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Hedging our bets: choosing hedgerow plants to enhance beneficial insects to optimise crop pollination and pest management on Canterbury farms

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We undertook a desk-top study to examine the associations between plants, insect herbivores, their natural enemies and pollinators to evaluate the potential of using perennial plant assemblages on non-productive areas of a farm to maximise the establishment and abundance of beneficial insects. Pollination and pest suppression are key on-farm services provided by beneficial insects (pollinators, predators, and parasitoids). Yet the potential of beneficial insects to provide these essential services is often not realised because they are absent or low in numbers, generally due to historical management practices.

Based on database (Plant Synz) and general internet searches, the present study revealed that many of the native plants examined are superior to existing hedgerow and shelterbelt species growing in Canterbury for their associations with pollinating insect species.

- Only two pollinating species, *Apis mellifera* and *Bombus terrestris*, were found to be associated with *Pinus radiata* or *Ulex europaeus*, while none were found associated with *Cupressus macrocarpa*, the three most common shelterbelt or hedgerow species in Canterbury.

- Seventeen of 45 pollinator species are associated with both exotic and native (including endemic) plant species.

As for native plants acting as pest reservoirs, 41 insect pest species (out of 961 herbivorous species) were common to some of the native and exotic plant species included in this study. Eighteen were endemic (only found in New Zealand) or native, and 26 were exotic species. The vast majority of the 122 pest species identified in this study are not found in vegetable or arable crops.

With regards to native plants becoming weeds, there was no information suggesting that the native plant species listed in Appendix 1 could become or had ever been described as weeds, unlike *P. radiata* and *U. europaeus*, which are well known weeds in New Zealand.

From a beneficial insect perspective, evidence to date suggests improving resources for pollinators (e.g. food, habitats for establishing populations) may bring about the most obvious benefits at the farm scale.

While there is also potential for natural enemies from surrounding non-crop vegetation to attack pests in a crop, how many and how far such insects will move into the crop, and how mortality factors (e.g. hyperparasitism, intraguild predation) will affect their ability to suppress pest populations is not known.

This study provides a starting point for exploring plant–insect herbivore–beneficial insect associations and interactions. The associations outlined in the current research need to be verified in the field. Results suggest that the use of native plant species in non-productive areas has promise, but further research is required to confirm this. For example, it would be helpful to determine how far beneficial insects may move out of these native plant assemblages into the crop and whether the floral resources from the native plants provide optimal nutrition for

beneficial insects. Beyond the entomological questions, consideration should also be given to other factors that may promote or limit their use. These include:

- the accessibility and cost-effectiveness of such native plant species relative to exotic species
- the ability to quickly and easily establish the identified plants
- how well they fit within the non-productive areas
- how they may compete with or overshadow neighbouring crop plants
- how they may affect livestock that may feed on them
- what pathogens may be associated with the plants.

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1 Introduction

We examined the associations between plants, insect herbivores, their natural enemies and pollinators to evaluate the potential for using perennial plant assemblages on non-productive areas of farms to maximise the establishment and abundance of beneficial insects. Pollination and pest suppression are key on-farm services provided by beneficial insects (pollinators, predators, and parasitoids). Yet the potential of beneficial insects to provide these essential services is often not realised because they are absent or low in numbers, generally due to historical management practices. Pest management strategies and honey bee pollination may be compatible with the use of "natural" beneficial insects, although greater scientific knowledge is needed to understand how this could be achieved. The aim of this project was to identify optimal host plant associations that could maximise and support stable populations of beneficial insect species.

Beneficial insects have great potential to suppress insect pests and/or pollinate crops. For example, the predatory brown lacewing significantly reduced aphid levels in outdoor lettuces and was critical to the success of the integrated pest management programme (Walker et al. 2007). Increasing costs associated with honey bee management (up to $0.5 B to New Zealand's agricultural industries over the next 15 years (MAF 2000, 2002)) may threaten the viability of some industries unless alternative pollinating species are encouraged. Recent research has demonstrated the benefit that many unmanaged bees and flies can provide to crop pollination in New Zealand (Rader et al. 2009). Introducing the right combination of indigenous vegetation into non-productive areas (e.g. hedgerows), could sustain larger populations of beneficial insect species while inhibiting pest populations (Altieri 1999).

We determined the species composition of insect herbivores (pests and non-pests) associated with a range of crop plants, and existing hedgerow and shelterbelts composed of non-native species (predominantly *Pinus radiata*, *Cupressus macrocarpa* and *Ulex europaeus*) in Canterbury. In the early 1990s hedges and shelterbelts on the Canterbury Plains were predominantly made up of these three exotic species and extended to a combined length of almost 300,000 km (Price 1993). We compared insect associations of these plant species with those of native plant species that could be used as alternative hedgerows, shelterbelts, or in other areas of non-productive land. We wanted to see if native plants would be less likely to act as a reservoir for crop pests than non-native species. We then examined the relationships of natural enemies and pollinators with native and/or exotic hosts (plant and/or insect species). The associations between plants and their herbivores was examined using current information to determine: 1) if the plants could support exotic insect pests, 2) whether the alternative prey/hosts of the native predators and parasitoids could become pests on nearby crops, and 3) whether the biology of the plants would limit/negate their ability to become weeds.

