Native and exotic flower visitors in the Christchurch Botanic Gardens and their contrasting plant preferences

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Abstract

The Christchurch Botanic Gardens in New Zealand provide a landscape of closely intermixed native and exotic plants. This site was ideal for the study of bird and insect flower visitors and their relative importance for plant regeneration. Thirty-seven species of native and exotic plants were chosen to determine the frequency of bird and insect visitation rates. From these data, plant preferences of native and exotic flower visitors were investigated. A total of 24 insect species from 5 orders were observed. Over 50% of all insect visits were made by the native bee *Lasioglossum sordidum*. Native insects were found to prefer native plants (70.1% of visits), whereas exotic insects preferred exotic plants (70.4% of visits). Silvereyes (*Zosterops lateralis*) were the main bird flower visitors, and showed no preferences for native vs exotic plants. Exotic birds made up less than 5% of all plant visits, consistent with their relative unimportance to pollination in other New Zealand studies.

Key words: Pollination – native – exotic – Coleoptera – Diptera – Hymenoptera – Lepidoptera

Introduction

The ecosystem service of pollination by animals is important on a global scale, both for biodiversity, and for human welfare as 35% of global crop production is dependent on pollinators (Klein *et al.* 2007). In New Zealand, insects are the main pollinators of commercial crops and also play an important role in the pollination of native plants (Kelly *et al.* 2006; Donovan 2007). New Zealand pollinators include native and exotic bees, flies, moths, butterflies, beetles, and several bird species (Newstrom & Robertson 2005). Bees of the Apoidea superfamily are of particular importance. New Zealand has 40 species of bee, 27 being native and 13 having arrived since European settlement (Donovan 2007; Donovan & Maynard 2010). Eight species (*Apis mellifera, Bombus terrestris,*

B. hortorum, B. ruderatus, B. subterraneus, Megachile rotundata, Nomia melanderi, and *Osmia coerulescens*) were purposely imported from the Northern Hemisphere to aid in crop pollination (Donovan 2007). The honey bee (*A. mellifera*) is heavily relied upon for pollination of seed, vegetable, fruit crops and pastures (Howlett & Donovan 2010). With the spread of the varroa mite (*Varroa destructor*) throughout New Zealand recent research has focussed on the effectiveness of alternative pollinator taxa, such as native bee species and flies (Rader *et al.* 2009).

Recent research on bird-plant mutualisms and pollination in New Zealand has shown that native birds are more important pollinators than previously thought. Godley (1979) proposed that since many New Zealand flowers are not ornithophilous (i.e. structurally resembling typical bird visited flowers), bird visits were most likely to be incidental and resulting in self-pollination. However, birds are now known to frequently visit small-flowered native species (Kelly *et al.* 2010), and fruit production of native plants is reduced when birds are excluded (Anderson 2003).

Introduced birds, such as the chaffinch (*Fringilla coelebs*) and house sparrow (*Passer domesticus*) made less than 5% of flower and fruit visits to native plants in a recent review (Kelly *et al.* 2006). Of the native birds, there were four species which regularly visited flowers: bellbird (*Anthornis melanura*), tui (*Prosthermadera novaeseelandiae*), stitchbird (*Notiomystis cincta*) and silvereye (*Zosterops lateralis*). Silvereyes were reported to be responsible for 31% of all flower visits to native plants; stitchbirds were important where present, but are now very restricted in distribution (Kelly *et al.* 2006). Native birds have also been seen regularly visiting exotic plants (Newstrom & Robertson 2005). With large declines in bird numbers both worldwide and within New Zealand's native bird fauna (Şekercioğlu *et al.* 2004), preferences of native and exotic birds towards native plants can be used to give an indication of the extent to which pollination may become limited.

Our research aimed to determine the relative importance of native and exotic pollinators (both insects and birds) to native and exotic plants based on the frequency of visits to flowers. We investigated to what extent native and exotic flower visitors show preferences towards different plant species in the urban setting of the Christchurch Botanic Gardens (CBG) where both native and exotic plants were abundant. We identified insects to species level where possible in order to add knowledge of the species identity of flower visitors in this urban setting.

