Australian Journal of Entomology (2007) **46**, 325–331

Arthropod prey of shelterbelt-associated birds: linking faecal samples with biological control of agricultural pests

Sagrario Gámez-Virués,[1] Ronald S Bonifacio,[1] Geoff M Gurr,[2]* Cilla Kinross,[2] Anantanarayanan Raman[2] and Helen I Nicol[2]

[1]*Pest Biology and Management Group, The University of Sydney, 346 Leeds Parade, Orange, NSW 2800, Australia*
[2]*Pest Biology and Management Group, Charles Sturt University, 346 Leeds Parade, Orange, NSW 2800, Australia*

Abstract The value of insectivorous birds as agents for biological control of arthropod pests has been little studied, especially in Australia. This paper reports on the extent to which arthropods from various pest and non-pest taxa feature in the diets of birds captured in farm shelterbelts in central western New South Wales. The parameters examined were the types of arthropod fragments in bird faeces and percentage volume and frequency of occurrence of each component. The faecal data were compared with samples of the arthropod fauna trapped in shelterbelts during the period the birds were captured. In 26 of 29 faecal samples, arthropod fragments were the predominant components, the most common being from Coleoptera, Hymenoptera (especially Formicidae), Orthoptera and Araneae. The recognisable pest taxa in faecal samples were Scarabaeidae and wingless grasshopper *Phaulacridium vittatum* (Sjöstedt) (Orthoptera: Acrididae). The results indicate that the native bird species common in farm shelterbelts preyed on a range of arthropod taxa including several that are pests of crops and pastures. Accordingly, conservation of birds in farmlands could contribute to suppression of arthropod pests.

Key words biological control, bird diet, faecal analysis, shelterbelt.

INTRODUCTION

The extent to which birds contribute to pest suppression in agroecosystems is an important issue but remains unclear, especially for Australian systems. Several studies around the world have demonstrated that birds can reduce the abundance of pest species including rodents in Toronto, Canada (Baker & Brooks 1982) and weeds such as quackgrass, *Agropyron repens*, in Alaska, USA (Wurtz 1995). In the case of arthropod prey, the great tit, *Parus major* (L.), significantly reduced damage caused by four species of caterpillars to apple orchards, thus increasing fruit yield in an experimental orchard at Kesteren in the Netherlands (Mols & Visser 2002). The woodpeckers *Picoides pubescens* (L.) and *P. villosus* (L.) foraged selectively on larvae of codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) in apple orchards in Nova Scotia, Canada, and a positive relationship between the extent of forests around the orchards and the degree of predation by woodpeckers was found (MacLellan 1959). Indirect effects on plant growth of predation of leaf-chewing insects by birds were demonstrated in a deciduous forest of white oak *Quercus alba* (Fagaceae) in Missouri, USA (Marquis & Whelan 1994). Bird predation reduced abundance of Lepidoptera and levels of herbivory but did not increase biomass production in saplings of sugar maple *Acer saccharum* (Aceraceae) in New Hampshire, USA (Strong *et al.* 2000).

On-farm conservation of birds may be necessary for achieving ecosystem services such as arthropod predation (Kirk *et al.* 1996), but in Australia evidence for them feeding on pests comes primarily from studies of forests, rather than farms. A study of the effects of bird predation on canopy arthropods in *Eucalyptus wandoo* (Myrtaceae) saplings in Western Australia indicated that birds had limited effects on temporal variation in arthropod abundance. Birds did, however, reduce abundance of Araneae, adult Coleoptera and Lepidoptera larvae, thus affecting the size and trophic composition of the entomofauna (Recher & Majer 2006). In an open forest dominated by *E. radiata* in Victoria, the removal of a colony of bell miners *Manorina melanophrys* (Latham) that communally defend their territory (Loyn *et al.* 1983; Poiani *et al.* 1990) had a positive effect on the diversity and abundance of other insectivorous birds (Grey *et al.* 1997; Clarke & Schedvin 1999). When *M. melanophrys* were removed, an existing infestation of *Glycaspis* sp. (Hemiptera: Psyllidae) on *E. radiata* was reduced via predation by colonising insectivorous birds of other species. Once *M. melanophrys* recolonised, populations of *Glycaspis* sp. returned to levels close to its original density (Clarke & Schedvin 1999). Better information on the role of birds as predators of arthropod pests in farmlands would help direct habitat manipulation to maximise this ecosystem service while helping to conserve avifauna outside reserve systems. There is scope for conserving even forest-inhabiting birds on

*Present address: E. H. Graham Centre for Agricultural Innovation, Charles Sturt University, Orange, NSW 2800, Australia (ggurr@csu.edu.au).

doi:10.1111/j.1440-6055.2007.00608.x

farms as a result of the increasing practice of establishing shelterbelts or windbreaks. These linear plantations are common in temperate Australia for sheltering crops and livestock from weather, managing hydrology and timber production. Native shelterbelts and other farm tree plantings help bird conservation by providing many bird species with appropriate habitat, foraging sites and food (Johnson & Beck 1988; Haas 1995; Hinsley & Bellamy 2000; Majer *et al.* 2000; Ryan 2000; Kinross 2004).