2 Methods

We accessed all available published and unpublished information via the PlantSynz database and the internet in general and identified: 1) native plant species which would support beneficial insects, 2) common pest species and their host plants (both native and exotic), and 3) beneficial insect species. “Beneficial insects” were defined in this study as all known insect pollinators and natural enemies (parasitoids and predators) of pest species commonly found on vegetable and arable crops grown within Canterbury.

We determined the numbers and origins (native and endemic, or exotic) of pest and non-pest herbivorous species associated with economically important exotic plants, native plants, and existing shelterbelt and hedgerow plant species. The term endemic describes species that are found only in New Zealand. We focussed on economically important exotic plant species. We defined “non-pest insects” as plant-feeding insect species that may be associated with the plant but do not require active management and “pests” as plant-feeding insect species that have to be controlled or managed. Economically important plants included vegetable, arable, horticultural and agricultural (e.g. grass) species. An association between a plant and an insect herbivore (non-pest or pest) occurred where at least one life stage of the insect could feed on a plant species without being harmed and could pass on to the next life stage or lay fertile eggs. For pollinators, an association occurred where an insect species visited and foraged (collected nectar or pollen) from a flower.

We then summarised information on: a) the associations between beneficial insects and plants, b) whether native plants could become a reservoir for insect pests from within the crops, c) whether the insect prey/hosts that support predators/parasitoids on the native plants could become pests on the crop, d) species composition of native pollinators, e) when flowering of native plants occurs, and f) the likelihood of the native plant species becoming weeds.

3 Results

We looked at the insects associated with 103 native plant species, 41 exotic species, and 3 exotic species commonly used in shelterbelts and hedgerows, including the economically important species *P. radiata*. The vegetable and arable crops included in the present study were: *Brassica oleracea, B. rapa, Solanum tuberosum, Alium cepa, Raphanus sativus, Cucurbita moschata, Pisum sativum, Daucus carota, Cucurbita pepo, Cucurbita moschata, Triticum aestivum, Avena sativa, Hordeum vulgaris, Medicago sativa,* and *Trifolium* sp. (seed).

We derived our native (and endemic) plant species list from information we could gather on those plants with which insect pollinators may be associated (Table 1). We limited the list to plant species known to grow in the South Island, particularly Canterbury, assuming that these species would have the best chance to establish in Canterbury. There is very little information on possible plant associations with natural enemies (predators and parasitoids). Consequently, we have listed the prey or host associations with predators and parasitoids commonly found in vegetable and arable crops (Table 2). We also determined the number of species of herbivorous insects from the different orders that predators may feed on, associated with native plants listed in Table 1, and the predominant shelterbelt and hedgerow species in Canterbury (Table 3). Not surprisingly, the more plant species there are, the greater the number of herbivorous insect species and potential prey for generalist predators. Of particular note are the high number of non-pest Hemiptera (191 species) associated with the 44 native plant species examined, while only one hemipteran species was associated with one of the three exotic plant species. Hemiptera, which includes aphids, whiteflies, mealybugs and scale insects, may be important prey for a number of generalist predators.

We found 839 herbivorous insect species (pests and non-pests), based predominantly on information in PlantSynz (accessed May and June 2010). An additional 122 insect species described as pests were also found to be associated with the selected plant species (Scott 1984; general internet searches (accessed 4, 5 June 2010)). We also identified an additional 45 species described as pollinators associated with the plant species we examined (Chinn 2005; Donovan 2007; Heine 1937; Howlett & Lankin 2005; Howlett et al. 2009; Lankin & Howlett 2005; Primack 1983; Rader et al. 2009; Walsh 1967). Of those insect species associated with the exotic plant species, including the hedgerow and shelterbelt species, 35 pest species were native or endemic, and 70 pest species were exotic. Of those associated with the native plant species, 21 pest insect species were native or endemic and 35 pest species were exotic. There were 41 pest species common to some of the native and exotic plant species, 18 of which were endemic or native and 26 were exotic insect species (Appendix 1). The vast majority of pests listed in Appendix 1 are not found in vegetable or arable crops.

While a large number of pest species were associated with plant species commonly used in shelterbelts and hedgerows (Table 4), none of these species was described as a pest of vegetable or arable crops (Appendix 2). However, the only pollinators reported to be associated with *C. macrocarpa*, *P. radiata* or *U. europaeus* were *Apis mellifera* and *Bombus mellifera* (Appendix 2),whereas all but one of the insect pollinators listed in Appendix 3 have been found to be associated with native plant species. This may be an underestimate of the range of both exotic and native plants these pollinators could visit.