Methods

Site and plant selection

This study was conducted at the Christchurch Botanic Gardens (CBG; 43.53°S, 172.6°E) in central Christchurch, New Zealand. The CBG cover an area of 21 ha and contain large collections of both exotic and native plant species (Christchurch Botanic Gardens Management Plan, http://wwwlocal.ccc.govt.nz, date accessed 7th Feb 2012). The surrounding urban area has numerous gardens containing native and exotic plants less than 1 km distant although separated by the open, mown parkland of Hagley Park; the closest remnant of

native forest vegetation is Riccarton Bush 2 km to the west. These plants are divided between smaller garden areas with similar plants grown together: exotic plants concentrated in the Herbaceous Border and native plants in the New Zealand Gardens. An approximately equal number of native and exotic plant species were chosen for both insect and bird observations. In order to maximise the amount of insect data collected, the plant species chosen were those which were seen to have frequent insect visitors, and which gained full exposure to the sun at midday. Plant species used for bird observations were chosen based on previous sightings of birds feeding on nectar, or species known from previous research to attract bird visitors.

Insect observation

Observations were carried out once per day in the early afternoon. Although insect visitors vary temporally, preliminary observations indicated the highest volume of insect activity as this time of day. Thus, this time of day was used in order to capture as much information as possible from single observations. Observations were taken under warm and dry weather conditions, with a small amount of cloud or wind. Overcast, windy or rainy days where the foraging activity of certain species could be limited were discounted to prevent skewing of the data. An instantaneous sampling method was used, where the numbers and identity of all insects in or on the flowers at the time of approach were recorded. To remove any potential size bias when observing larger plants, a subsection of approximately 2 m x 2 m was observed (as in Burgess *et al.* 2006). Insects were identified as close as possible to species level through a combination of sight, photographs and collected specimens. Species such as *Apis mellifera* were easily recognised and therefore identified by sight. Unknown insects were caught using a sweep net and given a tag number. These insects were later identified through the use of identification keys (Klimaszewski *et al.* 1997; Donovan 2007; Thompson 2008; Landcare Research http://www.landcareresearch.co.nz/research/biocons/pollination/documents/Insect_Guide.pdf accessed 15 Nov 2011) and expert advice (Brad Howlett pers. comm.). Where possible, photographs of insects were taken to aid in identification. Pinned samples of the main insects identified have been retained in the School of Biological Sciences, University of Canterbury invertebrate collection.

Bird observations

Each plant species was watched once per day for a period of 15 minutes during the late afternoon. Observations were recorded of any 'flower visitors', defined as a bird approaching a flower with or without incidental pollination (Kelly *et al.* 2006). The amount of time each bird spent at the plant was also recorded, along with any feeding behaviour. For this project, silvereyes were classified as native flower visitors, as their arrival in New Zealand in 1856 occurred without direct human assistance (Heather & Robertson 1996). It is important to note that silvereyes have not been in New Zealand long enough to have affected the evolution of flower characteristics (Godley 1979), although they are widespread and are now the most common bird visitor to the flowers of native plants (Kelly *et al.* 2006).

Table 1. Native and exotic plant species used for visitor observations.

(a) bird-visited plants

Exotic	**Native**
Callistemon polendii	*Knightia excelsa*
Callistemon citrinus	*Leptospermum scoparium*
Callistemon viminalis	*Weinmannia racemosa*
Lobelia tupa	*Phormium cookianum*
Kniphofia uvaria	*Sophora microphylla*
	Clianthus maximus

(b) insect-visited plants

Exotic	**Native**
Callistemon polendii	*Hebe salicifolia*
Melaleuca wilsonii	*Hebe* 'Wiri Joy'
Bulbine semibarbata	*Hebe* 'Wiri Mist'
Contoneaster horizontalis	*Hebe* 'Patty's Purple'
Weigela 'Florida variegata'	*Hebe* 'Autumn Snow'
Deutzia scabra cultivar	*Hebe franciscana*
Campanula sp.	*Brachyglottis greyi*
Crambe cordifolia	*Muehlenbeckia astonii*
Francoa appendiculata	*Pachystegia insignis*
Hydrangea macrophylla	*Lophomyrtus x ralphii*
Eryngium cultivar	*Leptospermum scoparium*
Salvia verticillata	
Salvia pratensis cultivar	
Stachys cretica ssp. *cassia*	
Leptospermum nitidum	

Data analysis

As very few exotic birds were observed visiting flowers, no statistics were calculated comparing bird visitors. For insect flower visitors, we tested whether there were overall numerical preferences for one type of plant (native vs exotic) among the two groups of insects (native vs exotic) with a chi-square test. Insects and plants were grouped into native or exotic, and the total visitors recorded for each combination was tallied. As all visitors were recorded at each plant observed, the exact number of visitors to a particular plant, and the exact numbers of plant species observed in each group, will not affect this test of relative preferences.

