more natural sites containing trees with leaf litter beneath. (Model equation: logit [group species richness] = - 0.184 + 0.025 AREA + 0.010 LITT).

Species richness of Group 5 is plotted as a function of vegetation cover in Figure 5e to allow comparison with the other groups.

Species Group 6 comprised a single species, the Singing Honeyeater (on right of two-way table). This appears to be one of the very few native species to have adapted to living in the suburban areas of a major city – it has become an urban specialist. The observational frequency of Singing Honeyeaters was positively related to the proportion of urban cover and large water bodies (Swan River and Indian Ocean), to understorey height, bare areas, lack of weeds, small wetlands and to the presence of Teatree and Sheoak, and negatively related to the proportion of native vegetation and other vegetation, distance from the coast, distance from Perth GPO, canopy cover, understorey, hollows, litter, logs and fire, and the presence of banksias, Marri, and Jarrah (Table 1). The final, most parsimonious model included the proportion of urban cover with two kilometres (PU2), and the presence of Teatree (MEL) and She-oak (CAS). These variables accounted for 23% of the total deviance (Table 2). (Model equation: logit [frequency of occurrence] = - 0.882 + 2.646 PU2 + 0.439 MEL + 0.650 CAS).

The frequency of occurrence of Singing Honeyeaters increased with decreasing distance from the Perth GPO, and decreased with increasing vegetation cover (Figure 5f).

Individual species models

For all species used in the pattern analysis, except those in Group 4 (rarely-recorded species), we built individual forward stepwise logistic regression models, initially fitting only the proportion of urban cover, in order to rank the species on their relative sensitivity to urbanisation. We then fitted most parsimonious models, with significant positive landscape variables fitted prior to the fine-scale site variables (Table 2). In the final models only landscape variables measured at the 2 kilometre scale were used as these were found to provide a better fit to the data for most species and allowed for easier comparison between species. The ranking of species (n = 33) was based on the value of the slope of the relationship between observational frequency and the proportion of urban cover within 2 kilometres (Table 2).

Logically, the rarest, most sensitive species should be the most appropriate for determining threshold values that identify critical levels of habitat loss and fragmentation beyond which species are lost from the community. Therefore, in Table 2, the species have been ranked within the groups allocated by the pattern analysis, where Species Group 4 contained the rarest species, followed by Group 1, Group 2, Group 3, Group 6 and Group 5, with the most common species. As we were unable to model species in Group 4, we considered those species at the top of Species Group 1 (Table 2) to be those most likely to provide useful threshold information. Thresholds (obtained from the observational frequencies converted to presence/absence; see Methods) are shown in Table 3. For the landscape variables, thresholds were obtained for native vegetation and all vegetation, rather than native vegetation and other vegetation, as the "other vegetation" category was not definable in a predictive sense.

Of the 14 moderately rare species in Species Group 1, the Scarlet Robin was found to be the most sensitive to urbanisation, followed by Grey Shrike-thrush, Common Bronzewing, Red-capped Parrot, Inland Thornbill, Splendid Fairy-wren, Western Thornbill, Western Spinebill, and Yellow-rumped Thornbill, listed in decreasing order of sensitivity (Table 2). All nine species were differentially sensitive to the loss of both native and other vegetation. Landscape variables alone accounted for 61-65% of the total deviances in observational frequency of the first three species.

Threshold values for the landscape variables (Table 3) showed that the most sensitive species, Scarlet Robin (Figure 6a), was unlikely to be found in landscapes with less than 61% total vegetation cover, containing less than 24% native vegetation cover. Grey Shrike-thrush, Common Bronzewing, Red-capped Parrot and Western Thornbill were similarly sensitive to both total vegetation and native vegetation cover, but had slightly lower threshold values. Inland Thornbill had a high total vegetation threshold but low native vegetation threshold (Figure 6b). Inland Thornbills may require specialised habitats that are usually present in landscapes with greater than 50% total vegetation cover but present only on some sites in landscapes with less than 50% total cover. The same may apply to

Splendid Fairy-wren, Western Spinebill and Yellow-rumped Thornbill, which also had relatively high total vegetation thresholds with low native vegetation thresholds.

Common Bronzewings (Figure 6c), White-browed Scrubwrens, Red-capped Parrots, Western Wattlebirds (Figure 6d), Splendid Fairy-wrens and Western Spinebills had area thresholds of from 10 – 22 ha. This suggests that sites smaller than 20 ha would be unlikely to contain a full suite of species.

Habitat quality was important for the majority of Group 1 species (Table 2). As mentioned previously, positive relationships with the presence of logs (LOGS), and leaf litter (LITT), the depth of leaf litter (LITCM) and the presence of hollows (HOLL) are all indicative of mature well established woodland, and a high percentage of canopy cover (CCOV) indicates both a closed canopy and healthy trees.

One counter-intuitive finding was a significant positive relationship between the occurrence of Inland Thornbills and the presence of weeds (WEEDS). One possible explanation for this is that woodland with sparse understorey and weeds might mimic the original grassy woodlands on the Swan Coastal Plain which have now largely disappeared.

Discussion

Bird species occurrences

The dividing line between urban, rural and wilderness is often blurred – urban environments represent the expanding end of a continuum of disturbance, the other end of which is the shrinking domain of relatively undisturbed natural areas (Ehrlich 2007). Our results illustrate this continuum and its consequences for the native avifauna of the Perth region.

The two-way classification (Figure 1) ranked the sites from species-poor to species-rich and grouped the species according to six different patterns of occurrence. In terms of sensitivity to vegetation cover, Groups 1, 2 and 4 (bushland birds) were the most sensitive (Figure 5), commonly occurring in variegated landscapes (60-90% cover) but rarely in relictual landscapes (less than 10% cover). Groups 3 and 5 and the Singing Honeyeater (urban birds) were either insensitive to the amount of vegetation cover, or actually preferred relictual and fragmented landscapes (Singing Honeyeater), occurring most frequently in suburban areas with less than 50% vegetation cover. Singing Honeyeaters were also most likely to be encountered closer to the city. One explanation for these findings is that, since European settlement, Singing Honeyeaters have become increasingly adapted to suburbia. In Perth, the older established suburbs surrounding the city centre have more vegetation in backyard gardens and along sidewalks than is the case in newly-established suburbs in which backyard gardens are non-existant, very small or not yet established. These small elements of vegetation, present in leafy suburbs, but largely absent from the newer suburbs on the periphery of the metropolitan area, were of too fine a scale to be picked up by the broad-scale classification of landcover types, but could explain the findings from the model.