This study aimed to provide initial data on the species of shelterbelt-associated birds and their arthropod prey, thereby identifying the bird species that may contribute to the suppression of pest arthropods of shelterbelts and adjacent crops and pastures.

MATERIALS AND METHODS

Study area

Five shelterbelts (Table 1) were studied on the property 'Belgravia', located between Orange and Molong in central western NSW (centred on 33°07′36″S; 149°02′58″E). The shelterbelts were distributed over an area of 3 km^2 between 75 and 1560 m apart. They included only native trees dominated by *Eucalyptus albens*, *E. blakelyi*, *E. bridgesiana*, *E. melliodora*, *E. polyanthemos*, *E. rossii*, *E. viminalis* (Myrtaceae), *Acacia dealbata*, *A. decurrens*, *A. implexa* and *A. vestita* (Mimosaceae), which are local indigenous species (Tame 1992; Bower & Semple 1993; Sivertsen & Clarke 2000). Two unidentified eucalypt species (*E.* sp.1 and *E.* sp.2), *E. camaldulensis*, *E. populnea*, *A. longifolia* and *Hakea salicifolia* (Proteaceae), were also present.

Sampling

Samples were taken within a 3000 m^2 area marked out in each shelterbelt. Arthropods were sampled using sticky, pitfall and light traps in February 2005. These traps are biased towards flying insects, epigeic and nocturnal arthropods, respectively (New 1998). Sticky traps were made using Petri dishes (90 mm diameter) with tangle-trap coating the inner surface. Three pairs of sticky traps, each pair consisting of one yellow and one white, were placed 100 cm from ground level on separate wooden sticks and removed after 5 days. The use of both colours was to maximise the attractiveness to a range of taxa (New 1998). Pairs of sticky traps were uniformly distributed over a 45 m length of each shelterbelt's sample area. Pitfall traps were made of plastic containers (250 mL) which were sunk into the soil, so the mouth of the container was flush with ground level. Three pitfall traps were used in each shelterbelt, each one next to a pair of sticky traps and removed after 5 days. Light traps were made with opaque-white plastic containers (27.5 × 35 × 19 cm) lit with a battery operated (4D-size alkaline batteries × 1.5v) lantern. A transparent sticky film (20.5 × 29.5 cm) was placed on the lid of each light trap to collect arthropods. Lamps were turned on at 18:00 h and off the next morning at 07:00 h. One light trap was used in each shelterbelt and was operated for two consecutive nights. All arthropods were preserved in 70% ethanol.

During the arthropod-sampling period, birds were trapped from the same shelterbelt using mist nets with varying mesh sizes (16–31 mm). Nets were operated between 07:30 and 13:00 h for 130 min per shelterbelt. Trapped birds were held individually in cardboard cartons (15 × 15 × 10 cm) and released at the same site after 60 min. Faecal droppings within the cartons were preserved in 70% ethanol. Christidis and Boles's (1994) nomenclature for birds was followed.

Faecal analysis

A reference collection of fragments was created for frequently trapped arthropods. Individuals were ground in 5 mL of 70% ethanol using steel-ball bearings (1.5 cm diameter) in a plastic container by shaking vigorously by hand for 30 s. The resulting fragments were similar to those present in bird faeces. Selected fragments were air-dried at room temperature (18–22°C) for 24 h then gold-coated (Microvac PM323A) and photographed under a scanning electron microscope (JEOL T200, 15 kV) between 75× and 350×.

Analysis of bird faeces followed the method of Whitaker (1988). Each ethanol-preserved sample was spread over the base of a Petri dish and examined using a stereo-binocular microscope (10–80 × magnification). Faecal material was sorted into components based on morphological features (e.g. colour, texture). Diet components were initially categorised into arthropod and non-arthropod fragments (e.g. seed fragments). Arthropod fragments were sorted and identified using Comstock (1918), Borror and DeLong (1971), Naumann (1991) and Lepley (1994), as well as the reference fragments. Volumetric proportions ('percentage volume') and frequency of occurrence of every arthropod and non-arthropod type were recorded following Rosenberg and Cooper (1990). A canonical variate analysis (CVA) in GenStat® 8.1 was used to explore percentage volume and frequency of occurrence values.

