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Species interactions and habitat associations of birds inhabiting urban areas of Sydney, Australia

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Abstract The absence of small birds from many suburban areas may be due to adverse garden characteristics, interspecific aggression or human behaviour such as supplementary food provisioning that encourages predators. We investigated the relationship between these factors and the presence of seven small bird species in Sydney through a community-based survey. The survey was conducted by participants over a 7-day period between 7 AM and 10 AM in November and early December 2000. Three dominant species, the noisy miner (*Manorina melanocephala*), pied currawong (*Strepera graculina*) and common myna (*Acridotheres tristis*) were each present in over 59% of gardens. Each small bird species was present in less than 40% of gardens. All small birds were negatively associated with noisy miners, but only the silvereye (*Zosterops lateralis*) was negatively associated with pied currawongs. None of the species of small birds was negatively associated with common mynas. Four species of small birds were associated with at least one habitat variable, notably the proportion of native vegetation. Although more birds were recorded in gardens in which meat was provided, there were significantly fewer small birds in these gardens. There were also more birds recorded in gardens where seed was provided, with red-browed finches (*Neochmia temporalis*) positively associated with seed provisioning in most regions of Sydney. The presence of dogs and cats was not related to the total abundance of birds overall or small birds in gardens. While garden characteristics may influence the presence of small birds to some degree, the presence of noisy miners, a species that are thought to aggressively exclude other species from their territories, is likely to be an important influence on these species in suburban areas. Furthermore, supplementary feeding by people is likely to negatively influence some small birds. The presence of carnivorous pets does not seem to influence the presence of small birds at the scale of the individual garden.

Key words: garden characteristics, noisy miner, small birds, species interactions, urban.

INTRODUCTION

As cities grow and expand, the urban environment replaces and modifies a large proportion of the natural habitat. This habitat loss is resulting in some of the highest rates of local extinction of a range of native fauna, including local extinctions in avian assemblages (Vale & Vale 1976; Marzluff *et al.* 2001; McKinney 2002). However, in most cities some native vegetation is still available within the urban matrix, both as remnants and in suburban gardens. Therefore, if vegetation in gardens could be managed to promote a diversity of native bird species, it may provide a valuable secondary habitat for conserving native bird populations.

There are a number of bird species that survive successfully in the urban matrix. These urban bird communities are generally dominated by introduced birds together with a limited suite of native species that are often in abundance (Emlen 1974; Huhtalo & Jarvinen 1977; Blair 1996; Jokimaki *et al.* 1996). Other native species, such as smaller species, or species with restricted habitat requirements, may be common in remnant habitats within the city matrix yet occur infrequently in urban areas (Jokimaki & Suhonen 1993; Blair 1996). The factors influencing the distribution of uncommon urban birds are not well understood. We investigate the effect of four components of the urban environment on patterns of distribution of uncommon urban species: the vegetation characteristics of suburban gardens, the presence of dominant birds, supplementary feeding and the presence of predatory pets.

Gardens are a characteristic feature of suburban areas and the presence of different bird species may be related to both the floristics and structure of these areas (Green 1984; Catterall *et al.* 1989; Germaine *et al.* 1998; Sewell & Catterall 1998). In particular, the composition of gardens has been shown to influence native bird species distributions, with native birds foraging more frequently among indigenous plants than

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among exotic ones (Jones 1983; Mills *et al.* 1989; Day 1995; French *et al.* 2004). In Australia, the structural composition of these gardens also has been found to be important in determining the occurrence of bird species in gardens (Sewell & Catterall 1998). While data are scarce, it is believed that ground and shrub-nesting species are less common in suburban areas owing to a lack of suitable vegetation cover, while hollow-nesting and canopy-nesting species have abundant nesting sites and protection from predators (Sewell & Catterall 1998). Further, it is also believed that nectarivorous species (e.g. Meliphagidae and some Psittacidae) are more common in suburbs that have prolific-flowering plants, while many shrub-foraging insectivores are disadvantaged (Green 1984; Sewell & Catterall 1998; Catterall 2004). There is currently a shortage of data supporting these ideas.

The presence of aggressive or highly abundant species, hereafter referred to as 'dominant' species, is thought to influence the abundance of many species in urban areas. For instance, the pied currawong (*Strepera graculina:* Artamidae) has been identified as a dominant member of Sydney's urban avifauna whose success is, at least partially, due to the availability of introduced fruits such as blackberries (*Rubus* spp.), camphor laurels (C*innamomum camphora*) and privets (*Ligustrum* spp.) in suburban gardens (Buchanan 1989; Bass 1995). Furthermore, it has been suggested that this species may be responsible for the decline in numbers of small birds in cities, as currawongs prey upon adults, eggs and nestlings of small birds (Recher 1972; Cooper & Cooper 1981; Priddel & Carlile 1995; Major *et al.* 1996; Wood 1998). Their predatory impact is exacerbated by a change in breeding range. While pied currawongs were historically non-breeding visitors to Sydney, they now breed there regularly (Hoskin *et al.* 1991), overlapping with the nesting period of small birds.