For the bushland birds (Groups 1, 2 and 4), clearly the most important factor determining species occurrences was the amount of native or other vegetation in the immediate surroundings (within 2 kilometres). For the urban birds (Goups 3, 5 and 6), fine-scale site attributes were more important.

Similar effects of urbanisation were found by Brooker and Brooker (1998) in a comparison of garden birds at Gooseberry Hill, on the Darling Scarp near Perth, and at Cook, a suburb of Canberra, Australian Capital Territory. Group 1 species (White-browed Scrubwren, Splendid Fairy-wren, Western Thornbill) were absent or rare in the Gooseberry Hill garden but present in native vegetation 1.5 kilometres away; while Group 1 equivalents (Common Bronzewing, White-browed Scrubwren, Eastern Yellow Robin *Eopsaltria australis*) were absent or rare in the Cook garden but present in native vegetation at Black Mountain, 1.5 kilometres away. Another study in Canberra, Australian Capital Territory, (Watson *et al.* 2005) found a significant response to different landscape states (agricultural, peri-urban and urban) where some species were lost as the amount of native vegetation declined and the degree of fragmentation increased, while other species appeared insensitive to different degrees of habitat fragmentation.

Landscape state and scale of measurement

Although McIntyre and Hobbs (1999) described a continuum of habitat loss and modification, and the definitions they gave for intact, variegated, fragmented and relictual states were somewhat arbitrary, they found that a functional distinction between variegated and fragmented landscapes is supported by theoretical landscape models that indicate organisms are operationally unfragmented when there is more than 60% habitat retention. Our data (Table 3) support this idea that, for some species, there is a fragmentation threshold below which species are lost from the landscape because, to them, the matrix has become, in some way, unsuitable.

However, the importance of landscape variables may vary, depending on the scale of measurement and the species in question. In this study the scale of measurement of the habitat (1 kilometre and 2 kilometre radius) appears to have been appropriate for most of the birds under study. For 30 of the 33 species from Groups 1, 2, 3, 5 and 6 that were modelled independently (Table 2), at least one of the 2 kilometre habitat measures was a significant or the most significant variable. Hostetler and Holling (2000) found that, overall, body size was an approximate predictor of the scale at which a species responds. Therefore it seems likely that taxa that are smaller than birds, especially ground dwelling vertebrates, might respond at smaller scales, as smaller animals have a more limited dispersal capacity. Therefore landscape mosaics designed at a 2 kilometre scale should be appropriate for small birds whereas a larger scale would need to be employed for large birds (e.g. raptors) and mammals.

Whatever the scale, measurement of the level of fragmentation tolerated by a species (e.g. percentage habitat remaining within 2 kilometres) should not be confused with the total amount of habitat needed for population persistence.

Variegated landscapes

Perth is perhaps fortunate, in that variegated landscapes (60 – 90% vegetation cover) still exist as part of the complex landscape mosaic of the Swan Coastal Plain. Because the biota appears to respond to the different landscape states in different ways, areas of variegated urban habitat need to be planned for and managed in a somewhat different manner to fragmented and relictual urban areas.

In this study, Inland Thornbill, Splendid Fairy-wren, Western Spinebill and Yellow-rumped Thornbill, all had relatively high total vegetation thresholds with low native vegetation thresholds. These findings support the idea of a continuum of landscape alteration states (McIntyre and Hobbs 1999), where there is a functional distinction between landscapes with more than 60% vegetation cover and those with less than 60% cover. In the former (variegated landscapes) organisms perceive the landscape as essentially unfragmented, while in the latter (fragmented landscapes), different species respond to the degree of fragmentation in different ways.

In variegated urban habitats, or intact areas planned for urban development, the primary emphasis for conservation should therefore be the integrity of the remaining habitat; i.e. maintaining the percentage vegetation cover at 60% or greater. This is because organisms may perceive this variegated habitat state as essentially unfragmented. Once the integrity of the habitat is compromised (e.g. by clearing more than 40% of the vegetation within any 2 kilometre radius) then the broader landscape state will change from variegated to fragmented, with associated consequences for the biota. How large any continuous area of variegated habitat would need to be in order to support viable populations of species is not known, although the 2 kilometre "areas of influence" described here certainly would be insufficient, in themselves, to support viable populations of birds. There are very few estimates of minimum viable population size (MVPS) for Western Australian birds even in prime habitat, let alone an urbanised environment. However, in one such study of the Splendid Fairy-wren in largely unmodified habitat at Gooseberry Hill, in the Darling Range near Perth, it was estimated (from a computer simulation model) that a sub-population of this species may require at least 2000 ha of suitable habitat to remain viable in the long term (Brooker and Brooker, 1994). In the present analyses, the Splendid Fairy-wren was classed as Group 1 (sensitive to vegetation cover), with a 25% total vegetation cover threshold (Table 3). Assuming a variegated urban landscape configuration similar to that shown in Figure 4b, and assuming that all of the native vegetation in that configuration was suitable habitat for the Splendid Fairy-wren, then Brooker and Brooker's estimate would translate to a continuous zone of around 5000 ha of variegated urban landscape on the Swan Coastal Plain. However, because information on MVPS is largely non-existent, and "suitable habitat" is difficult to define, a better strategy would be to ensure that those variegated urban landscape configurations still present on the Swan Coastal Plain should be left as linkages between the intact landscapes of the Darling Range and the fragmented urban landscapes of Perth's suburbs.

Large, continuous areas of variegated urban landscape left within the broader landscape mosaic will provide habitat for source populations of the more sensitive species that are able to permeate but not persist in fragmented or relictual landscapes.

Fragmented and relictual landscapes

In fragmented and relictual urban habitats, the occurrence of bushland birds (Groups 1, 2, 4) depends on, not only the amount of native vegetation in the landscape, but also the whole host of fragmentation variables pertaining to a particular site (e.g. patch size, inter-patch connectivity, isolation, barrier effects, edge effects, composition of matrix etc.), as well as habitat characteristics (e.g. vegetation type and vegetation condition), that may or may not be correlated with the degree of fragmentation. On the other hand, for urban birds (Groups 3, 5, 6), all of these factors seem relatively unimportant.