Table 1: List of plant species associated with pollinators, and of those plant species, numbers of associated insect herbivores and pests (all pests and those pests found in vegetable and arable crops). Numbers in parentheses for pollinator species indicate number of species also described as predators. Only those plants species with distributions in the South Island, particularly within Canterbury, are included.

Plant species	No. pollinator species[a]	No. non-pest species	No. all pest species[b]	No. vegetable, arable[c] pest species
Alectryon excelsus	1	12	6	0[e]
Carmichaelia corrugata	7 (1)	-[d]	-	0
Carmichaelia kirkii	1	-	-	0
Carmichaelia spp.	14	14	4	0
Carpodetus serratus	5	23	4	0
Celmisia spp.	6	5	-	0
Clematis afoliata	1	-	-	0
Clematis paniculata	4	4	1	0
Clematis spp. (Perennial herb)	1	-	-	0
Colobanthus spp. (Perennial herb)	1	3	-	0
Coprosma lucida	1	20	3	0
Coprosma repens	1	14	5	0
Coprosma sp.	3	-	-	0
Cordyline australis	18 (2)	24	7	0
Coriaria arborea	1	11	4	0
Corokia cotoneaster	7 (1)	4	2	0
Corynocarpus laevigatus	1	38	11	0
Cotula spp. (Perennial herb)	3	-	-	0
Discaria toumatou	4	23	-	0
Disphyma sp.	1	-	-	0
Epilobium sp. (Perennial herb)	2	9	-	0
Fuchsia excorticata	2	21	8	1 (*Aulacorthum solani*)
Gentiana spp.	7	3	-	0
Hebe elliptica	9	19	5	1 (*Myzus persicae*)
Hebe loganioides	3	-	-	0
Hebe macrocarpa	5	15	1	0
Hebe salicifolia	18	12	2	1 (*Aphis gossypii*)
Hebe stricta	8 (2)	32	8	2 (*Macrosiphum euphorbiae*, *Myzus persicae*)
Hebe subalpina	9	6	1	0
Hebe traversii	5	-	-	0
Hebes spp.	23 (1)	4	-	0
Helichrysum bellidioides (Perennial herb)	1	-	-	0
Hoheria angustifolia	8	12	1	0
Hoheria glabrata	1	-	-	0
Hoheria populnea	5	26	4	0
Hoheria sexstylosa	4	12	1	0
Hoheria spp.	7 (1)	25	1	0
Kunzea ericoides	21	54	8	0
Leptospermum scoparium	27 (1)	60	6	0
Leucopogon fraseri	5 (1)	5	-	0

Plant species	No. pollinator species[a]	No. non-pest species	No. all pest species[b]	No. vegetable, arable[c] pest species
Lophomyrtus obcordata	8	4	1	0
Melicope simplex	1	8	4	0
Metrosideros spp.	17 (1)	76	14	0
Meuhlenbeckia australis	6	-	-	0
Meuhlenbeckia complexa	3	-	-	0
Meuhlenbeckia spp.	6	-	-	0
Mimulus repens (Perennial herb)	3	-	1	0
Myoporum laetum	2	33	11	1 (*Myzus persicae*)
Myrsine australis	1	33	4	0
Olearia adenocarpa	5 (2)	-	-	0
Olearia avicenniifolia	1	10	-	0
Olearia spp.	15 (2)	17	4	0
Ozothamnus leptophyllus	8	50	5	0
Pachystegia insignis (Perennial herb)	3	-	-	0
Parahebe hulkeana	4	-	-	0
Parahebes spp.	1	2	1	0
Parsonsia heterophylla	1	29	-	0
Pennantia sp.	4	-	-	0
Peraxilla colensoi	2	7	2	0
Phormium tenax	14	34	9	1 (*Aulacorthum solani*)
Pittosporum crassifolium	5 (1)	18	5	2 (*Aphis gossypii, Myzus persicae*)
Pittosporum eugenioides	4	24	5	2 (*Macrosiphum euphorbiae, Trialeurodes vaporariorum)*
Pittosporum tenuifolium	4	47	8	1 (*Aphis* craccivora)
Pseudopanax crassifolium	2	26	2	0
Pseudopanax spp.	3	-	-	0
Raoulia sp. (Perennial herb)	8	-	-	0
Rubus australis	1	17	1	0
Rubus schmidelioides	1	-	-	0
Samolus repens (Perennial herb)	1	1	-	0
Solanum laciniatum	2	2	8	1 (*Bactericera cockerelli*)
Sophora microphylla	7 (1)	3	1	0
Sophora spp.	1	-	-	0
Tupeie antarctica	1	-	-	0

[a] Pest species causing levels of damage requiring management of populations

[b] Herbivore insect species described species that did not have any information indicating levels of damage that could require management of insect populations

[c] Some typical vegetable and arable crops grown include, *Brassica oleracea, B. rapa, Solanum tuberosum, Alium cepa, Raphanus sativus, Cucurbita moschata, Pisum sativum, Daucus carota, Cucurbita pepo, Cucurbita moschata, Triticum aestivum, Avena sativa, Hordeum vulgaris, Medicago sativa, Trifolium* sp. (seed).