RESULTS

Twenty-nine faecal samples were obtained from 11 bird species (Table 1). All bird species were native to Australia with the exception of the house sparrow, *Passer domesticus*. Arthropod fragments obtained from bird faeces matched the body parts of Acarina, Araneae, Coleoptera, Diptera, Heteroptera, Hymenoptera, Isoptera, Lepidoptera, Neuroptera and Orthoptera (Table 2). For 26 of the faecal samples, arthropod fragments dominated, although some categorised as 'undetermined' were too small to designate to taxa.

A total of 28 arthropod taxa were recognised within the faecal samples. The maximum number of taxa recognised in the faecal sample of a single bird was seven (*Rhipidura leucophrys*). Sixteen faecal samples contained fragments from five or six arthropod taxa. The most frequent prey taxon was Coleoptera, followed by Hymenoptera, Araneae and Orthoptera (Table 2). Fragments of Acarina, Heteroptera and

Table 1 Numbers and relative importance (%) of arthropods (pooled sticky, pitfall and light traps) and birds (mist-nets) in shelterbelts in central western New South Wales

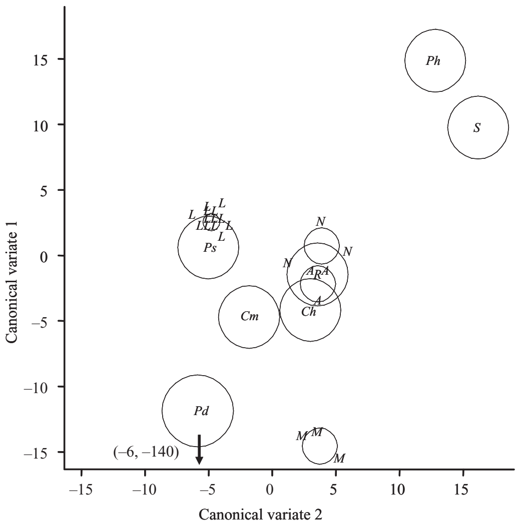
Shelterbelt	1	2	3	4	5	
Age (year)	15	5	6	8	8	
Mean height (m)	6	4	4	10	8	
Width (m)	30	8	30	20	12	
Area (m^2)	18 795	4136	6522	13 923	3000	
Distance from nearest remnant of native vegetation (m)	663	69	544	1 477	497	
Arthropod taxon	**Numbers of individuals caught in each shelterbelt**					**Contribution of taxon to overall arthropod trapped (%)**
Acarina	1	0	0	0	3	0.09
Araneae	10	10	9	14	11	1.30
Coleoptera						
Carabidae	3	1	0	5	0	0.20
Chrysomelidae	3	0	0	1	1	0.12
Scarabaeidae	1	9	8	2	13	0.77
Other	17	5	5	17	59	2.39
Total	24	15	13	25	73	3.48
Diptera	59	90	38	49	37	6.33
Heteroptera	0	1	0	2	0	0.10
Hymenoptera						
Formicidae	778	294	398	1 390	327	73.91
Wasps	41	68	29	44	43	5.22
Total	819	362	427	1 434	370	79.13
Isoptera	0	0	0	0	1	0.02
Lepidoptera (adults)	31	57	14	5	28	3.10
Orthoptera						
Acrididae	2	2	0	7	0	0.26
Gryllidae	0	0	0	0	1	0.02
Total	2	2	0	7	1	0.28
Other	43	37	115	18	53	6.17
Total individuals	989	574	616	1 554	579	100.00
Bird species						**Bird common names**
Psephotus haematonotus (Gould)	0	0	0	0	1	Red-rumped Parrot
Malurus cyaneus (Latham)	0	1	0	2	0	Superb Fairy-wren
Pardalotus striatus (Gmelin)	0	1	0	0	0	Striated Pardalote
Lichenostomus penicillatus (Gould)	0	0	3	1	9	White-plumed Honeyeater
Colluricincla harmonica (Latham)	0	0	0	1	0	Grey Shrike-thrush
Rhipidura leucophrys (Latham)	0	0	0	1	0	Willie Wagtail
Anthus australis (Vieillot)	3	0	0	0	0	Richard's Pipit
Passer domesticus (L.)	0	0	0	0	1	House Sparrow
Neochmia temporalis (Latham)	0	0	3	0	0	Red-browed Finch
Stagonopleura guttata (Shaw)	0	0	0	0	1	Diamond Firetail
Cincloramphus mathewsi (Iredale)	0	0	1	0	0	Rufous Songlark
Total individuals	3	2	7	5	12	