However, in urban areas one thing is certain − that a fragmented or relictual urban landscape will never return to an intact or even variegated state. For this reason it seems to us pointless to be overly-concerned with attempts to redress fragmentation in urban areas − shopping malls and highways will not be removed to increase the size, connectivity or isolation of a small nature reserve. In fact the opposite is usually the case − in urban areas, after the initial broad-scale clearing of native vegetation, the remnants continue to be slowly eaten away until the landscape becomes relictual, unless the local community is sufficiently concerned about protecting and caring for them. Therefore, in fragmented urban habitats, the primary emphasis for conservation of the remaining biota should be directed toward public awareness, coupled with management of the quality of the remnant native vegetation.

The results of our individual species models (Table 2) provide some clues regarding critical habitat types and remnant quality. For 10 of the 33 birds modelled, the presence of permanent or ephemeral wetland (or an indicator of wetland, such as Tea-tree, She-oak or Flooded Gum) was an important habitat variable in determining whether or not the species was recorded. It is therefore recommended that, in fragmented landscapes on the Swan Coastal Plain, this habitat in particular should be protected from further development. Periodic winter flooding and summer drying out is the normal regime in Perth's Mediterranean climate, yet these areas are often filled in, drained or made into permanent lakes during the process of urbanisation while, left in their natural state, they provide valuable bird habitat.

For a further 15, different species the presence of fallen logs, leaf litter, litter depth or tree hollows were important predictors of species presence (Table 2). These factors, taken together, are indicative of undisturbed old-growth woodland. Fallen, rotting timber, deep leaf litter, mature tree trunks and healthy tree canopies promote the species richness and abundance of invertebrates that are food for 55% of the 65 bird species studied here - 64% of Group 1 and 87% of Group 2 (Recher and Serventy 1991). Large mature trees provide plentiful tree hollows of different sizes that can be used by hollow-nesting birds such as cockatoos and other parrots. Therefore, allowing urban remnants of native vegetation to "grow old gracefully", by leaving fallen logs and leaf litter *in situ*, controlling weed species, taking care of the canopy by controlling against dieback *Phytophthora cinnamomi,* and controlling wildfires by public awareness and vigilance, will improve the quality of native vegetation remnants for many bird species.

Since European settlement at least nine avian species once common on the Swan Coastal Plain, are now scarce or extinct (see Appendix) (Storr and Johnstone 1988). That

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attrition of the bird fauna on the Swan Coastal Plain is continuing cannot be doubted when one of the native vegetation survey sites in this study was cleared for development during the Perth Biodiversity Project bird survey period. Even in large remnants of native vegetation such as the 4200 ha Whiteman Park (Brooker 2006), sensitive species like the Hooded Robin have recently disappeared from where they were regularly recorded during the period 1990 to 2003.

This past and continuing decline is due, in most part, to the destruction of native vegetation. Therefore the solution is in our hands. While we continue to allow the spread of urban development without consideration for the needs of the native avifauna then, eventually, the most sensitive birds will be confined to intact landscapes outside urban areas, if any still exist.

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Table 1. Summary of environmental variables that were found to be significantly positively related to the group species richness values of the six groups of birds (as identified in Figure 1), when fitted independently to the models (i.e. during the first run of each model).

Regression model developed using Genstat for Windows (Payne *et al.* 2006). Change in deviance is distributed as χ^2. For each variable the degrees of freedom = 1, except weediness*, which was a three level categorical variable with degrees of freedom = 2. (cd = change in deviance; P = level of significance).

Parameter	**Species Group 1**		**Species Group 2**		**Species Group 3**		**Species Group 4**		**Species Group 5**		**Species Group 6 (Singing Honeyeater)**	
	cd	***P***	**cd**	***P***	**cd**	***P***	**cd**	***P***	**cd**	***P***	**cd**	***P***
Broad-scale variables (landscape)												
Proportion of native vegetation within 1 km (PNV1)	69.44	< 0.001	35.34	< 0.001			13.30	< 0.001	10.82	< 0.001		
Proportion other vegetation within 1 km (POV1)	33.00	< 0.001	40.73	< 0.001			11.82	< 0.001	5.20	< 0.05		
Proportion of all vegetation within 1 km (TV1)	97.60	< 0.001										
Proportion water with 1 km (PW1)											26.20	< 0.001
Proportion ocean within 1 km (PO1)											18.70	< 0.001
Prportion urban within 1 km (PU1)											54.42	< 0.001
Proportion of native vegetation within 2 km (PNV2)	71.15	< 0.001	26.29	< 0.001			9.65	< 0.01	6.80	< 0.01		
Proportion other vegetation within 2 km (POV2)	39.67	< 0.001	42.19	< 0.001			12.97	< 0.001	6.78	< 0.01		
Proportion of all vegetation within 2 km (TV2)	94.20	< 0.001										
Proportion water with 2 km (PW2)											7.05	< 0.01
Proportion ocean within 2 km (PO2)											29.50	< 0.001
Proportion urban within 2 km (PU2)											110.20	< 0.001
Distance inland (DISTIN)	8.40	< 0.01	5.45	< 0.05								
Distance from Perth GPO (DISTGP)			39.80	< 0.001			20.11	< 0.001				
Fine-scale variables (survey site)												
Area surveyed (ha) (AREA)	42.15	< 0.001	46.86	< 0.001	4.67	< 0.05	23.48	< 0.001	19.34	< 0.001		
Area of survey site covered by trees (ha) (TREE)	45.06	< 0.001	48.93	< 0.001			14.59	< 0.001	23.13	< 0.001		
% Canopy cover (CCOV)	9.95	< 0.01	26.58	< 0.001					10.79	< 0.01		
% Understorey (UND)												
Height of understorey (UNDHT)											23.29	< 0.001
Presence of hollows (HOLL)	4.08	< 0.05	28.05	< 0.001					9.75	< 0.01		
% Litter (LITT)	5.86	< 0.05	19.60	< 0.001					13.65	< 0.001		
Depth of litter (LITTCM)			24.21	< 0.001					16.64	< 0.001		
Presence of logs (LOGS)	9.08	< 0.01	24.47	< 0.001					11.80	< 0.001		
Evidence of fire (FIRE)												
% Bare ground (BARE)											7.24	< 0.01
Weediness* (WEEDS)			10.6	< 0.01							7.13	< 0.01
Presence of wetland or water (WETLAND)	11.22	< 0.001			5.63	< 0.05					5.16	< 0.05
Presence of banksia (BANK)												
Presence of Marri *Corymbia calophylla* (MARR)			8.90	< 0.01					5.81	< 0.05		
Presence of Jarrah *Eucalyptus marginata* (JARR)									7.12	< 0.01		
Presence of Teatree *Melaleuca* spp. (MEL)	8.43	< 0.01			6.07	< 0.05					22.62	< 0.001
Presence of Flooded Gum *E. camaldulensis* (FLOO)			5.73	< 0.05							4.65	< 0.05
Presence of Wandoo *E. wandoo* (WAND)												
Presence of Tuart *E. gomphocephala* (TUART)			5.87	< 0.05								
Presence of Sheoak *Allocasuarina* sp. (CAS)					3.85	< 0.05					32.90	< 0.001