Figure 1. The six most common flower visitors encountered at the Christchurch Botanic Gardens, in order of abundance. A Native solitary bee *Lasioglossum sordidum*, c. 6 mm long, on exotic daisy; B exotic bumblebee *Bombus terrestris*, c. 20 mm long, on exotic *Cotoneaster horizontalis*; C exotic honeybee *Apis mellifera*, c. 11 mm long, on exotic *Leptospermum nitidum*; D native march fly *Dilophus nigrostigma*, c. 10 mm long, on native *Hebe* species; E native black hoverfly *Melangyna novaezelandiae*, c. 10 mm long, on native *Brachyglottis greyi*; F native solitary bee *Leioproctus monticola*, c. 11 mm, on native *Pachystegia insignis* (Photos Christie J. Webber and Finn K. Sumner). Specimens are deposited in the University of Canterbury collection.

Results

In total, bird visitors to 5 exotic and 6 native plants were observed, and insect visitors to 15 exotic and 11 native plant taxa, including some horticultural cultivars in both cases (Table 1). We observed visitors to all plant species, equally divided in species diversity between natives and exotics for both birds (3 native species, 3 exotics) and insects (12 native taxa of which 10 were identified to species, and 12 exotic species [Table 2]).

Bird observations

Over 95% of visits to both exotic and native plants were by native birds (silvereyes, bellbirds and fantails). Silvereyes were the most frequent bird visitors to all plant species observed, except for *Phormium cookianum* where 57.1% of visits were by bellbirds (Table 3). Of the exotic plants, *Lobelia tupa* and all *Callistemon* species were visited exclusively by silvereyes. Three species of exotic birds were observed: starlings occasionally visited *Knightia excelsa*, redpolls were seen on *Phormium cookianum*, and chaffinches visited *Kniphofia uvaria* (Table 3). Most frequently visited was the exotic plant *Callistemon citrinus*, with an average of 12 silvereye visits per 15 min observation. It was also the plant on which silvereyes spent the most time (Table 4).

Insect observations

Large numbers of insects were recorded

Table 2. Details of all insect taxa observed.

	Order	Family	Genus	Species	Common name
Native	Odonata	Coenagrionidae	*Xanthocnemis*	*zealandica*	Damselfly
	Coleoptera	Cerambycidae	*Zorion*		Flower longhorn
	Coleoptera	Melyridae	*Dasytes*		Flower beetles
	Diptera	Syrphidae	*Melangyna*	*novaezelandiae*	Black hoverfly
	Diptera	Syrphidae	*Helophilus*	*trilineatus*	Threelined hoverfly
	Diptera	Syrphidae	*Helophilus*	*cingulatus*	
	Diptera	Bibionidae	*Dilophus*	*nigrostigma*	March fly
	Lepidoptera	Nymphalidae	*Vanessa*	*itea*	Yellow admiral
	Hymenoptera	Halictidae	*Lasioglossum*	*sordidum*	
	Hymenoptera	Colletidae	*Leioproctus*	*fulvescens*	
	Hymenoptera	Colletidae	*Leioproctus*	*monticola*	
	Hymenoptera	Colletidae	*Hylaeus*	*relegatus*	
Exotic	Diptera	Syrphidae	*Eristalis*	*tenax*	European drone fly
	Diptera	Syrphidae	*Merodon*	*equestris*	Narcissus bulb fly
	Diptera	Calliphoridae	*Calliphora*	*stygia*	Australian brown blowfly
	Diptera	Calliphoridae	*Lucilia*	*sericata*	European green blowfly
	Lepidoptera	Nymphalidae	*Danaus*	*plexippus*	Monarch butterfly
	Lepidoptera	Pieridae	*Pieris*	*rapae*	Cabbage white butterfly
	Hymenoptera	Apidae	*Apis*	*mellifera*	Honey bee
	Hymenoptera	Apidae	*Bombus (Bombus)*	*terrestris*	Two banded bumble bee
	Hymenoptera	Apidae	*Bombus (Megabombus)*	*hortorum*	Garden bumble bee
	Hymenoptera	Eumenidae	*Ancistrocerus*	*gazella*	European tube wasp
	Hymenoptera	Pompilidae	*Sphictostethus*	*nitidus*	Golden hunting wasp
	Hymenoptera	Megachildae	*Anthidium*	*manicatum*	Wool carder bee