The noisy miner (*Manorina melanocephala:* Meliphagidae) is another common urban-dwelling species whose interactions with other birds may lead to decline of smaller bird species. However, the interspecific aggression displayed by this species is largely unstudied in urban areas. In both remnant and rural settings, interspecific aggression exhibited by groups of noisy miners has resulted in the harassment of other birds. This has lead to the exclusion of most other species from its territory (Dow 1977; Grey *et al.* 1997; Grey *et al.* 1998; Arnold 2000). In city environments, this species occurs abundantly in areas with thick canopies and, being nectarivorous, the productive flowering of hybridized native plants such as *Grevillea* species in suburban gardens may also promote increased numbers (Sewell & Catterall 1998).

Finally, the exotic common myna (*Acridotheres tristis*) appears to be one of the most abundant species in Sydney. Its ubiquitous presence in cities in eastern Australia (Blakers *et al.* 1984) and in many other cities (e.g. South Africa, Sinclair & Hockey 1996; Florida and Hawaii, National Geographic 1999) has suggested that it may affect the ability of other species to occur in urban areas through competition for resources (Pell & Tidemann 1997a,b).

It would therefore appear that there might be a strong interaction between vegetation characteristics of suburban gardens, the presence of aggressive or competitive species, and the composition of native bird assemblages. Through examining the interaction of dominant aggressive species with smaller native birds and a range of habitat variables from suburban gardens, the requirements of urban avifauna, particularly the rarer species may be established.

Apart from the choice of garden structure and plant species composition, people modify the environment of birds by a number of behavioural practices. In particular, the provisioning of food for birds and the ownership of pets is believed to influence the species composition and abundance of birds occupying suburban areas (Waterhouse 1997; Morneau *et al.* 1999). With enormous interest in feeding birds in the United States and in Britain, and 5.2% of suburban Australians frequently feeding a single species (the laughing kookaburra, *Dacelo novaehollandiae*; Major *et al.* 1996; Howard & Jones 2004), it would seem likely that some species will benefit from artificial food resources. On the other hand, because the average domestic cat is estimated to consume about three birds per year (Barratt 1998) and dogs are known to chase and harass birds, ownership of pets is likely to have a negative effect on population sizes of some species.

This study uses data collected throughout the Greater Sydney region to examine interactions between dominant and uncommon members of urban avifauna and the degree to which this might be influenced by suburban garden characteristics and human behaviour. In order to obtain broad-scale information of bird distribution throughout Greater Sydney (including the surrounding cities of Newcastle and Wollongong), a community-based survey was used.

METHODS

Experimental design

Information on the presence of 20 target species was assembled from volunteers who assessed the presence of birds in their backyards using a detailed instruction kit prepared by the authors. These species consisted of: (i) one native aggressive species (noisy miner); (ii) one abundant introduced species (common myna); (iii) one native predatory species (pied currawong); (iv) seven small native species (willie wagtail *Rhipidura* *leucophrys*, silvereye *Zosterops lateralis*, red-browed finch *Neochmia temporalis*, superb fairy-wren *Malurus cyaneus*, eastern spinebill *Acanthorhynchus tenuirostris*, new holland honeyeater *Phylidonyris novaehollandiae* and eastern yellow robin *Eopsaltria australis*); and (v) 10 medium to large species considered common in urban areas (red wattlebird *Anthochaera carunculata*, little wattlebird *Anthochaera chrysoptera*, australian magpie *Gymnorhina tibicen*, australian raven *Corvus coronoides*, magpie-lark *Grallina cyanoleuca*, laughing kookaburra *Dacelo novaehollandiae*, sulphur-crested cockatoo *Cacatua galerita*, galah *Cacatua roseicapilla*, rainbow lorikeet *Trichoglossus haematodus* and crimson rosella *Platycercus elegans*). Participants were provided with photographs of all 20 species to aid in identification and were asked to self-assess their accuracy. Data from participants that indicated that they were not confident in their identification of birds were not included in the analysis.

Species interrelationships and garden preferences were analysed only for the noisy miner, common myna, pied currawong and the seven small birds as it was the interactions between these aggressive species and small birds that was of particular interest. The influence of body size, presence of pets and supplementary feeding was analysed for all 20 species.

The bird survey was conducted for a 20-min period each day between 7 AM and 10 AM over 7 days between 1 November and 4 December 2000. This coincided with the breeding season of all of the bird species examined. Surveyors were also instructed not to conduct the survey during rain or strong winds, as birds are less likely to be visible in these situations.

In order to investigate the relationship between species distribution and suburban garden characteristics, participants recorded the following categorical information: (i) garden species composition (mostly native plants/equal mix of native and introduced plants/mostly introduced plants); (ii) percent composition (None 0%, A Few < 25%, Some 25–50%, Most > 50%) of lawn, shrubs less than 5 m tall and trees over 5 m tall; (iii) presence and identity of pets (cat, dog, other); and (iv) supplementary food (seed or meat) and availability (at least weekly, monthly or never).

Bird interactions and vegetation characteristics

Log-linear models were used to determine the effect of the habitat variables (per cent coverage of lawn, shrubs and trees, and garden species composition) on the interaction of pairs of species, that is, three variables (small bird species, dominant bird species, and habitat characteristic) were included in each model. The analyses were performed using the SYSTAT statistical package on the frequency of occurrence of each species in gardens.