Table 2 . Changes in deviances from forward stepwise logistic regression models relating environmental variables to the observational freqencies of 33 bird species (dependent variable was the total number of sightings, and the binomial denominator was the number of surveys). Species are ranked in decreasing order of sensitivity to urbanisation based on the slope of the relationship between observational frequency and the proportion of urban cover within 2 kilometres (PU2). Individual variables have been grouped into categories and the changes in deviance summed for each category. For the GLM logistic model change in deviance is distributed as Chi squared, df = 1, * = *P* < 0.001, ** = *P* < 0.01, * = *P* < 0.05. Species Groups are those derived from the pattern analysis.**

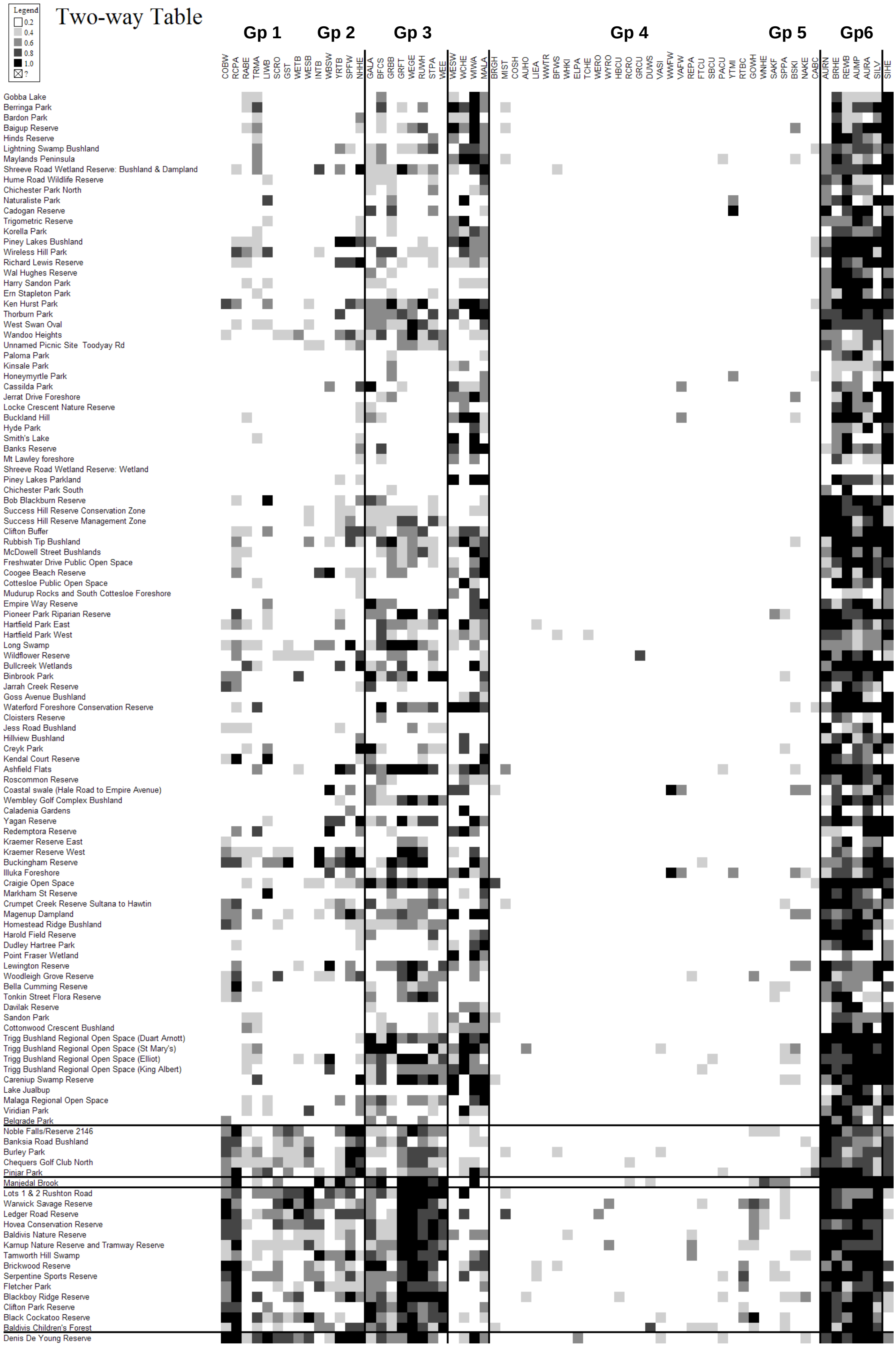
	Slope of relationship with urban cover	Total deviance	Change in deviance due to proportions of native and other vegetation in landscape	Site variables		
				Additional change in deviance due to size of area surveyed or size of treed area	Additional change in deviance due to habitat quality	Additional change in deviance due to habitat type
Species Group 1						
Scarlet Robin	-8.9	328.4	PNV2 + POV2 213.8 ***	TREE 21.1 ***	CCOV 11.0 ***	WETLAND 4.2 *
Grey Shrike-thrush	-7.3	334.7	PNV2 + POV2 204.3 ***		LOGS 8.5 **	
Common Bronzewing	-6.8	569.7	PNV2 + POV2 350.5 ***	AREA 15.8 ***		
Red-capped Parrot	-5.3	718.0	PNV2 + POV2 354.2 ***	AREA 12.9 ***	LOGS 24.2 ***	
Inland Thornbill	-5.2	463.1	PNV2 + POV2 150.6 ***		WEEDS 11.6 **	WETLAND 25.7 ***
Splendid Fairy-wren	-4.4	793.0	PNV2 + POV2 234.3 ***	AREA 45.8 ***		
Western Thornbill	-4.3	269.2	PNV2 + POV2 66.1 ***	AREA 5.7 *	LOGS 18.3 ***	
Western Spinebill	-3.9	379.0	PNV2 + POV2 134.7 ***	TREE 25.3 ***		
Yellow-rumped Thornbill	-1.6	548.8	PNV2 + POV2 67.6 ***	AREA 20.5 ***		WETLAND 79.7 ***
Tree Martin	-0.9	327.9	POV2 4.8 *	AREA 23.8 ***		WETLAND 12.4 ***
New Holland Honeyeater	-0.7	575.5	PNV2 64.3 ***			MEL 25.4 ***
Western Wattlebird	-0.7	520.7	PNV2 25.5 ***	TREE 25.8 ***	LITT 16.9 ***	
White-browed Scrubwren	-0.7	526.1	PNV2 23.6 ***	AREA 30.8 ***		
Species Group 2						
Western Gerygone	-4.2	853.1	PNV2 + POV2 257.2 ***	AREA 78.6 ***	CCOV + LOGS 20.0 ***	
Grey Fantail	-4.2	808.0	PNV2 + POV2 254.6 ***	AREA + TREE 34.0 ***	CCOV 49.7 ***	
Rufous Whistler	-3.7	742.3	PNV2 + POV2 223.8 ***	AREA 93.4 ***	LITCM + LOGS 27.8 ***	
Weebill	-3.5	658.8	PNV2 + POV2 86.4 ***	AREA 12.4 ***	LITCM + LOGS 23.3 ***	
Striated Pardalote	-1.4	537.1	PNV2 + POV2 83.9 ***	TREE 28.3 ***	CCOV + LITT 27.8 ***	MARR 9.4 **
Galah	-1.0	452.9	POV2 20.6 ***	AREA 16.4 ***	HOLL + LOGS 94.6 ***	
Black-faced Cuckoo-shrike	-0.9	418.8	POV2 21.2 ***	AREA 62.1 ***		WETLAND 15.8 ***
Grey Butcherbird	-0.9	531.6	PNV2 47.4 ***	AREA 18.6 ***	LOGS 36.9 ***	TUART 24.9 ***