on the plants (3838 in total, excluding 3 visits by moths that were not collected and so could not be identified). Although some beetles, butterflies and flies were seen, the majority of flower visitors were bees (both native and exotic). *Lasioglossum sordidum* was the most common flower visitor, contributing 50.3% of all native and exotic visits. March flies (*Dilophus nigrostigma*) made 5.7% of all visits, and black hoverflies (*Melangyna novaezelandiae*) made 3.4%. The most frequent exotic insect visitors were *Bombus* spp. (21.6% of visits), followed by *A. mellifera* (10.1%). The full list of insects observed on each plant is given in Appendix 1.

Native insects were more likely to visit native plants (70.1% of 2468 visits), whereas exotic insects were more likely to visit exotic plants (70.4% of 1370 visits) and this difference was highly significant ($x^2 = 585.6$, $df = 1$, $p < 0.001$).

Table 3. Percentage of all visits by each bird to native and exotic plant species.

		Percentage of all visits	Total no. of bird visits
Native	*Knightia excelsa*	98 % silvereye 2 % starling	55
	Leptospermum scoparium	100 % silvereye	5
	Weinmannia racemosa	83 % silvereye 17 % fantail	6
	Phormium cookianum	57 % bellbird 29 % silvereye 14 % redpoll	7
Exotic	*Callistemon polendii*	100 % silvereye	15
	Callistemon citrinus	100 % silvereye	36
	Callistemon viminalis	100 % silvereye	33
	Lobelia tupa	100 % silvereye	7
	Kniphofia uvaria	75 % silvereye 8 % chaffinch 7 % bellbird	12

Discussion

The main finding from the bird observation data is that native birds were the predominant visitors to both native and exotic plants, and silvereyes were the most important flower visiting species. This indicates that introduced birds are relatively unimportant as pollination mutualists, as also found by Kelly *et al.* (2006). Visits to eight of the nine plant species consisted almost entirely of silvereyes. Chaffinches showed the highest contribution of visits by exotic species, with 8.3% of visits to *K. uvaria*. Visits to *W. racemos*a by fantails (*Rhipidura fuliginosa*, 16.7% of visits) may not be contributing to pollination, as fantails are mainly insectivorous (Clout & Hay 1989), although there are previous records of them visiting flowers and consuming fruit (O'Donnell & Dilks 1994; Kelly *et al.* 2006; T. Wyman pers. comm.; A. Macfarlane pers. comm.).

The data show that silvereyes are a generalist species, visiting both native and exotic plants. For some exotic plants such as the various *Callistemon* species, silvereyes were the only bird flower visitors. Bellbirds were observed visiting ornithophilous flowers of both exotic and native species (*P. cookianum* and *K. uvaria*), which has also been commonly observed in other studies (Kelly *et al.* 2006), but were still relatively rarely recorded on our study plants despite being resident in the CBG and regularly heard calling.

In contrast, the insect data showed that native insects were more likely to visit native plants, and introduced insects were more likely to visit exotic plants. Native bees made over half of all insect visits to flowers, and were the most abundant group, even though the CBG constitutes

Table 4. Bird visitors to flowers of native and exotic plants with the average number of bird visitors of each species within 15 min time period (±), as well as the average length of visit (±).