Table 2 Estimated volumetric importance (%) of arthropod remains in the faeces of birds captured from farm shelterbelts in central western New South Wales

Category	Bird species											Frequency of occurrence overall birds	
	Aa $n = 3$	*Ch* $n = 1$	*Cm* $n = 1$	*Lp* $n = 13$	*Mc* $n = 3$	*Nt* $n = 3$	*Pd* $n = 1$	*Ph* $n = 1$	*Ps* $n = 1$	*Rl* $n = 1$	*Sg* $n = 1$	Individuals $n = 29$	Species $n = 11$
Acarina	0	0	0	0	0.1	0	0	0	0	0	0	1	1
Araneae	0.2	0	0.5	5.2	2.1	0	0	0	0	1.5	0	14	5
Coleoptera													
Carabidae	0	0	0	2.1	0.7	0	0	0	1.0	2.5	0	4	4
Chrysomelidae	0	0	0	1.0	0	0	0	0	0	0	0	5	1
Scarabaeidae	8.1	32.0	1.0	4.3	21.0	0.8	0.2	0	0	7.5	0	13	8
Other	0	0	0	6.6	1.0	0	0.4	17.0	0	0	0	4	4
Total												25	10
Diptera	0	0	0	1.0	0	0	0	0	0	2.0	0	4	2
Heteroptera	0	0	1.5	0	0	0	0	0	0	0	0	1	1
Hymenoptera													
Formicidae	1.8	0	3.0	5.6	65.5	0	0	0	0.5	50.0	0	13	6
Wasps	0.1	0	0	0.4	0	0	0	0	0	0	0	5	2
Total												14	6
Isoptera	0	0	0	0.1	0	0	0	0	0	0	0	1	1
Lepidoptera	0	0	0	5.5	9.3	0	0	2.5	16.0	0	0	7	4
Neuroptera													
Hemerobiidae	0	0	0	0.4	0	0	51.0	0.5	0	7.5	0	5	4
Orthoptera													
Acrididae	47.2	24.0	12.0	0	0	61.3	0	0	0	0	0	8	4
Gryllidae	0	0	0	0	0	0	2.0	0	0	0	0	1	1
Total												9	5
Undetermined†	42.4	44.0	82.0	51.3	0.3	30.6	44.4	33.0	82.0	29.0	37.0	–	–
Total overall arthropods	99.8	100	100	83.5	100	92.7	98.0	53.0	99.5	100	37.0	–	–
Sand	0.2	0	0	5.9	0	7.3	2.0	47.0	0.5	0	50.0	9	7
Seeds	0	0	0	10.6	0	0	0	0	0	0	13.0	5	2

†Arthropod fragments.

Aa, *Anthus australis*; *Ch*, *Colluricincla harmonica*; *Cm*, *Cincloramphus mathewsi*; *Lp*, *Lichenostomus penicillatus*; *Mc*, *Malurus cyaneus*; *Nt*, *Neochmia temporalis*; *Pd*, *Passer domesticus*; *Ph*, *Psephotus haematonotus*; *Ps*, *Pardalotus striatus*; *Rl*, *Rhipidura leucophrys*; *Sg*, *Stagonopleura guttata.*



Anthus australis (A) *Colluricincla harmonica (Ch)* *Cincloramphus mathewsi (Cm)*
Lichenostomus penicillatus (L) *Malurus cyaneus (M)* *Neochmia temporalis (N)*
Passer domesticus (Pd) *Psephotus haematonotus (Ph)* *Pardalotus striatus (Ps)*
Rhipidura leucophrys (R) *Stagonopleura guttata (S)*

Fig. 1. Shelterbelt bird species grouped by composition of arthropod fragments in faeces. Circles represent 95% confidence intervals.

Isoptera were the lowest in overall frequency of occurrence. Neuroptera, Lepidoptera and Diptera were also recognised in the samples. The majority of the arthropod taxa on which birds fed were caught in the shelterbelts (Tables 1,2). This was especially evident in the overall faecal analysis of the birds trapped in shelterbelt 5 probably as a consequence of the bird sample size (12 individuals of four species). However, all the trapped birds appeared to feed in a selective fashion.