Effect of food provisioning

The effect of providing meat (either pet food or fresh meat) or seed to birds was tested by separate analyses of variance, using the following dependent variables: total bird abundance, small bird abundance and selected individual species. We derived an index of bird abundance from the number of days in which each species was recorded in each garden. Each species could therefore contribute between 0 and 7 'species days' such that the possible maximum total bird abundance in a single garden was 140 species days (20 species $\times$ 7 days).

As the style of suburban areas varies from one part of Greater Sydney to another (associated with historical and geographical factors), we divided the study area into five regions that were included as a second factor in the analyses of variance.

Effect of pets

The association between pets and bird abundance was tested by separate two factor analyses of variance, using dog or cat and region as independent variables. Two levels of dog/cat abundance were used: 'present' if they accessed the garden weekly or more frequently, or 'absent' if they accessed the garden monthly or less frequently. Total bird and small bird abundance, both measured in species days, were used as dependent variables.

Body size relationships

To test the relative strength of a negative association between the presence of noisy miners and birds of different sizes, it was necessary to have a measure of body size. We used body mass and compiled mean masses of each of the 20 target species from banding data collated by the Australian Bird and Bat Banding Scheme (Baker *et al*. 1997). From all the gardens in which a particular species was present, we calculated the proportion of gardens in which noisy miners were common (defined as present on more than 30% of days), and plotted this percentage against body mass. The strength of the relationship between the body mass of all species and the percentage of gardens with noisy miners was determined by correlation. Fisher's exact test was used to determine whether the relationships between noisy miners and each species differed significantly from random association.

RESULTS

Species distributions

Seven hundred and twenty-one surveys were obtained from 190 postcode areas (out of a total of 335) within the Greater Sydney region. Not all regions within the study area were sampled equally, with areas to the south and west of the city centre receiving greater survey effort.

The common myna was the most widely distributed species, and was observed in 80% of gardens (Fig. 1). Other common species included the parrots (45% crimson rosella, 76% rainbow lorikeet), pied currawongs (64%) and noisy miners (59%). Each small native species was present in fewer than 40% of the gardens. The willie wagtail was the most common of these species (37% of gardens) while the eastern yellow robin, the rarest species, was observed in only 7% of the gardens surveyed.

Associations between birds and garden characteristics

There were no significant three-way interactions between the presence of any species of small bird, the level of any habitat variable and the presence of any of the species of dominant bird investigated. However, all the small birds showed significant associations with particular habitat variables, the presence of dominant birds, or both (see below for details). As is to be expected with a non-significant three-way interaction, comparable χ^2 results were generally obtained for each of the two-way interactions regardless of which category of the third variable was entered in the model. For simplicity, the χ^2 values reported in the text and in Tables 1–4 for associations between each species of small bird and the habitat variables, or species of dominant bird and between each species of dominant bird, and habitat variables, represent the range of χ^2 values for the multiple models run.

Small birds

Willie wagtails were positively associated with the amount of lawn in gardens (Table 1) and the presence of common mynas ($\chi^2 = 24.81$–38.76, d.f. = 3–4, $P < 0.001$). Willie wagtails also showed a negative association with noisy miners (Table 2). This is unlikely to be due to conflicting habitat preferences as the noisy miner was not negatively correlated with the percentage composition of lawn ($\chi^2 = 3.47$–8.91, d.f. = 6, $P > 0.05$).

Eastern spinebills were associated with several habitat variables and the noisy miner. They were more