	Plant species	Bird species	Mean no. of birds per obs.	Mean duration of visit (s)
Native	*Knightia excelsa*	Silvereye	6.88 ± 5.79	518 ± 359
		Starling	0.13 ± 1.00	1.50 ± 10.5
	Leptospermum scoparium	Silvereye	2.00 ± 0.87	20.0 ± 8.66
	Weinmannia racemosa	Silvereye	1.25 ± 0.42	111 ± 18.3
		Fantail	0.25 ± 0.75	67.8 ± 203
	Phormium cookianum	Bellbird	1.00 ± 0.71	8.50 ± 9.25
		Silvereye	0.50 ± 1.50	27.0 ± 81.0
		Redpoll	0.25 ± 0.75	1.75 ± 5.25
Exotic	*Callistemon polendii*	Silvereye	5.00 ± 1.63	703 ± 152
	Callistemon citrinus	Silvereye	12.0 ± 9.72	739 ± 162
	Callistemon viminalis	Silvereye	8.25 ± 2.73	497 ± 203
	Lobelia tupa	Silvereye	2.34 ± 1.24	124 ± 81.1
	Kniphofia uvaria	Bellbird	0.50 ± 0.43	41.0 ± 63.0
		Chaffinch	0.25 ± 0.75	4.50 ± 13.5
		Silvereye	2.25 ± 0.63	107 ± 42

a heavily modified landscape. This finding supports Newstrom and Robertson's assertion (2005) that New Zealand plants rely on pollination from a high proportion of indigenous pollinators. The results are also similar to those of Kelly *et al.* (2006), who found that introduced Hymenoptera (*A. mellifera*, *Bombus* spp. and *V. vulgaris*) contributed to around a quarter of visits to native flowers.

The native plant *Muehlenbeckia astonii*, whose tiny green flowers measure 2-3 mm across, was visited by only the small native bee *L. sordidum*. This exclusive relationship could result from the plant's inability to attract other pollinators as *L. sordidum* was recorded visiting a total of 23 native and exotic plants (Appendix 1). Most plant species were visited by a mixture of native and exotic insects, showing that insect preferences are not always exclusive.

Both native and exotic pollinating species were identified visiting flowers in the CBG. Little is currently known about what impacts introduced *A. mellifera* and *Bombus* species have on the native bee species of New Zealand. Howlett and Donovan (2010) suggest there is potential for competition for floral resources between the native and exotic pollinators as there is an overlap in the plant species they visit. Our results show that in the CBG native flower visitors are more likely to visit native plants and exotic flower visitors are more likely to visit exotic plants,

which would reduce the potential for competition for floral resources. Of the four native bee species identified, three are ground-nesting (*Leioproctus fulvescens, L. monticola* and *Lasioglossum sordidum*) and the fourth (*Hylaeus relegatus*) nests within plant material. Therefore, there would be no competition with exotic species for nesting sites (Donovan 1980; Donovan 2007).

Although there is the potential for interference competition among pollinators from aggressive behaviour, a previous study found very little evidence for this between *Vespula* spp. and *A. mellifera* in the Canterbury foothills (Markwell *et al.* 1993) However, that conclusion may not apply to a new exotic species. The presence of the wool carder bee (A*nthidium manicatum*) in the CBG is of particular interest because to our knowledge these are the first published sightings of this species in the Canterbury region. *Anthidium manicatum* was first found in New Zealand on 28 January 2006 in Napier (Donovan 2007). Males of this species patrol an area of flowers from which they drive other flower visitors away (especially *A. mellifera* and *Bombus* spp.) by dive-bombing them, apparently to protect floral resources for visiting female *A. manicatum* (Donovan 2007). We observed *A. manicatum* on only one plant species (*Stachys cretica* ssp. *cassia*) and on several occasions saw displays of its aggressive behaviour. The potential impacts of *A. manicatum* on native and exotic pollinators are yet to be assessed, but Soper (2011) has begun such studies.

As in Kelly *et al.* (2006), *A. mellifera* was not the most frequent flower visitor. The native *L. sordidium* and the exotic *Bombus* species were both recorded visiting flowers more often. This finding is consistent with the current worldwide decline of *A. mellifera* caused by the combined impacts of Colony Collapse Disorder and the Varroa destructor mite (Rader *et al.* 2009). Overall, our results are surprising both for the high diversity and abundance of native flower visitors in a central-city, managed landscape, and for the relative (although not absolute) specialisation of both exotic and native insects on exotic and native plants, respectively.