The CVA generated several distinct clusters of bird species that were statistically separated according to their dietary components. This resulted in 78% of the variation in diet composition being explained using the first two canonical variates (Fig. 1).

Faecal samples from the bird cluster comprising *Colluricincla harmonica*, *Anthus australis*, *Cincloramphus mathewsi*, *Neochmia temporalis* and *R. leucophrys*, all of which forage extensively on the ground (Cameron 1985; Ford 1985; Recher & Holmes 1985; Adriano & Calver 1995; Martin *et al.* 2004) (Fig. 1, centre), were characterised largely by fragments from adult Scarabaeidae (Table 2). These nine individual birds were caught in shelterbelts 1, 3 and 4 (Table 1). All birds contained fragments of Scarabaeidae in their faeces despite these insects being relatively rare in the shelterbelts at the sampling time. Of the 989, 616 and 1554 individual arthropods caught from shelterbelts 1, 3 and 4, respectively, only one, eight and two of them were Scarabaeidae (Table 1). The apparently disproportionate representation of scarabs in the diet of these birds may have implications for pest management. Although the faecal fragments were too small to allow definitive identification, all of the beetles trapped were from herbivorous families Melolonthinae (root and foliage feeders) and Rutelinae (pests of grasses and eucalypts).

Rhipidura leucophrys was statistically separated from this cluster because, unlike the foregoing list of species, this individual did not include fragments of the wingless grasshopper *P. vittatum*, despite these insects being present in shelterbelt 4 where *R. leucophrys* was caught (Table 1). Ants (Hymenoptera: Formicidae) were the predominant component in the faeces of *R. leucophrys*, which was consistent with the abundance of these insects in the study site. Of 1554 individual arthropods caught from shelterbelt 4, 1390 were Formicidae (Table 2). In contrast to *R. leucophrys*, the acridid *P. vittatum* was the dominant diet component of the three *N. temporalis* (61.3%; Table 2), although none of these insects was trapped within shelterbelt 3 where these birds were caught (Table 1). In the case of *A. australis*, *C. harmonica* and *C. mathewsi*, this acridid occupied between 12% and 47.2% of volume (Table 2). Twelve mandibles of *P. vittatum* were found in the faeces of a single *A. australis*.

Faecal samples from birds in the second cluster comprising *P. striatus* and *L. penicillatus*, both canopy foliage gleaners with a dependence on lerps (Hemiptera: Psyllidae) (Recher & Holmes 1985; Woinarski 1985) (Fig. 1, left), were not dominated by any single component, rather fragments from various arthropod taxa occurred in their faeces. The bird species best represented was *L. penicillatus* (13 individuals) and this may account for it exhibiting the widest diet range including arthropods from seven orders and seeds (Table 2). The coleopteran families Carabidae, Chrysomelidae and Scarabaeidae comprised the largest fraction of faecal remains, though Hymenoptera and Lepidoptera were also common for *P. striatus* and *L. penicillatus*.

Psephotus haematonotus and *S. guttata*, principally seed feeders (Higgins 1999; Martin *et al.* 2004; Higgins *et al.* 2006), were caught in shelterbelt 5 (Table 1). These two bird species formed a distinct cluster in the CVA (Fig. 1, top right). *P. haematonotus* was the only non-passerine caught. This individual had been feeding extensively on Coleoptera and was also the only bird that had preyed on lepidopteran larvae (eight head capsules). Lepidoptera constituted 28 individuals out of the 579 arthropods trapped in shelterbelt 5, although all were adults most likely as a consequence of the sampling method (Table 1). Only Hemiptera have previously been reported as part of the diet of *P. haematonotus* (Barker & Vestjens 1989). *Stagonopleura guttata* was the only bird in which no arthropod fragments could be assigned to the order level, although a significant proportion was identifiably of arthropod origin being composed of material such as leg fragments and abdominal terga, the balance being seed fragments.

The three individuals of *M. cyaneus*, a ground-foraging insectivore (Keast 1985; Recher & Holmes 1985; Higgins *et al.* 2001), were statistically separated (Fig. 1, bottom), and their faeces were characterised by the ants *Iridomyrmex* sp. (Dolichoderinae), *Monomorium* sp. (Myrmicinae), *Rhytidoponera* sp. (Ponerinae) and two unknown genera, one from Myrmicinae and one from Ponerinae. The diet of *M. cyaneus* also included mites of unknown identity, possibly phoretic/parasitic species that were consumed inadvertently. Formicidae comprised 294 and 1390 individuals, out of the 574 and

1554, respectively, of the arthropods trapped from shelterbelts 2 and 4 where *M. cyaneus* was caught (Table 1).