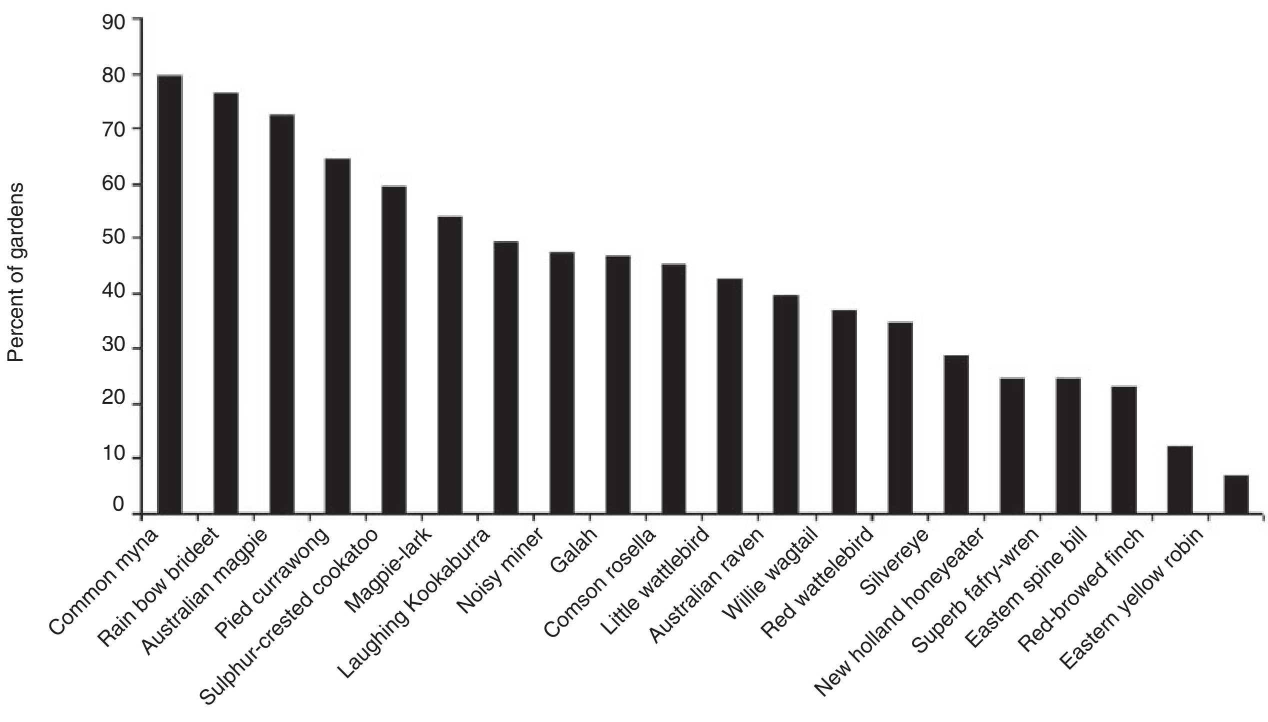

Fig. 1. The relative abundance of 20 focal bird species in Sydney gardens.

Table 1. The relationship between each of the focal bird species and lawn cover

Species	Percentage of occurrence of each species in gardens			Chi-square statistic	P
	(a) With <25% lawn cover ($n = 244$)	(b) With 25–50% lawn cover ($n = 292$)	(c) With >50% lawn cover ($n = 185$)		
New holland honey eater	23.8	27.1	21.2	4.99–14.64	$P > 0.05$
Eastern spinebill	24.2	27.4	13.5	35.84–37.9	$P < 0.01$
Silvereye	31.1	27.1	27.0	4.37–8.82	$P > 0.05$
Eastern yellow robin	6.6	7.5	4.9	2.65	$P > 0.05$
Red-browed finch	12.7	13.4	8.1	5.75–7.66	$P > 0.05$
Superb fairy-wren	18.9	26.4	27.6	0.81–8.09	$P > 0.05$
Willie wagtail	29.5	36.3	47.0	11.3–18.21	$P < 0.05$

Table 2. The association between noisy miners and each of the seven small bird species surveyed

Species	Total No. gardens present	Percentage of occurrence of each species in gardens		Chi-square statistic	P
		(a) without noisy miners ($n = 295$)	(b) with noisy miners ($n = 426$)		
New holland honeyeater	176	42.0	12.2	89.97–96.14	$P < 0.001$
Eastern spinebill	165	37.6	12.7	74.62–78.50	$P < 0.001$
Silvereye	206	43.7	18.1	107.95–118.13	$P < 0.001$
Eastern yellow robin	48	9.5	4.7	15.25–17.48	$P < 0.05$
Red-browed finch	86	15.6	9.4	28.10–31.36	$P < 0.001$
Superb fairy-wren	175	30.8	19.7	40.79–48.15	$P < 0.001$
Willie wagtail	265	47.1	29.6	35.33–39.52	$P < 0.001$

Table 3. The relationship between each of the focal bird species and garden composition

Species	Percentage of occurrence of each species in gardens			Chi-square statistic	P
	(a) with mostly exotic plants ($n = 142$)	(b) with a mixture of exotic and native plants ($n = 328$)	(c) with mostly native plants ($n = 240$)		
New holland honeyeater	16.2	24.7	27.9	8.35–10.48	$P > 0.05$
Eastern spinebill	13.4	21.3	29.6	17.51–18.80	$P < 0.05$
Silvereye	24.6	28.7	30.4	1.99–4.89	$P > 0.05$
Eastern yellow robin	3.5	5.2	10.4	11.01–16.63	$P < 0.05$
Red-browed finch	7.7	11.3	15	5.69–5.94	$P > 0.05$
Superb fairy-wren	18.3	22.9	29.2	9.77–12.43	$P < 0.05$
Willie wagtail	33.1	37.5	37.9	4.61–7.53	$P > 0.05$

Table 4. The relationship between each of the focal bird species and tree cover

Species	Percentage of occurrence of each species in gardens			Chi-square statistic	P
	(a) with < 25% tree cover ($n = 342$)	(b) with 25–50% tree cover ($n = 253$)	(c) with > 50% tree cover ($n = 126$)		
New holland honeyeater	26.0	22.5	23.8	0.87–2.14	$P > 0.05$
Eastern spinebill	18.7	25.7	27.8	8.70–12.35	$P < 0.05$
Silvereye	28.9	28.9	26.2	0.58–5.18	$P > 0.05$
Eastern yellow robin	5.6	4.3	13.5	13.27–16.27	$P < 0.05$
Red-browed finch	9.1	12.6	17.4	7.07–7.98	$P > 0.05$
Superb fairy-wren	21.3	26.4	27.0	5.64–10.86	$P > 0.05$
Willie wagtail	38.0	36.8	33.3	2.79–12.83	$P > 0.05$

common in gardens comprised mostly of native plants (Table 3), and they were more common in gardens with greater tree cover (Table 4). Conversely, they were negatively associated with the amount of lawn (Table 1) and with noisy miners (Table 2).