	Slope of relationship with urban cover	Total deviance	Change in deviance due to proportions of native and other vegetation in landscape	Site variables		
				Additional change in deviance due to size of area surveyed or size of treed area	Additional change in deviance due to habitat quality	Additional change in deviance due to habitat type
Species Group 3						
White-cheeked Honeyeater	0	844.0		AREA 11.7 ***	UND + WEEDS 128.8 ***	
Welcome Swallow	+0.7	538.0	PU2 6.5 *			WETLAND + CAS 30.5 ***
Willie Wagtail	+0.9	735.5	PU2 11.6 ***			MEL + FLOO 143.8 ***
Magpie-lark	+1.3	527.3	PU2 27.0 ***			WETLAND 29.3 ***
Species Group 6						
Singing Honeyeater	+2.9	686.3	PU2 110.2 ***			MEL + CAS 23.6 ***
Species Group 5						
Australian Ringneck	-2.4	794.2	PNV2 + POV2 163.7 ***		LITT + LOGS 93.9 ***	
Silvereye	-2.3	817.9	PNV2 + POV2 70.5 ***	AREA 66.9 ***	CCOV 16.3 ***	
Australian Magpie	0	554.9	PNV2 6.3 *	AREA 21.2 ***	LOGS 49.3 ***	JARR ***
Brown Honeyeater	0	398.0	POV2 24.8 ***	TREE 20.4 ***	LITCM 7.1 **	
Australian Raven	0	494.5	PNV2 12.7 ***	TREE 89.5 ***	HOLL 22.3 ***	
Red Wattlebird	0	423.7				BANK + MARR + TUART 50.6 ***
Rainbow Bee-eater	0	202.2		AREA 12.0 ***		JARR 9.4 **

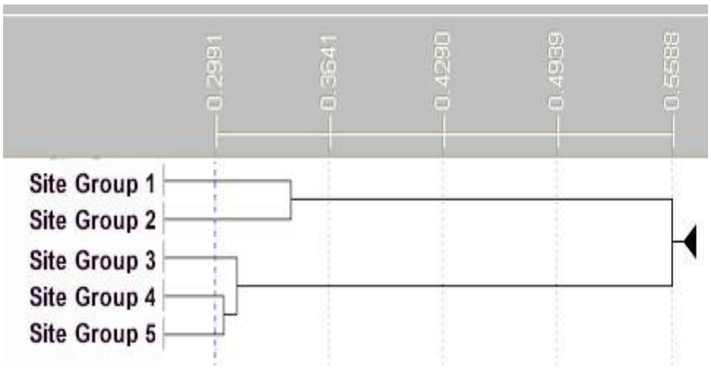
Table 3. Threshold values obtained from cumulative distribution functions (CDFs) for variables found to have a significant positive relationship with species occurrences.

	Threshold proportion of native vegetation cover within 2 km	Threshold proportion of all vegetation cover within 2 km	Threshold size of survey site (ha)	Threshold size of treed area on survey site (ha)
Species Group 1				
Scarlet Robin	0.24	0.61		3.1
Grey Shrike-thrush	0.23	0.32		
Common Bronzewing	0.18	0.34	22.1	
Red-capped Parrot	0.23	0.34	16.0	
Inland Thornbill	0.08	0.51		
Splendid Fairy-wren	0.08	0.25	12.9	
Western Thornbill	0.22	0.33	4.2	
Western Spinebill	0.07	0.33		12.6
Yellow-rumped Thornbill	0.07	0.38	5.6	
Tree Martin			9.8	
New Holland Honeyeater	0.07			
Western Wattlebird				13.0
White-browed Scrubwren			21.7	

Figure 1. Two-way table illustrating the re-ordering of the sites surveyed (y-axis) and bird species present (x-axis) based on a row and column classification of the frequency of bird observations (see Methods). Differences in shading represent the strength of observed correlations (see legend).