The single *P. domesticus*, a seed feeder that forages heavily on insects during spring and summer (the breeding season) (MacMillan 1981) was the only exotic species trapped. *Passer domesticus* was statistically separated because it had preyed largely (51%) on brown lacewing adults, *Hemerobius* sp. (Hemerobiidae: Neuroptera), although no Neuroptera were trapped in shelterbelt 5 from which it was caught (Table 1).

DISCUSSION

Information on the requirements of insectivorous birds at appropriate spatial and temporal scales is necessary to provide habitats such as shelterbelts that either suit particular species or maximise the number of species that can use the habitat. A diverse avifauna increases the breadth of prey taxa consumed and has the potential to dampen arthropod abundance and thereby reduce damage from herbivory (Recher & Majer 2006). Understanding the behaviour and needs of insectivorous birds is therefore necessary to enhance their potential for predation on pest arthropods.

Differential digestion rates of prey items impose a bias in any study of gut contents or faeces (Rosenberg & Cooper 1990). Nevertheless, information from faeces provides valuable information on aspects such as prey kinds and sizes (Ralph *et al.* 1985). In the current study, use of faecal analysis provides evidence for native bird consumption of pest arthropods including *P. vittatum*, a major pest of pastures (Roberts 1972). Faecal samples from *A. australis* individuals contained up to 12 mandibles of *P. vittatum*. Although these were no longer attached to each other in their original pairs, it indicates that at least six individuals had been consumed by one of the three birds. Coleoptera, Hymenoptera (Formicidae) and Araneae were the dominant prey arthropods in most of the faecal samples. It is noteworthy that taxa of natural enemy significance, as well as pests, were represented in faecal samples, so birds cannot be assumed at this stage to be of net benefit to arthropod pest management.

Results from the present study are in general agreement with the literature on diets of Australian birds (e.g. Barker & Vestjens 1989, 1990; Higgins 1999; Higgins *et al.* 2001, 2006; Higgins & Peter 2002), but contribute several new records of diet components: (1) *Phaulacridium vittatum* and scarabaeids in the diet of *N. temporalis*; (2) Neuroptera in the diet of *R. leucophrys*; (3) Carabidae and Isoptera in the diet of *L. penicillatus*; (4) Coleoptera, Lepidoptera and Neuroptera in the diet of *P. haematonotus*; (5) *Monomorium* sp. (Hymenoptera: Formicidae) in the diet of *M. cyaneus*; and (6) brown lacewing adults (Neuroptera) in the diet of *P. domesticus*.

The clusters obtained with the CVA reveal different foraging behaviours and food preferences of the shelterbelt-associated birds. The arthropod taxa observed in *A. australis*, *C. harmonica*, *C. mathewsi*, *L. penicillatus*, *M. cyaneus*, *P. striatus* and *R. leucophrys* reflect the composition of arthropods trapped in the same sites as the birds. *Neochmia temporalis* and *P. domesticus* contained prey taxa that were not trapped from the shelterbelts suggesting that they had been foraging in other habitats, probably adjacent fields.

ACKNOWLEDGEMENTS

We thank John O Whitaker, Jr for supplying some useful papers; Murray Fletcher and Holger Löcker for assistance with arthropod identification; Karen Gogola for help with scanning electronic microscope images; farmers and field staff at Belgravia, especially Fiona and Ben Watts, and Alan Hardy; and Harry F Recher and Hugh Ford for comments in an early draft of the manuscript. This study was supported by the Joint Venture Agroforestry Program (Project # US-117A).

REFERENCES

Adriano S & Calver MC. 1995. Diet of breeding Willie Wagtails *Rhipidura leucophrys* in suburban Western Australia. *Emu* **95**, 138–141.

Baker JA & Brooks RJ. 1982. Impact of raptor predation on a declining vole population. *Journal of Mammalogy* **63**, 297–300.

Barker RD & Vestjens WJM. 1989. *The Food of Australian Birds*: *Vol. 1 Non-Passerines.* CSIRO, Melbourne, Australia.

Barker RD & Vestjens WJM. 1990. *The Food of Australian Birds*: *Vol. 2 Passerines.* CSIRO, Melbourne, Australia.

Borror DJ & DeLong DM. 1971. *An Introduction to the Study of Insects*, 3rd edn. Holt, Rinehart & Winston, Inc, New York, USA.