Eastern yellow robins were the least commonly encountered target species, but despite their rarity, significant associations were detected with both habitat variables and dominant bird species. The species was positively associated with both the amount of tree cover (Table 4) and the degree to which gardens were comprised of native plant species (Table 3). Like all the other small species investigated, the eastern yellow robin was negatively associated with the presence of noisy miners (Table 2).

Three species of small bird showed no associations with any habitat variable: silvereyes, red-browed finches and new holland honeyeaters. However, all were negatively associated with noisy miners (Table 2). Silvereyes were also negatively associated with pied currawongs ($\chi^2 = 8.11–11.05$, d.f. = 3–4, $P < 0.001$), and new holland honeyeaters were commonly seen in gardens where common mynas were present ($\chi^2 = 8.38–13.21$, d.f. = 3–4, $P < 0.05$).

Superb fairy-wrens showed no association with any structural characteristic of gardens, but there was a significant association with the floristic composition (Table 3). The percentage of gardens with superb fairy-wrens increased with an increase in the proportion of native plant species in the gardens. Like the new holland honeyeater, the presence of superb fairy-wrens also was associated with two of the dominant urban birds examined. They were more commonly seen in gardens where noisy miners were absent (Table 2) and in gardens where common mynas were present ($\chi^2 = 7.83–11.06$, d.f. = 3–4, $P < 0.05$). These associations do not appear to be the result of differences in habitat because neither the noisy miner nor common myna showed any association with floristic composition of shrubs or trees.

Dominant birds and habitat characteristics

Pied currawongs were negatively associated with the amount of lawn in gardens ($\chi^2 = 28.93–40.43$, d.f. = 6, $P < 0.001$) and were positively correlated with the amount of tree cover ($\chi^2 = 19.39–23.16$, d.f. = 4, $P < 0.001$). Common mynas were positively associated with lawn ($\chi^2 = 22.76–30.15$, d.f. = 6, $P < 0.001$) which provides the simplest explanation for their positive relationship with willie wagtails. While they were negatively associated with tree cover ($\chi^2 = 12.65–23.51$, d.f. = 4, $P < 0.05$) there is no explanation for their association with new holland honeyeaters, as new Holland honeyeaters are not associated with any habitat variable.

Although noisy miners were negatively associated with every small bird species investigated, there was no relationship between noisy miners and any of the habitat variables examined. Therefore, the associations between the noisy miners and small birds are likely to be due to direct species interactions, although it is possible that they have a preference for some unmeasured habitat variable that is not favoured by the small bird species.

The possibility that bird size is an important factor in determining the coexistence of noisy miners with other bird species is supported by analysis of the 20 target species. The occurrence of 14 of the 19 species (noisy miners excluded) was significantly associated with gardens in which noisy miners were common (observed on more than 30% of surveys). Four of these species were more likely to be present in gardens where noisy miners were common (rainbow lorikeet, galah, australian magpie and pied currawong) while 10 were less likely to be present with noisy miners (eastern spinebill, new holland honeyeater, silvereye, eastern yellow robin, red-browed finch, superb fairy-wren, willie wagtail, little wattlebird, australian magpie-lark and common myna).

There was a strong correlation between the log of body mass and the percentage of gardens in which a species coexisted with noisy miners ($R^2 = 0.81$, $n = 19$, $t = 8.51$, $P < 0.001$). Small birds were much more likely to be absent from gardens in which noisy miners were present, and the four species that were significantly more likely to be found with noisy miners were all larger than 100 g, as were the five species which showed no significant association (Fig. 2).

Effect of food provisioning

The total abundance of birds, expressed in species days, was significantly associated with both the provisioning of meat ($F_{1,685} = 2.9$, $P = 0.022$; Fig. 3a) and the provisioning of seed ($F_{1,685} = 20.2$, $P < 0.001$; Fig. 3b). These relationships were consistent across regions with no significant meat × region ($F_{4,685} = 1.1$, $P = 0.335$) or seed × region ($F_{4,685} = 1.4$, $P = 0.238$) interactions. There was also a small, but significant ($F_{4,685} = 8.9$, $P < 0.001$) regional difference in bird abundance (Fig. 3c).

Although more birds were recorded in gardens in which meat was provided, there were significantly fewer small birds in these gardens ($F_{1,685} = 4.9$, $P = 0.027$) (Fig. 3d), with no significant meat–region interaction ($F_{4,685} = 1.1$, $P = 0.335$). However, there was a strong regional difference in small bird abundance ($F_{4,685} = 17.6$, $P < 0.001$; Fig. 3e). The abundance of several of the large birds was positively related to the provisioning of meat. Of particular interest, given the negative association between small birds and