[d] – indicates no record

[e] 0 indicates that no herbivorous insect species have been recorded as pests in vegetable or arable crops.

Table 2: Some insect natural enemies of pest species commonly found on vegetable and arable crops.

Function	Species	Prey/hosts
Predators	*Melanostoma fasciatum*[a]	Aphids (**Hemiptera**), Small larvae, eggs, nymphs belonging to a **range of orders**?
	Melangyna novaezealandiae[a]	Aphids (**Hemiptera**), Small larvae, eggs, nymphs belonging to a **range of orders**?
	Adalia bipunctata	Generalist predator (mostly aphids (**Hemiptera**), small caterpillars (**Lepidoptera**), Eggs – belonging to a **range of orders**?
	Coccinella undecimpunctata	Generalist predator (mostly aphids (**Hemiptera**), small caterpillars (**Lepidoptera**), Eggs – belonging to a **range of orders**?
	Micromus tasmaniae	Generalist predator; soft bodied sessile (low mobility) species, e.g. nymphs of **Hemiptera**
	Oechalia schellembergii	Generalist soldier bug predator; polyphagous, but prefer larvae of **Lepidoptera**
	Cermatulu nasalis	Generalist soldier bug predator; polyphagous, but prefer larvae of **Lepidoptera**
	Nabis kinbergii	Generalist predator (aphids, mirids, wheat bug, small larvae of **Lepidoptera**)
	Staphylinidae beetles	Generalist ground dwelling predators; **range of orders?**
	Carabidae beetles	Generalist ground dwelling predators; **range of orders**?
	Phytodeiidae mites	Predatory mites of Tetranychidae mites (**Acari**)
Parasitoids	Aphelinus spp.	Range of aphid species
	Aphidius spp.	Range of aphid species
	Diaretiella rapae	*Brevicoryne brassicae*
	Trichogramma spp.	Moth eggs
	Copidosoma floridanum	*Chrysodeixis eriosoma*
	Apanteles (Cotesia) ruficrus	*Mythima separata*
	Cotesia rubecula	*Pieris rapae*
	Cotesia (*Apanteles*) *subandinus*	*Phthorimaea operculella*
	Asobara persimilis	*Scaptomyza flava*
	Diadegma semiclausum	*Plutella xylostella*
	Diadromus collaris	*Plutella xylostella*
	Alloxysta brassicae	*Plutella xylostella*

[a] Adults are pollinators, larvae are predators

Table 3: Range of insect orders and number of herbivorous species within each order found on native plant species listed in Table 1 (with known associations) and on the predominant exotic plant species used for shelterbelts and hedgerows (*C. macrocarpa, P. radiata, U. europaeus*).

	Native plant species (n = 44)[a]	Shelterbelt & hedgerow exotic plant species (n = 3)
Acari (mites)	65	1
Coleoptera (beetles)	204	40
Diptera (flies)	59	0
Hemiptera (sucking insects)	191	1
Lepidoptera (moths, butterflies)	144	24
Orthoptera (e.g. grasshoppers)	16	2
Thysanoptera (thrips)	8	0

[a] Includes native plant species not listed specifically in Table 1, but encompassed within listed genera (e.g. *Coprosma* spp., *Hebe* spp., etc.)

Table 4: Number of pest and pollinator insect species associated with the predominant shelterbelt and hedgerow plant species in Canterbury. Insect species associated with each plant species are listed in Appendix 4.

Species	Herbivores	Pest	Pollinators
Cupressus macrocarpa	14	7	0
Pinus radiata	55	24	1
Ulex europaeus	16	9	2

We did not find any information suggesting that the native plant species listed in Table 1 could become or had been described as weeds, unlike *P. radiata* and *U. europaeus*, which are well known weeds in New Zealand.

4 Conclusions and recommendations

Many of the native plants examined in the present study are superior to existing hedgerow and shelterbelt species growing in Canterbury for their associations with pollinating insect species (Table 1 and Appendix 3). Hedgerows and shelterbelts are a substantial landscape feature in Canterbury. The most comprehensive analysis of Canterbury shelterbelts and hedgerows undertaken in the early 1990s determined that there was approximately 170,000 km of hedgerows, dominated by *U. europaeus,* and more than 100,000 km of shelterbelts, dominated by *P. radiata* (Price 1993). No equivalent information is available presently; however, it seems likely that this area of hedges and shelterbelts has been markedly reduced with the increased installation of pivot irrigation.