Study limitations

As our study was purely observational, conclusions could not be made on the pollination efficiency of flower visitors. Further studies on the effectiveness of bird pollination at the CBG could be carried out by determining the pollination limitation index for plant species studied. This would give a better indication of the relative importance of native bird pollinators, and implications of their preferences.

Insect species display temporal variation in flower visitation and therefore a single sample per day is unlikely to capture the full array of species present and their abundances. Multiple samples of the same plants throughout the day would give a better indication. Although weather was considered when sampling, more accurate measures such as recorded temperature could insure consistency and non-biased sampling. These limitations of our insect observations are important but the study still provides useful information on which further research can be built.

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References

Anderson, S.H. (2003). The relative importance of birds and insects as pollinators of the New Zealand flora. *New Zealand Journal of Ecology* 27: 83-94.

Burgess, V.J., Kelly, D., Roberston, A.W. & Ladley, J.J. (2006). Positive effects of forest edges on plant reproduction: literature review and a case study of bee visitation to flowers of *Peraxilla tetrapetala* (Loranthacae). *New Zealand Journal of Ecology* 30: 179-190.

Clout, M.N. & Hay, J.R. (1989). The importance of birds as browsers, pollinators and seed dispersers in New Zealand forests. *New Zealand Journal of Ecology* 12: 27-33.

Donovan, B.J. (1980). Interactions between nactive and introduced bees in New Zealand. *New Zealand Journal of Ecology* 3: 104-116.

Donovan, B.J. (2007). *Apoidea (Insecta: Hymenoptera)*. Fauna of New Zealand 57, Manaaki Whenua Press, Lincoln, New Zealand.

Donovan, B.J. & Maynard G.V. (2010). The New Zealand native bee *Leioproctus* (*Leioproctus*) *otautahi* Donovan (Hymenoptera: Apoidea: Colletidae) is synonymous with *Leioproctus* (*Leioproctus*) *launcestonensis* (Cockerell) from Australia. *New Zealand Entomologist* 33: 17-18.

Godley, E.J. (1979). Flower biology in New Zealand. *New Zealand Journal of Botany* 17: 441-466.

Heather, B.D. & Robertson, H.A. (1996). *The Field Guide to the Birds of New Zealand.* Viking, Auckland, New Zealand.

Howlett, B.G., & Donovan, B.J. (2010). A review of New Zealand's deliberately introduced bee fauna: current status and potential impacts. *New Zealand Entomologist* 33: 92-101.

Kelly, D., Ladley, J.J., Robertson, A.W., Anderson, S.H., Wotton, D.M. & Wiser, S.K. (2010). Mutualisms within the wreckage of an avifauna: the status of bird pollination and fruit dispersal in New Zealand. *New Zealand Journal of Ecology* 34: 66-85.

Kelly, D., Robertson, A. W., Ladley, J.J., Anderson, S.H. & McKenzie, R.J. (2006). Relative (un)importance of introduced animals as pollinators and dispersers of native plants. *Ecological Studies* 186: 227-245.

Klein, A., Vaissière, B.E., Cane, J.H., Dewenter, I.S., Cunningham, S.A., Kremen, C. & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. P*roceedings of the Royal Society B: Biological Sciences* 274: 303–313.

Klimaszewski, J, Watt, J.C. & Helmore, D.W. (1997). *Coleoptera: family-group review and keys to identification.* Fauna of New Zealand 37, Manaaki Whenua Press, Lincoln, New Zealand.

Markwell, T.J., Kelly, D. & Duncan, K.W. (1993) Competition between honey bees (*Apis mellifera*) and wasps (*Vespula* spp.) in honeydew beech (*Nothofagus solandri* var *solandri*) forest. *New Zealand Journal of Ecology* 17: 85-93.

Newstrom, L. & Roberston, A.W. (2005).

Progress in understanding pollination systems in New Zealand. *New Zealand Journal of Botany* 43: 1-59.

O'Donnell, C.F.J. & Dilks, P.J. (1994). Foods and foraging of forest birds in temperate rainforest, South Westland, New Zealand. *New Zealand Journal of Ecology* 18: 87-107.