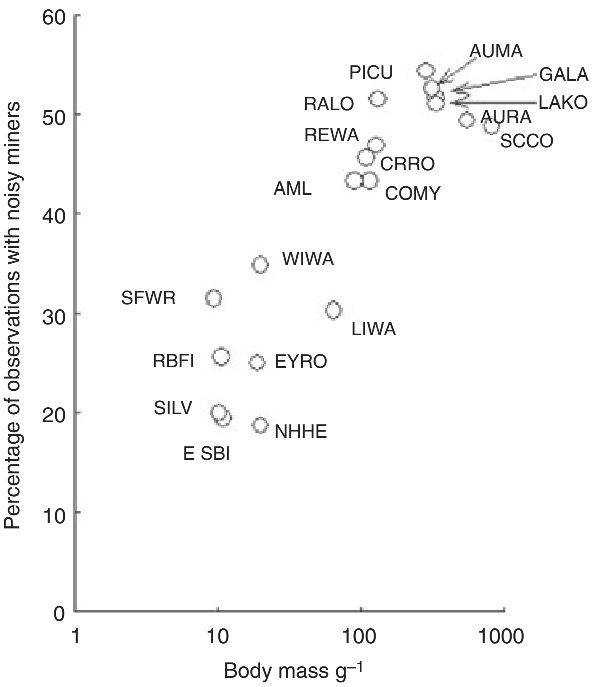

Fig. 2. The relationship between body mass and interspecific association with noisy miners. AMLA, australian magpie-lark; AUMA, australian magpie; AURA, australian raven; COMY, common myna; CRRO, crimson rosella; ESBI, eastern spinebill; EYRO, eastern yellow robin; GALA, galah; LAKO, laughing kookaburra; LIWA, little wattlebird; NHHE, new holland honeyeater; PICU, pied currawong; RALO, rainbow lorikeet; RBFI, red-browed finch; REWA, red wattlebird; SCCO, sulphur-crested cockatoo; SILV, silvereye; SFWR, superb fairy-wren; WIWA, willie wagtail.

noisy miners (Fig. 2), was the significant positive relationship ($F_{1,685} = 7.1$, $P = 0.008$) between noisy miners and the provisioning of meat (Fig. 3f). However, there were no significant relationships between the provisioning of seed and either small bird ($F_{1,685} = 1.7$, $P = 0.192$; Fig. 3g) or noisy miner abundance ($F_{1,685} = 2.0$, $P = 0.155$; Fig. 3h).

Only one species of small bird was significantly associated with the provisioning of food. There was a significant seed × region interaction effect ($F_{4,685} = 5.3$, $P < 0.001$) on the abundance of red-browed finches, the only small, seed-eating bird on the target list. Red-browed finches were between 2.5 and 9 times more abundant in gardens in which seed was provided, in all regions except southern Sydney, where the species was virtually absent.

Effects of pets

Cats were reported in 65% of gardens and dogs in 44% of gardens, with no significant association between cats and dogs (Fishers' exact test $n = 631$, $P = 0.217$). The presence of cats was not significantly related to the total abundance of birds ($F_{1,630} = 2.0$, $P = 0.157$) or the abundance of small birds ($F_{1,630} = 0.0$, $P = 0.945$). Similarly, there was no significant relationship between the presence of dogs and the total abundance of birds ($F_{1,667} = 1.2$, $P = 0.275$) or the abundance of small birds ($F_{1,667} = 3.0$, $P = 0.081$).

DISCUSSION

Habitat requirements of suburban bird species

The presence of four of the seven small birds and two of the three large dominant species were associated with, at least one of the habitat characteristics of suburban gardens that were measured. The availability of suitable vegetation structure and composition is therefore at least partially influencing the composition of suburban bird communities in Australia (Green 1984; Catterall *et al.* 1989; Germaine *et al.* 1998; Sewell & Catterall 1998; Catterall 2004). This supports studies in other continents (e.g. Beissinger & Osborne 1982; DeGraaf & Wentworth 1986). Eastern spinebills, eastern yellow robins and superb fairy-wrens visited gardens composed of at least 50% native vegetation more frequently than gardens that had mostly introduced vegetation, indicating that these species prefer to forage on native plants. Green (1984) found that eastern yellow robins and superb fairy-wrens were more commonly encountered foraging or perching on eucalypts, acacias or other native plants than on exotic species in Melbourne suburbs. Similarly, in New Zealand, native bird species were more abundant in gardens with native plants (Day 1995). While low frequencies of eastern spinebills did not allow interpretation of foraging or perching preferences in Green's (1984) study, it is likely that this species also responds in this way because it is strongly nectarivorous. Catterall *et al.* (1989) also suggested that native birds in Brisbane had a higher probability of selecting native vegetation but they did not provide data on individual species.

The availability of trees (>5 m) (irrespective of floristic origin) positively influenced the presence of pied currawongs, eastern yellow robins and eastern spinebills. Each of these species is, at least partially, reliant on trees for foraging and/or nesting (Pizzey 1980). Other studies of Australian urban birds have emphasized the importance of trees to a number of species (Green 1984; Catterall *et al.* 1989), but responses of individual species were not provided.

The common myna was the only exotic species studied, and was the only species to prefer gardens with fewer trees, probably because these gardens had a higher proportion of lawn, where this species forages.