From a beneficial insect perspective, evidence to date suggests improving resources for pollinators (e.g. food, habitats for establishing populations) may bring about the most obvious benefits at the farm scale. This is because pollinators can forage over large areas, from 100s of meters, to several kilometres (Cane 2001; Schulke & Waser 2001). However, it will be important to ensure flowering of non-crop vegetation occurs outside of the crop flowering time, to avoid competition between the floral resources.

We do not know if the generalist predators listed in Table 2 will prey on herbivorous insects associated with the native plants listed Table 1. Such predator/prey relationships would need to be verified in the field. If such generalist predators can utilise the native plant herbivores then there may be potential for them to attack pests in neighbouring crops. However, it is not known how far and how many natural enemies may disperse into surrounding crops, nor how effective such predators could be in the crop (e.g. predation rate). Also, predators can themselves be attacked by parasitoids or other predators. It is not known how these and other factors may impact on populations of natural enemies and thus possibly affect their ability to suppress pest populations.

This study provides a starting point for exploring plant–insect herbivore–beneficial insect associations and interactions. The associations outlined in the current research need to be verified in the field and further detailed information gathered relating to plant-insect interactions in the Canterbury district. The findings of this study demonstrate the potential benefits of using selective native plant species in non-productive areas for promoting populations of beneficial insects. Further research is required to determine:

- how far beneficial insects may move out of these native plant assemblages into the crop
- whether selected plantings within agro-ecosystems can maintain stable long-term populations of beneficial insects
- whether the floral resources from the native plants provide optimal nutrition for beneficial insects.

Beyond the entomological questions, consideration should also be given to the advantages and disadvantages of using native plants within non-productive areas. These include:

- how accessible and cost-effective such native plant species could be relative to exotic species
- how quickly and easily native plants establish and grow
- how well they fit within the non-productive areas
- how they may compete with or overshadow neighbouring crop plants
- how they may affect livestock that could feed on them
- and which pathogens may be associated with the plants.

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6 References

Altieri MA 1999. The ecological role of biodiversity in agroecosystems. Agriculture Ecosystems & Environment 74: 19–31.

Cane JH 2001. Habitat fragmentation and native bees: a premature verdict? Conservation Ecology 5(1): 149–161.

Chinn W 2005. Insect pollination of native plant species at McLeans Island, Canterbury. Report prepared for the Department of Conservation and the Christchurch City Council. 38 p.
Donovan BJ 2007. Apoidea (insecta: Hymenoptera). Fauna of New Zealand, 57. Christchurch, New Zealand, Landcare Research Ltd. 295 p.
Heine EM 1937. Observations on the pollination of New Zealand flowering plants. Transactions of the New Zealand Society 67: 133–148.
Howlett BG, Lankin GO 2005. A survey of white clover flower visitors in central Canterbury: the range of potential pollinators. Christchurch, Crop & Food Research Confidential Report No. 1486. 34 p.
Howlett BG, Walker MK, Newstrom-Lloyd LE, Donovan BJ, Teulon DAJ 2009. Window traps and direct observations record similar arthropod flower visitor assemblages in two mass flowering crops. Journal of Applied Entomology 133: 553–564.
Lankin GO, Howlett BG 2005. A survey of carrot flower visitors in central Canterbury and central Otago – the range of potential pollinators. Christchurch, Crop & Food Research Confidential Report No. 1422. 38 p.
MAF 2000. Varroa in New Zealand: economic impact assessment. Wellington, New Zealand, Ministry of Agriculture and Forestry. www.varroa.org.nz/resources/assessment.pdf. P. 24.
MAF 2002. Review of Varroa economic impact assessment: recommendations on revision. Wellington, New Zealand, Ministry of Agriculture and Forestry. http://www.biosecurity.govt.nz/files/pests-diseases/animals/varroa/assessment-review.pdf. P. 10.
Price LW 1993. Hedges and shelterbelts on the Canterbury Plains, New Zealand: transformation of an Antipodean landscape. Annals of the Association of American Geographers 83(1): 119–140.
Primack RB 1983. Insect pollination in the New Zealand mountain flora. New Zealand Journal of Botany 21: 317–333.
Rader R, Howlett B, Cunningham S, Westcott D, Newstrom-Lloyd L, Walker M, Teulon D, 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.
Schulke B, Waser NM 2001. Long-distance pollinator flights and pollen dispersal between populations of *Delphinium nuttallianum*. Oecologia 127(2): 239–245.
Scott RR 1984. New Zealand Pest and Beneficial Insects. Lincoln University College of Agriculture, Canterbury. 373 pp.
Walker .G, Cameron P, Workman P, Wright P, Fletcher J, Stufkens M 2007. Information guide for integrated pest management in outdoor lettuce. CD-rom, ISBN 978-0-473-13196-8.
Walsh RS 1967. Nectar and pollen sources of New Zealand. Wellington, National Beekeepers Association of New Zealand. 55 p.

7 Appendices

Appendix 1: Insect pest species associated with native and exotic plants examined in this study.