Bower CC & Semple WS. 1993. *A Guide to the Eucalypts of the Central West of NSW*. CaLM Technical Report No. 30. Department of Conservation and Land Management, Sydney, Australia.

Cameron E. 1985. Habitat usage and foraging behaviour of three fantails (*Rhipidura*: Pachycephalidae). In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation and Management* (eds A Keast, HF Recher, H Ford & D Saunders), pp. 177–191. Surrey Beatty & Sons Pty Limited and The Royal Australasian Ornithologists Union, Chipping Norton, NSW, Australia.

Christidis BG & Boles W. 1994. *The Taxonomy and Species of Birds of Australia and Its Territories*. Monograph 2. Royal Australasian Ornithologist Union, Melbourne, Australia.

Clarke MF & Schedvin N. 1999. Removal of bell miners *Manorina melanophrys* from *Eucalyptus radiata* forest and its effect on avian diversity, psyllids and tree health. *Biological Conservation* **88**, 111–120.

Comstock JH. 1918. *Outline of Laboratory Work in the Study of the Venation of the Wings of Insects*. The Comstock Publishing Company, Ithaca, New York, USA.

Ford HA. 1985. A synthesis of the foraging ecology and behaviour of birds in eucalypt forests and woodlands. In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation and Management* (eds A Keast, HF Recher, H Ford & D Saunders), pp. 249–254. Surrey Beatty & Sons Pty Limited and The Royal Australasian Ornithologists Union, Chipping Norton, NSW, Australia.

Grey MJ, Clarke MF & Loyn RH. 1997. Initial changes in the avian communities of remnant eucalypt woodlands following a reduction in the abundance of noisy miners, *Manorina melanocephala*. *Wildlife Research* **24**, 631–648.

Haas CA. 1995. Dispersal and use of corridors by birds in wooded patches on an agricultural landscape. *Conservation Biology* **9**, 845–854.

Higgins PJ, ed. 1999. *Handbook of Australian, New Zealand and Antarctic Birds*. *Vol. 4: Parrots to Dollarbird*. Oxford University Press, Melbourne, Australia.

Higgins PJ & Peter JM, eds. 2002. *Handbook of Australian, New Zealand and Antarctic Birds*. *Vol. 6: Pardalotes to Shrike-Thrushes*. Oxford University Press, Melbourne, Australia.

Higgins PJ, Peter JM & Steele WK, eds. 2001. *Handbook of Australian, New Zealand and Antarctic Birds. Vol. 5: Tyrant-Flycatchers to Chats*. Oxford University Press, Melbourne, Australia.

Higgins PJ, Peter JM & Cowling SJ, eds. 2006. *Handbook of Australian, New Zealand and Antarctic Birds. Vol. 7: Boatbills to Starlings, Part B: Dunnock to Starlings.* Oxford University Press, Melbourne, Australia.

Hinsley SA & Bellamy PE. 2000. The influence of hedge structure, management and landscape context on the value of hedgerows to birds: a review. *Journal of Environmental Management* **60**, 33–49.

Johnson RJ & Beck MM. 1988. Influences of shelterbelts on wildlife management and biology. *Agriculture, Ecosystems, and Environment* **22/23**, 301–335.

Keast A. 1985. Bird community structure in southern forests and northern woodlands: a comparison. In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation and Management* (eds A Keast, HF Recher, H Ford & D Saunders), pp. 97–116. Surrey Beatty & Sons Pty Limited and The Royal Australasian Ornithologists Union, Chipping Norton, NSW, Australia.

Kinross C. 2004. Avian use of farm habitats, including windbreaks, on the New South Wales Tablelands. *Pacific Conservation Biology* **10**, 180–192.

Kirk DA, Evenden MD & Mineau P. 1996. Past and current attempts to evaluate the role of birds as predators of insect pests in temperate agriculture. In: *Current Ornithology*, Vol. 13 (eds V Nolan Jr & ED Ketterson), pp. 179–269. Plenum Press, New York, USA.

Lepley M. 1994. L'étude des pelotes de réjection d'oiseaux insectivores: méthode, limite, et atlas de restes de proies du faucon crécerellette *Falco naumanni* en Plaine de Crau. *Faune de Provence CEEP* **15**, 5–15.

Loyn RH, Runnalls RG, Forward GW & Tyers J. 1983. Territorial bell miners and other birds affecting populations of insect prey. *Science* **221**, 1411–1412.