(a)



(b)

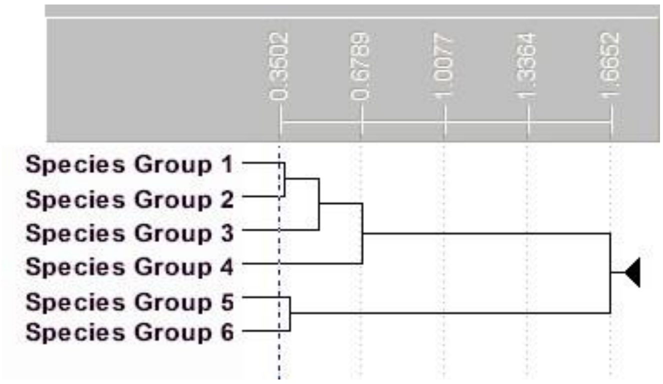


Figure 2. (a) Dendrogram showing the relationships between the site groups as interpreted by the pattern classification of sites using agglomerative hierarchical fusion. (b) Dendrogram showing the relationships between the species groups as interpreted by the pattern classification of species using agglomerative hierarchical fusion.

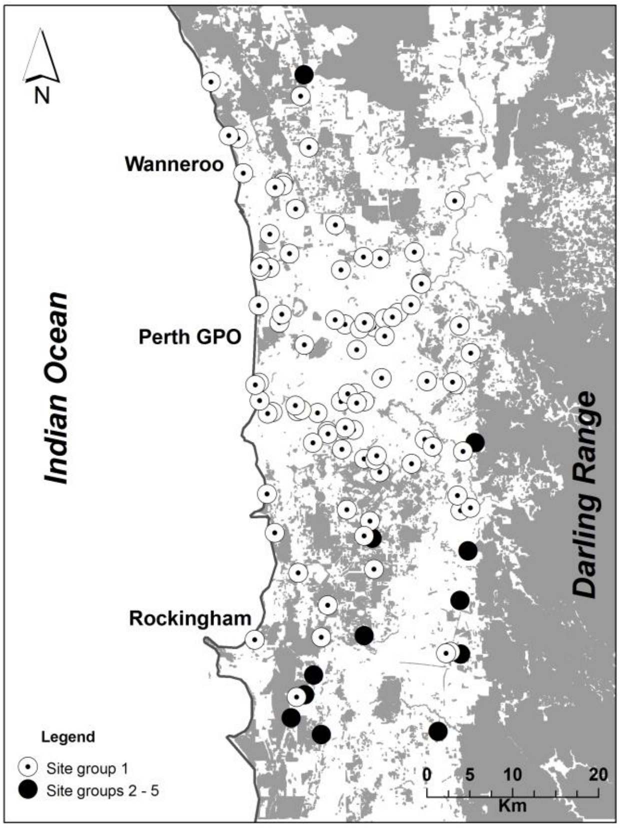


Figure 3. Map of Swan Coastal Plain indicating the relative locations of sites classified by the pattern analysis (Figure 1) as Site Group 1 (white circles) and Site Groups 2 – 5 (black circles).

Figure 4.

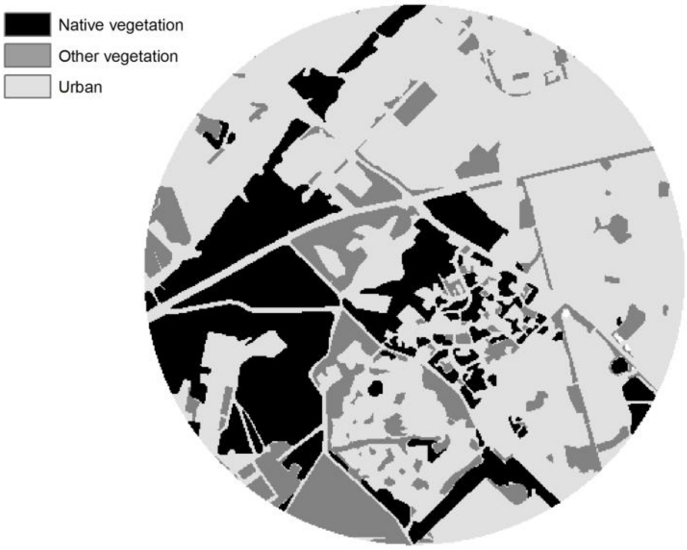


Figure 4a. Urban landscape configuration of 2 km radius containing 22% native vegetation, 15% other vegetation (total vegetation cover 37%), and 63% urban cover. This represents a fragmented landscape (sensu McIntyre and Hobbs 1999) .

Figure 4b. Urban landscape configuration of 2 km radius containing 40% native vegetation, 40% other vegetation (total vegetation cover 80%), and 20% urban cover. This represents a variegated landscape (sensu McIntyre and Hobbs 1999).