Pest species	Common name	Biostatus	Native plant sp.	Exotic plant species
Ambeodontus tristis	Two-toothed longhorn	endemic	*Pennantia corymbosa*	*Cupressus macrocarpa*
				Pinus radiata
Bactericera cockerelli	Potato-tomato psyllid		*Solanum laciniatum*	*Solanaceae*
Carystoterpa fingens	Spittle bug	endemic	*Myoporum laetum*	*Brassica oleracea*
				Citrus limon
				Vitis vinifera
Chrysodeixis eriosoma	Green looper	native	*Urtica ferox*	*Brassica oleracea*
				Brassica rapa
				Ipomoea batatas
				Lactuca sativa
				Medicago sativa
				Pisum sativum
				Raphanus sativus
				Solanum tuberosum
				Solanum tuberosum
Cnephasia jactatana	Nz leafroller	endemic	*Coprosma robusta*	*Actinidia chinensis*
			Metrosideros spp.	*Citrus sinensis*
			Muehlenbeckia complexa	*Pinus radiata*
			Phormium tenax	*Trifolium repens*
			Urtica ferox	
Coptomma lineatum	Longhorn beetle	endemic	*Corynocarpus laevigatus*	*Pinus radiata*
			Hebe stricta	
			Leptospermum scoparium	
			Myrsine australis	
Ctenopseustis herana	Brownheaded leafroller	endemic	*Carpodetus serratus*	*Persea americana*
			Fuchsia excorticata	*Pinus radiata*
			Leucopogon spp.	*Prunus armeniaca*
			Muehlenbeckia australis	*Prunus domestica*
			Olearia spp.	*Trifolium repens*
				Ulex europaeus
Ctenopseustis obliquana	Brownheaded leafroller	endemic	*Clematis foetida*	*Actinidia chinensis*
			Coprosma repens	*Citrus limon*
			Coprosma robusta	*Citrus sinensis*
			Corynocarpus laevigatus	*Malus sylvestris*
			Fuchsia excorticata	*Persea americana*
			Hoheria populnea	*Pinus radiata*
			Kunzea ericoides	*Prunus armeniaca*
			Metrosideros spp.	*Prunus avium* & *cerasus*
			Metrosideros spp.	*Prunus domestica*
			Mimulus repens	*Prunus persica*

Pest species	Common name	Biostatus	Native plant sp.	Exotic plant species
			Myrsine australis	*Trifolium repens*
			Olearia spp.	*Ulex europaeus*
			Peraxilla colensoi	*Vitis vinifera*
			Phormium tenax	
			Pseudopanax arboreus	
Kalotermes brouni	(Dead wood borer)	endemic	*Alectryon excelsus*	*Cupressus macrocarpa*
			Cordyline australis	*Pinus radiata*
			Corynocarpus laevigatus	*Prunus persica*
			Kunzea ericoides	
			Metrosideros spp.	
			Pittosporum eugenioides	
Leanobium flavomaculatum	Household borer	endemic	*Carpodetus serratus*	*Cupressus macrocarpa*
			Leptospermum scoparium	*Pinus radiata*
Oemona hirta	Lemon tree borer	endemic	*Alectryon excelsus*	*Citrus limon*
			Coprosma robusta	*Citrus reticulata*
			Corynocarpus laevigatus	*Citrus sinensis*
			Hebe salicifolia	*Malus sylvestris*
			Kunzea ericoides	*Persea americana*
			Leptospermum scoparium	*Pinus radiata*
			Metrosideros spp.	*Prunus avium & cerasus*
			Myoporum laetum	*Prunus domestica*
			Other Hoheria	*Prunus persica*
			Ozothamnus leptophyllus	*Prunus persica var. nucipersica*
			Pennantia corymbosa	*Pyrus communis*
			Pittosporum crassifolium	*Ulex europaeus*
			Pittosporum eugenioides	*Vitis vinifera*
			Pittosporum tenuifolium	
Planotortrix excessana	Greenheaded leafroller	endemic	*Fuchsia excorticata*	*Citrus limon*
			Metrosideros spp.	*Pinus radiata*
			Peraxilla colensoi	*Prunus armeniaca*
			Urtica ferox	*Prunus domestica*
				Prunus persica
				Trifolium repens
				Ulex europaeus
Planotortrix octo	Greenheaded leafroller	endemic	*Corynocarpus laevigatus*	*Citrus sinensis*
			Pittosporum crassifolium	*Medicago sativa*
				Prunus armeniaca
				Prunus persica
				Trifolium repens
				Vitis vinifera
Platypus apicalis	New Zealand pinhole borer	endemic	*Cordyline australis*	*Pinus radiata*
			Corynocarpus laevigatus	
			Pseudopanax crassifolium	