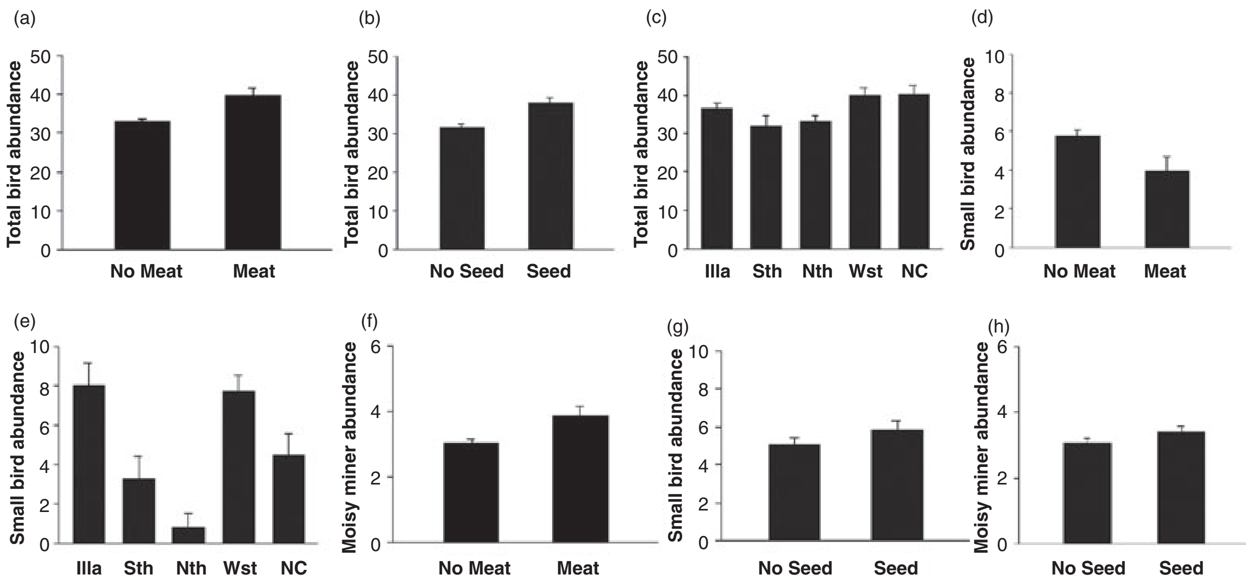

Fig. 3. Relationships between the abundance of birds, the provisioning of food, and geographical region of greater Sydney. (a) Total bird abundance *versus* provisioning of meat, (b) total bird abundance *versus* provisioning of seed, (c) total bird abundance *versus* geographical region, (d) small bird abundance *versus* provisioning of meat, (e) small bird abundance *versus* geographical region, (f) noisy miner abundance *versus* provisioning of meat, (g) small bird abundance *versus* provisioning of seed, (h) noisy miner abundance *versus* provisioning of seed. Error bars show standard deviation. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

Conversely, both the pied currawong and eastern spinebill were negatively associated with lawn cover and, following the inverse of the trend of common mynas, this is likely to be due to an associated reduction in trees. The ground has previously been identified as the most common foraging site for suburban bird species (Emlen 1974; Falk 1976; Green 1984). Of the native species analysed here, however, only the willie wagtail showed a positive correlation with lawn cover. This species is a ground-forager that uses the open space to catch insects (Pizzey 1980).

The most surprising finding on habitat use was the lack of species that were associated with shrub understorey in gardens. Many of the small native species that we surveyed have been previously identified as reliant on shrubs for foraging, nesting or protection (Catterall *et al.* 1989). This included the red-browed finch, eastern yellow robin, superb fairy-wren, silvereye, new holland honeyeater and eastern spinebill. Our initial characterization of habitat characteristics was necessarily broad and therefore crude. Further research should investigate more precise variables of shrub cover to investigate the relationship further.

Four of the 10 species examined for vegetation preferences were not correlated with any habitat characteristic. One of these, the noisy miner, has been shown to be strongly influenced by the presence of trees with dense canopies resembling their traditional woodland habitats (Catterall *et al.* 1989; Sewell & Catterall 1998). However, in this study noisy miners were not correlated with tree cover. Dow (1977) has suggested that this species lives in colonies in woodlands, aggressively defending resources within a group territory. Therefore, in a suburban setting, noisy miners might defend a garden with less-preferred structural characteristics, provided suitable habitat is located nearby, as several gardens may be included within a single territory. It is also likely that for other large species, the individual garden is not the predominant scale at which bird/habitat interactions operate.

Interactions of suburban bird species

Small native species were not only associated with habitat variables, but also with the presence of some large common native (pied currawong, noisy miner) and introduced (common myna) species. While this study has found associations between some of these species, causal relationships between species cannot be determined without experiments involving removal of one of the two interacting birds.

The avifauna in urban areas within Sydney is likely to be, at least partially, structured by one species of bird, the noisy miner. As the noisy miner was not associated with any of the habitat characteristics examined, it is unlikely that interactions between noisy miners and small birds are due to differences in resource utilization. It therefore appears that the presence of noisy miners is a major influence of small bird distribution throughout the Greater Sydney region. Strong negative correlations previously have been found in non-urban areas between noisy miners and avian diversity. The relationship is particularly strong with small honeyeaters and insectivores such as the ones surveyed here (e.g. Dow 1977; Loyn 1987). Grey *et al.* (1997) used experimental removal of noisy miners from eucalypt woodland to show rapid recolonization by small native birds, conclusively demonstrating that noisy miners aggressively exclude these species from their territories in rural remnants. The impact of noisy miners on suburban bird communities needs to be further examined to determine its role in structuring urban bird communities.