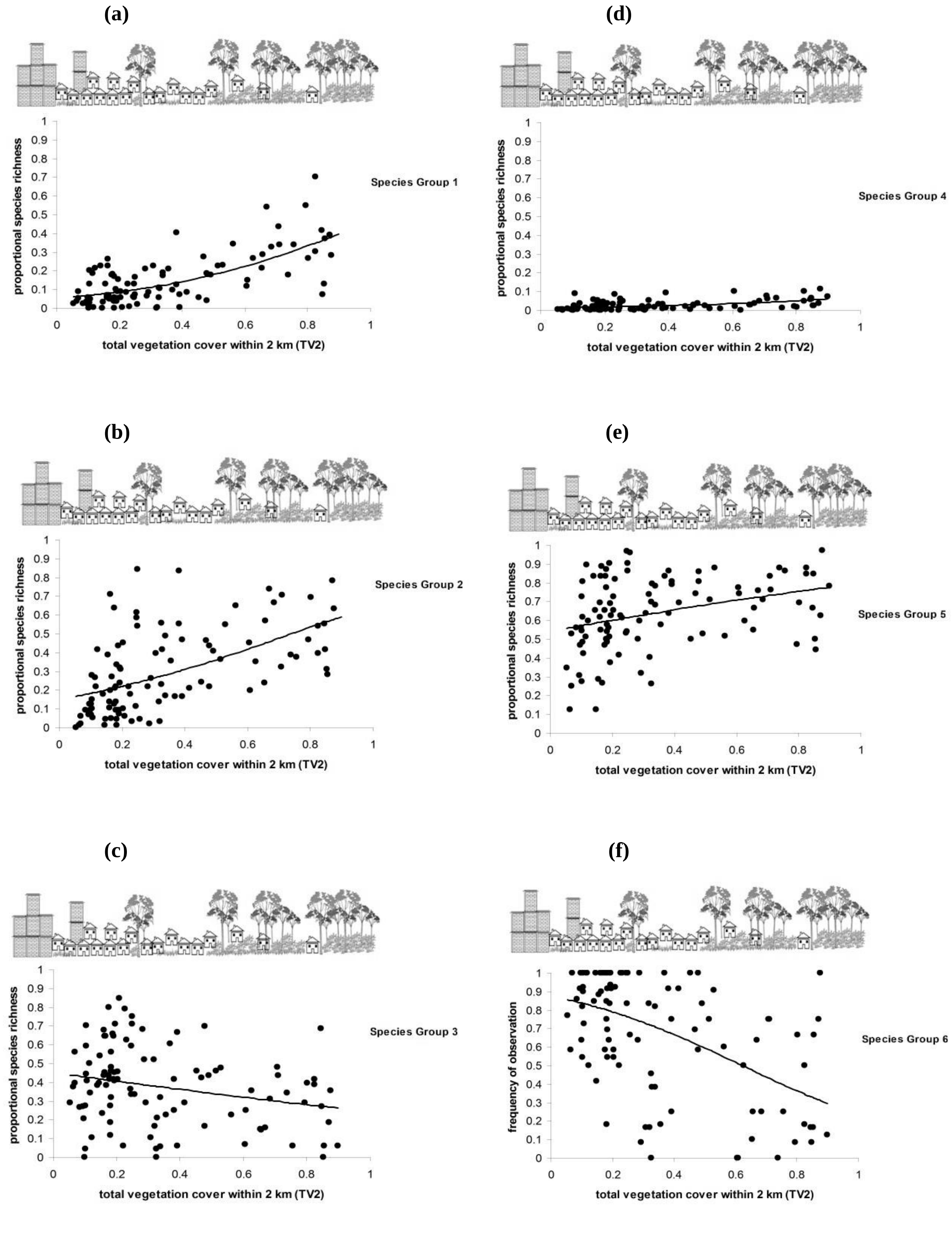


Figure 5. Relationship between proportional species richness (Groups 1 to 5) or observational frequency (Group 6) and the total proportion of vegetation (native plus other) within 2 kilometres of the survey site (TV2 = PNV2 +POV2).

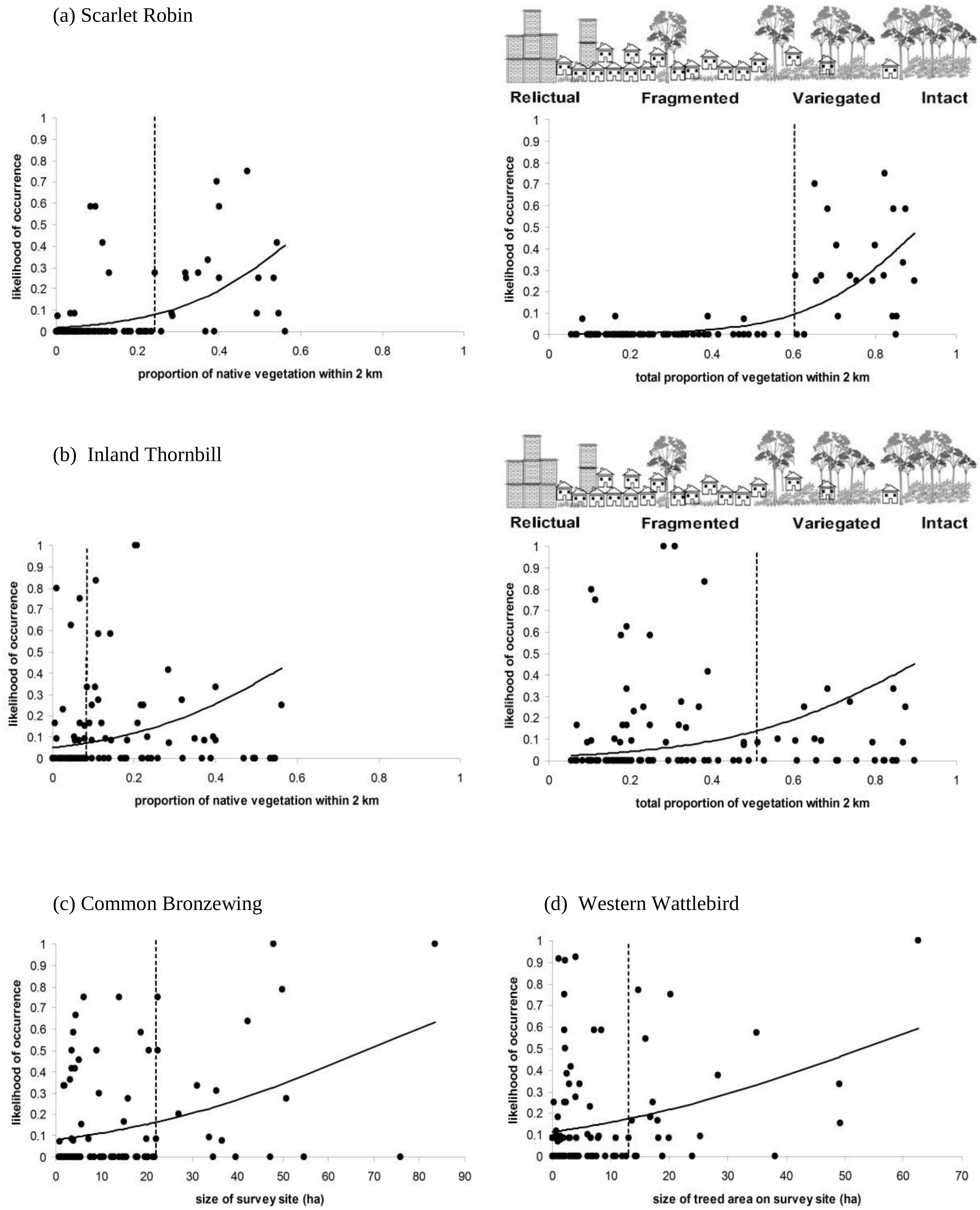


Figure 6. Relationships between observational frequencies and landscape and site variables, illustrating threshold values shown in Table 3. Solid lines are fitted relationships from logisitic regression models; dotted lines are threshold values obtained from CDFs of presence/absence data (see Methods).