Pest species	Common name	Biostatus	Native plant sp.	Exotic plant species
Pseudocoremia suavis	Common forest looper	endemic	*Carmichaelia* sp.	*Cupressus macrocarpa*
			Coprosma robusta	*Pinus radiata*
			Coriaria arborea	*Ulex europaeus*
			Corokia cotoneaster	
			Kunzea ericoides Leptospermum scoparium	
			Leucopogon spp.	
			Metrosideros spp.	
			Metrosideros spp.	
Pyrgotis plagiatana	(Leafroller)	endemic	*Carmichaelia* sp.	*Pinus radiata*
			Coriaria arborea	*Ulex europaeus*
			Fuchsia excorticata	
			Hebe elliptica	
			Hebe stricta	
			Hebe subalpina	
			Melicope simplex	
			Metrosideros spp.	
			Ozothamnus leptophyllus	
			Pittosporum tenuifolium	
			Tupeia antarctica	
Scolypopa australis	Passionvine hopper	endemic	*Coprosma lucida*	*Persea americana*
			Coprosma robusta	
			Fuchsia excorticata	
			Myrsine australis	
			Phormium tenax	
			Pseudopanax arboreus	
Stathmopoda skelloni		endemic	*Phormium tenax*	*Actinidia chinensis*
				Malus sylvestris
Thrips obscuratus	New Zealand flower thrips	endemic	*Bulbinella* spp.	*Malus sylvestris*
			Carmichaelia sp.	*Medicago sativa*
			Cordyline australis	*Prunus armeniaca*
			Hoheria angustifolia	*Prunus persica*
			Hoheria sexstylosa	*Pyrus communis*
			Kunzea ericoides Leptospermum scoparium	*Trifolium pratense*
				Ulex europaeus
			Muehlenbeckia australis	*Vicia faba*
			Phormium tenax	*Vitis vinifera*
			Pittosporum tenuifolium	
Amasa truncata	Ambrosia beetle	adventive	*Kunzea ericoides Leptospermum scoparium*	*Pinus radiata*
			Metrosideros spp.	
Ambrosiodmus compressus		adventive	*Kunzea ericoides*	*Pinus radiata*
				Prunus persica
Asynonychus	Fuller's rose weevil	adventive	*Corynocarpus laevigatus*	*Malus sylvestris*

Pest species	Common name	Biostatus	Native plant sp.	Exotic plant species
cervinus				
				Medicago sativa
				Prunus persica
				Pyrus communis
Aulacorthum solani	Foxglove aphid, glasshouse potato aphid	adventive	*Fuchsia excorticata*	*Lactuca sativa*
			Phormium tenax	*Lycopersicon esculentum*
			Solanum laciniatum	*Solanum tuberosum*
Brachycaudus helichrysi	Leaf-curling plum aphid	adventive	*Coriaria arborea*	*Prunus domestica*
			Hebe elliptica	
			Ozothamnus leptophyllus	
Brevipalpus obovatus	Privet mite, ornamental flat mite	adventive	*Coprosma repens*	*Citrus limon*
				Malus sylvestris
Ceroplastes destructor	White wax scale	adventive	*Pittosporum tenuifolium*	*Citrus limon*
				Citrus reticulata
Ceroplastes sinensis	Chinese or hard wax scale	adventive	*Coprosma robusta*	*Citrus limon*
			Hebe stricta	*Citrus reticulata*
			Hoheria populnea	
			Melicope simplex	
			Olearia spp.	
Coccus hesperidium	Soft brown scale	adventive	*Carmichaelia* sp.	*Medicago sativa*
			Myoporum laetum	*Pinus radiata*
			Pseudopanax crassifolium	*Prunus armeniaca*
				Prunus avium & cerasus
				Prunus persica
				Vitis vinifera
Epiphyas postvittana	Lightbrown apple moth	adventive	*Phormium tenax*	*Actinidia* sp.
			Pseudopanax arboreus	*Citrus sinensis*
				Pinus radiata
				Prunus armeniaca
				Prunus avium & *cerasus*
				Prunus domestica
				Prunus persica
				Trifolium repens
				Ulex europaeus
				Vitis vinifera
Heliothrips haemorrhoidalis	Greenhouse thrips	adventive	*Alectryon excelsus*	*Actinidia* sp.
			Corynocarpus laevigatus	*Pinus radiata*
			Fuchsia excorticata	*Ulex europaeus*
			Hoheria populnea	
			Kunzea ericoides	
			Metrosideros spp.	
			Muehlenbeckia complexa	
			Myoporum laetum	