MacLellan CR. 1959. Woodpeckers as predators of the codling moth in Nova Scotia. *Canadian Entomologist* **91**, 673–680.

MacMillan BWH. 1981. Food of house sparrows and greenfinches in a mixed farming district, Hawke's Bay, New Zealand. *New Zealand Journal of Zoology* **8**, 93–104.

Majer JD, Recher H & Keals N. 2000. Canopy arthropod faunas in fragmented agricultural landscapes. In: *Temperate Eucalypt Woodlands in Australia* (eds RJ Hobbs & CJ Yates), pp. 235–247. Surrey Beatty & Sons, Chipping Norton, NSW, Australia.

Marquis RJ & Whelan CJ. 1994. Insectivorous birds increase growth of white oak through consumption of leaf-chewing insects. *Ecology* **75**, 2007–2014.

Martin W, Eyears-Chaddok M, Wilson B & Lemon J. 2004. The value of habitat reconstruction to birds at Gunnedah, New South Wales. *Emu* **104**, 177–189.

Mols CMM & Visser ME. 2002. Great tits can reduce caterpillar damage in apple orchard. *Journal of Applied Ecology* **39**, 888–899.

Naumann ID. 1991. *The Insects of Australia: A Textbook for Students and Research Workers*, 2nd edn. CSIRO Publishing, Melbourne, Australia.

New TR. 1998. *Invertebrate Surveys for Conservation*. Oxford University Press, Oxford, UK.

Poiani A, Rogers A & Rogers D. 1990. Asymmetrical competition between the bell miner (*Manorina melanophrys*, Meliphagidae) and other honeyeaters: evidence from Southeastern Victoria, Australia. *Oecologia* **85**, 205–256.

Ralph CP, Nagata SE & Ralph J. 1985. Analysis of droppings to describe diets of small birds. *Journal of Field Ornithology* **56**, 165–174.

Recher HF & Holmes RT. 1985. Foraging ecology and seasonal patterns of abundance in a forest avifauna. In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation and Management* (eds A Keast, HF Recher, H Ford & D Saunders), pp. 79–96. Surrey Beatty & Sons Pty Limited and The Royal Australasian Ornithologists Union, Chipping Norton, NSW, Australia.

Recher HF & Majer JD. 2006. Effects of bird predation on canopy arthropods in wandoo *Eucalyptus wandoo* woodland. *Austral Ecology* **31**, 349–360.

Roberts RJ. 1972. A newly recognized form of pasture damage by *Phaulacridium vittatum* (Acrididae) on the Northern Tablelands of NSW. *Journal of the Australian Entomological Society* **11**, 257–258.

Rosenberg KV & Cooper RJ. 1990. Quantification of diets approaches to avian diet analysis. *Studies in Avian Biology* **13**, 80–90.

Ryan PA. 2000. The use of revegetated areas by vertebrate fauna in Australia: a review. In: *Temperate Eucalypt Woodlands in Australia* (eds RJ Hobbs & CJ Yates), pp. 318–335. Surrey Beatty & Sons, Chipping Norton, NSW, Australia.

Sivertsen D & Clarke PJ. 2000. Temperate woodlands in New South Wales: a brief overview of distribution, composition and conservation. In: *Temperate Eucalypt Woodlands in Australia* (eds RJ Hobbs & CJ Yates), pp. 6–16. Surrey Beatty & Sons, Chipping Norton, NSW, Australia.

Strong AM, Sherry TW & Holmes RT. 2000. Bird predation on herbivorous insects: indirect effects on sugar maple saplings. *Oecologia* **125**, 370–379.

Tame T. 1992. *Acacias of Southeast Australia*. Kangaroo Press, Kenthurst, NSW, Australia.

Whitaker JO Jr. 1988. Food habits analysis of insectivorous bats. In: *Ecological and Behavioral Methods for the Study of Bats* (ed. TH Kunz), pp. 171–189. Smithsonian Institution Press, Washington, USA.

Woinarski J. 1985. Foliage-gleaners of the Treetops, the Pardalotes. In: *Birds of Eucalypt Forests and Woodlands: Ecology, Conservation and Management* (eds A Keast, HF Recher, H Ford & D Saunders), pp. 165–175. Surrey Beatty & Sons Pty Limited and The Royal Australasian Ornithologists Union, Chipping Norton, NSW, Australia.

Wurtz TL. 1995. Domestic geese: biological weed control in an agricultural setting. *Ecological Applications* **5**, 570–578.

Accepted for publication 9 April 2007.