Appendix.

List of species mentioned in the text ordered according to species groups and their food preferences (taxonomy according to Birds Australia Draft Working List of Birds of Australia and Australian Territories; www.birdsaustralia.com.au/checklist) (* = species once common on Swan Coastal Plain, now scarce or extinct there according to Storr and Johnstone 1988) (= migrant).**

	Food					
Species Groups	**Vertebrates**	**Seed**	**Invertebrates**	**Nectar**	**Fruit**	**Omnivore**
Previously common*						
Red-eared Firetail *Stagonopleura oculata*		■				
Brush Bronzewing *Phaps elegans*		■				
Painted Button Quail *Turnix varia*		■				
Rufous Treecreeper *Climacteris rufa*			■			
Restless Flycatcher *Myiagra inquieta*			■			
Western Whipbird *Psophodes nigrogularis*			■			
Yellow-plumed Honeyeater *Lichenostomus ornatus*				■		
Bush Stone-curlew *Burhinus grallarius*						■
Emu *Dromaius novaehollandiae*						■
Bushland Group						
Common Bronzewing *Phaps chalcoptera*		■				
Red-capped Parrot *Purpureicephalus spurius*		■				
Splendid Fairy-wren *Malurus splendens*			■			
Yellow-rumped Thornbill *Acanthiza chrysorrhoa*			■			
Scarlet Robin *Petroica multicolor*			■			
White-browed Scrubwren *Sericornis frontalis*			■			
Inland Thornbill *Acanthiza apicalis*			■			
Western Thornbill *Acanthiza inornata*			■			
Grey Shrike-thrush *Colluricincla harmonica*			■			
Tree Martin *Hirundo nigricans*			■			
Rainbow Bee-eater *Merops ornatus* **			■			
New Holland Honeyeater *Phylidonyris novaehollandiae*				■		
Western Spinebill *Acanthorhynchus superciliosus*				■		
Western Wattlebird *Anthochaera lunulata*				■		
Tree Group						
Grey Butcherbird *Cracticus torquatus*	■		■			
Galah *Cacatua roseicapillus*		■				
Grey Fantail *Rhipidura fuliginosa*			■			
Striated Pardalote *Pardalotus striatus*			■			
Weebill *Smircornis brevirostris*			■			
Western Gerygone *Gerygone fusca*			■			
Rufous Whistler *Pacycephala rufiventris*			■			
Black-faced Cuckoo-shrike *Coracina novaehollandiae*			■			

Species Groups	Food					
	Vertebrates	Seed	Invertebrates	Nectar	Fruit	Omnivore
Park Group						
Willie Wagtail *Rhipidura leucophrys*			■			
Magpie-lark *Grallina cyanoleuca*			■			
Welcome Swallow *Hirundo neoxena*			■			
White-cheeked Honeyeater *Phylidonyris nigra*				■		
Rarely-Recorded Group						
Black-shouldered Kite *Elanus axillaris*	■					
Whistling Kite *Haliastur sphenurus*	■					
Little Eagle *Hieraaetus morphnoides*	■					
Brown Goshawk *Accipiter fasciatus*	■					
Collared Sparrowhawk *Accipiter cirrhocephalus*	■					
Australian Hobby *Falco longipennis*	■					
Nankeen Kestrel *Falco cenchroides*	■		■			
Sacred Kingfisher *Todiramphus sanctus* **	■		■			
Grey Currawong *Strepera versicolor*	■		■			
Red-tailed Black-Cockatoo *Calyptorhynchus banksii*		■				
Carnaby's Black-Cockatoo *Calyptorhynchus latirostris*		■				
Regent Parrot *Polytelis anthopeplus*		■				
Western Rosella *Platycercus icterotis*		■				
Elegant Parrot *Neophema elegans*		■				
Pallid Cuckoo *Cuculus pallidus* **			■			
Fan-tailed Cuckoo *Cacomantis flabelliformis* **			■			
Horsfield's Bronze-Cuckoo *Chrysococcyx basalis* **			■			
Shining Bronze-Cuckoo *Chrysococcyx lucidus* **			■			
Varied Sittella *Daphoenositta chrysoptera*			■			
Variegated Fairy-wren *Malurus lamberti*			■			
White-winged Fairy-wren *Malurus leucopterus*			■			
Spotted Pardalote *Pardalotus punctatus*			■			
Red-capped Robin *Petroica goodenovii*			■			
Western Yellow Robin *Eopsaltria griseogularis*			■			
Golden Whistler *Pachycephala pectoralis*			■			
White-winged Triller *Lalage suerii* **			■			
Black-faced Woodswallow *Artamus cinereus*			■			
Dusky Woodswallow *Artamus cyanopterus*			■			
Yellow-throated Miner *Manorina flavigula*				■		
White-naped Honeyeater *Melithreptus lunatus*				■		
Tawny-crowned Honeyeater *Phylidonyris melanops*				■		
Mistletoebird *Dicaeum hirundinaceum*					■	

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Species Groups	Food					
	Vertebrates	Seed	Invertebrates	Nectar	Fruit	Omnivore
Generalist Group						
Australian Ringneck *Barnardius zonarius*		■				
Red Wattlebird *Anthochaera carunculata*				■		
Brown Honeyeater *Lichmera indistincta*				■		
Australian Magpie *Gymnorhina tibicen*						■
Australian Raven *Corvus coronoides*						■
Silvereye *Zosterops lateralis*						■
Urban Specialist						
Singing Honeyeater *Lichenostomus virescens*				■		