Rader, R., Howlett, B.G., Cunningham, S.A., Westcott, D.A., Newstrom-Lloyd, L.E., Walker, M.K., Teulon, D.A.J. & Edwards, W. (2009). Alternative pollinator taxa are equally efficient but not as effective as the honeybee in a mass flowering crop. *Journal of Applied Ecology* 46: 1080–1087.

Şekercioğlu, C. H., Daily, G.C. & Ehrlich, P.R. (2004). Ecosystem consequences of bird declines. *Proceedings of the National Academy of Sciences of the United States of America* 52: 18042-18047.

Soper, J.-A. (2011) The distribution and potential impacts of the wool-carder bee (*Anthidium manicatum*) in New Zealand. Unpublished M.Sc. thesis, University of Auckland, New Zealand.

Thompson, F.C. (2008). A conspectus of New Zealand flower flies (Diptera: Syrphidae) with the description of a new genus and species. *Zootaxa* 1716: 1–20.

Appendix 1 Full details of insect visitors to native and exotic plants.

	Exotic insects									
	Bumble bee	Honey bee	European tube wasp	Golden spider hunter wasp	Wool carder	Blowflies	Drone fly	Bulb fly	Monarch	Cabbage butterfly
Exotic plants										
Callistemon polendii	42	54	1			1				
Melaleuca wilsonii	11	17				1				
Bulbine semibarbata	16	1				5				
Cotoneaster horizontalis	72	10	2			5	10		1	1
Weigela 'Florida Variegata'	16	3				3	2		3	1
Deutzia scabra	22	2				1	3	1		
Campanula	17	11	4			3	1			
Crambe cordifolia	5						1			
Francoa appendiculata	3	11					1			
Hydrangea macrophylla	74	2				1	2			
Eryngium cultivar	34	58					7			
Stachys cretica ssp. *cassia*	167	2			16					
Salvia pratensis cultivar	14	85								
Salvia verticillata	40	30					1			
Leptospermum nitidum	41	16	1				6		3	
Native plants										
Hebe salicifolia	7	19				1				1
Hebe 'Wiri Joy'	27	13	6			1	3			
Brachyglottis greyi	14	11				1	10			2
Hebe franciscana	3	12	2	3		1	1			
Muehlenbeckia astonii										
Pachystegia insignis	7									
Lophomyrtus x ralphii	1									
Hebe 'Patty's Purple'	43	15	6			4				
Hebe 'Wiri Mist'	117	15	4			1	10			
Hebe 'Autumn Snow'	20		2							
Leptospermum scoparium	15	2	2				3		1	

Appendix 1 continued. Full details of insect visitors to native and exotic plants.

	Native insects											
	L. fulvescens	*H. relegatus*	*L. monticola*	*Lassioglossum sordidum*	Black hoverfly	Threelined hoverfly	*H. cingulatus*	March fly	Damselfly	Yellow admiral	Flower Beetle	Flower longhorn
Exotic plants												
Callistemon polendii				39	3			5				
Melaleuca wilsonii					6							1
Bulbine semibarbata				9				14		1		
Cotoneaster horizontalis				1	22	1		1		1	1	
Weigela 'Florida Variegata'					1			21		1		
Deutzia scabra			1	3	1		2	5	6			11
Campanula				2	4							
Crambe cordifolia			11	17	5			10			1	
Francoa appendiculata			6	189	2							
Hydrangea macrophylla				102	3							
Eryngium cultivar				131	3						3	3
Stachys cretica ssp. *cassia*				1	2				1			
Salvia pratensis cultivar												
Salvia verticillata				3	2							
Leptospermum nitidum			1	15	4	1		41		17		
Native plants												
Hebe salicifolia		5	16	167		1					2	1
Hebe 'Wiri Joy'		2	24	142	7							
Brachyglottis greyi	13		8	144	3							
Hebe franciscana		1	2	162	2				1			
Muehlenbeckia astonii				470	1							
Pachystegia insignis	13		4	16	7							
Lophomyrtus x ralphii				38	8							
Hebe 'Patty's Purple'				82	11			2		1	1	
Hebe 'Wiri Mist'			1	134	15	2	1	20		7		
Hebe 'Autumn Snow'			2	55	12			2		1	2	
Leptospermum scoparium				10	7			97		3	3	