Pied currawongs have also been considered as a threat to small birds of eastern Australia due to their predatory nature (Bass 1995; Major *et al.* 1996; Fulton & Ford 2001). In this study however, the species was negatively associated only with silvereyes, and again, this was unlikely to be due to habitat differences. As well as being predatory on eggs, nestlings and occasionally adult small birds, the species is also frugivorous, especially favouring fruits of introduced plants (Buchanan 1989; Bass 1995; Wood 1998). There was no association between pied currawongs and introduced garden vegetation, but pied currawongs travel large distances (Farrell 1995; Wood 2001), much larger than the individual garden scale. If they feed on eggs and nestlings opportunistically as they move about in search of fruiting trees, it is unlikely that a negative association would be detected between currawongs and small birds inhabiting individual gardens. Their predatory activities might reduce the supply of new recruits at a landscape scale such that they may be having a negative effect on small birds in cities even though this is not reflected in a negative association with adult birds at the individual garden scale.

Finally, the most common species observed throughout the Greater Sydney region was the common myna. This species was common throughout the entire survey area and occurred in 80% of gardens. However, the common myna was not negatively associated with any of the other birds surveyed. This might be due in part to a lack of statistical power, as only 20% of gardens lacked common mynas, resulting in a small sample size for categories where common mynas were absent. However, common mynas were positively associated with willie wagtails probably because of a common preference for lawn. They also were positively correlated with superb fairy-wrens and new holland honeyeaters although mynas and these species did not share habitat preferences. Therefore, despite public hostility towards this species, there is no evidence here to suggest that common mynas are negatively native species. Given their generalized diet and their tendency to nest primarily in artificial structures, this is unsurprising. However, as they are so prolific throughout the Greater Sydney region, detailed examinations of any other potential impacts of common mynas such as the interactions with other hollow-nesting species are needed (Pell & Tidemann 1997a,b).

The influence of human behaviour

There has been debate as to whether bird feeding is desirable in terms of bird conservation (Jones & Howard 2001; Nattrass 2001). Against the benefits of furthering interests in wildlife is the possibility that feeding birds increases the spread of disease (Brittingham & Temple 1988), results in malnourishment (Cannon 1979) and favours large, aggressive or predatory species that displace smaller birds (Major *et al.* 1996). We found that gardens, in which meat and seed were provided, were associated with an increase in the total abundance of birds, but that the abundance of small birds was lower in gardens in which meat was provided. A partial explanation of this pattern is the association between noisy miners and food provisioning: noisy miners were significantly more abundant in gardens in which meat was provided but there was no association with the provisioning of seed. Therefore, it seems plausible that providing fresh meat increases the abundance of noisy miners, which act aggressively towards the smaller birds, resulting in a reduction in small bird abundance. This provides some support for the claim that bird feeding, in the form of meat, can have a negative effect on urban avifauna by increasing dominance of larger species.

The provisioning of seed was not found to have a negative effect through this mechanism, and was associated with increased numbers of the red-browed finch as well as total bird abundance. Thus it is reasonable to recommend that if food is to be provided, it is preferable to provide seed (particularly seeds of a size suitable for finches) to meat. However, this conclusion can only be considered preliminary because these data are only correlative. It is possible that people's decision to feed birds is influenced by the fact that the birds are already present in their gardens. Thus, a higher abundance of birds in gardens in which seed was provided might only reflect existing high abundance.

This study provided no support for the claim that the presence of pets in gardens has an impact on bird abundance. There were no significant associations between pet access to gardens and the abundance of all birds, or the abundance of small birds. The commonly held expectations are that cats have a negative effect on bird abundance through predation, and dogs have either a negative impact by chasing birds or a positive impact by chasing cats. The lack of association between dogs and cats observed in this study supports the rejection of the latter hypothesis.

Given the amount of bird mortality that has previously been attributed to cats in urban areas (Barratt 1997, 1998; Meek 1998), and the high-observed level of cat access to gardens (65%), it is important to consider why we did not observe lower bird abundance in gardens with cats. Again, we suspect that the scale at which a predation effect is manifest is larger than the single garden. Predation of nest contents or adult birds, whether it be by cats or pied currawongs reduces the number of birds that will occupy a whole neighbourhood. In contrast, the presence of a garden within the territory of a noisy miner has a persistent impact at the garden scale. Furthermore, recent Australian studies have identified that small mammals are the favoured prey item of cats, with relatively few birds and lizards being eaten (Barratt 1997, 1998).

This study represented a large survey effort at a brief period, and contributes to our understanding of a range of factors that may influence the presence of small birds in city areas. It has highlighted a number of important associations between these small birds and garden characteristics that imply that even by making simple adjustments to the composition of a garden, many of these small birds may be able to utilize suburban gardens. However, the situation is complicated by the intense pressure of a dominant competitor whose habitat preferences require further investigation. It would be naive to prescribe best practice guidelines for urban design without understanding the overriding impact of the noisy miner (Catterall 2004). Further experimental work is likely to lead to greater understanding of how urban habitats can be used to conserve native small bird populations.

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