Pest species	Common name	Biostatus	Native plant sp.	Exotic plant species
Hemiberlesia lataniae	Latania scale	adventive	*Carpodetus serratus*	*Actinidia* sp.
			Cordyline australis	
			Ozothamnus leptophyllus	
			Rubus australis	
Hemiberlesia rapax	Greedy scale	adventive	*Alectryon excelsus*	*Actinidia* sp.
			Clematis paniculata	
			Coprosma propinqua	
			Coprosma robusta	
			Corokia cotoneaster	
			Corynocarpus laevigatus	
			Fuchsia excorticata	
			Hebe stricta	
			Lophomyrtus obcordata	
			Myoporum laetum	
			Tupeia antarctica	
Icerya purchasi	Cottony cushion scale	adventive	*Myoporum laetum*	*Citrus limon*
			Pittosporum eugenioides	*Citrus reticulata*
			Pittosporum tenuifolium	
			Urtica ferox	
Isotenes miserana	Orange fruit borer	adventive	*Metrosideros* spp.	*Citrus sinensis*
Macrosiphum euphorbiae	Potato aphid	adventive	*Clematis foetida*	*Brassica oleracea*
			Hebe stricta	*Lactuca sativa*
			Muehlenbeckia complexa	*Solanum tuberosum*
			Pittosporum eugenioides	*Zea mays*
Maleuterpes spinipes	Dicky rice weevil	adventive	*Melicope simplex*	*Citrus* sp.
Myzus persicae	Green peach aphid	adventive	*Hebe elliptica*	*Brassica oleracea*
			Hebe stricta	*Brassica rapa*
			Myoporum laetum	*Pisum sativum*
			Pittosporum crassifolium	*Raphanus sativus*
				Solanum tuberosum
Orchamoplatus citri	Australian citrus whitefly	adventive	*Alectryon excelsus*	*Citrus* sp.
			Metrosideros spp.	
Parasaissetia nigra	Nigra scale	adventive	*Pittosporum tenuifolium*	*Prunus armeniaca*
Phthorimaea operculella	Potato tuber moth	adventive	*Solanum laciniatum*	*Solanum tuberosum*
Pseudococcus longispinus	Long-tailed mealybug	adventive	*Phormium tenax*	*Prunus domestica*
				Pyrus communis
				Vitis vinifera
Pseudococcus viburni	Obscure mealybug	adventive	*Pittosporum tenuifolium*	*Vitis vinifera*
			Solanum laciniatum	
Saissetia coffeae	Hemispherical scale	adventive	*Coprosma robusta*	*Prunus persica*
			Cordyline australis	*Vitis vinifera*
			Hebe macrocarpa	
			Hebe stricta	

Pest species	Common name	Biostatus	Native plant sp.	Exotic plant species
			Myoporum laetum	
			Other parahebes	
Saissetia oleae	Black scale, mediterranean black scale, olive scale, olive soft scale	adventive	*Coprosma repens*	*Pyrus communis*
			Hebe elliptica	*Vitis vinifera*
			Myoporum laetum	
			Myrsine australis	
			Olearia spp.	
			Ozothamnus leptophyllus	
Sceliodes cordalis	Eggfruit caterpillar	adventive	*Solanum laciniatum*	*Solanum tuberosum*

Appendix 2: Insect species associated with existing exotic plant species historically used for shelterbelts and hedgerows.

Cupressus macrocarpa

Herbivores	Pests	Pollinators
Kalotermes banksiae	*Anobium punctatum*	?
Chrysorthenches virgata	*Ambeodontus tristis*	
Declana floccosa	*Calliprason pallidus*	
Garyus altus	*Kalotermes brouni*	
Hadrobregmus magnus	*Leanobium flavomaculatum*	
Hierodoris atychioides	*Pseudocoremia suavis*	
Mitrastethus baridioides	*Xyleborinus saxesenii*	
Planotortrix notophaea		
Prionophus reticularis		
Pseudocoremia fenerata		
Stolotermes inopinus		
Stolotermes ruficeps		
Torostoma apicale		
Xylotoles laetus		

Pinus radiata

Herbivores	Pests	Pollinators
Kalotermes banksiae	*Amasa truncata*	*Bombus terrestris*
Anagotus helmsi	*Anobium punctatum*	
Androporus discedens	*Arhopalus tristis*	
Apoctena conditana	*Hylotrupes bajulus*	
Apoctena flavescens	*Ambeodontus tristis*	
Apoctena orthropis	*Ambrosiodmus compressus*	
Blosyropus spinosus	*Calliprason pallidus*	
Chloroclystis filata	*Cnephasia jactatana*	
Coptomma sulcatum	*Coccus hesperidium*	
Crisius binotatus	*Coptomma lineatum*	
Declana floccosa	*Costelytra zealandica*	
Declana hermione	*Ctenopseustis herana*	
Declana leptomera	*Ctenopseustis obliquana*	
Eiratus ornatus	*Epiphyas postvittana*	
Euophryum rufum	*Eucolaspis brunnea*	
Gellonia dejectaria	*Heliothrips haemorrhoidalis*	
Hadrobregmus australiensis	*Kalotermes brouni*	
Hadrobregmus magnus	*Leanobium flavomaculatum*	
Helmoreus sharpi	*Oemona hirta*	
Hemideina crassidens	*Planotortrix excessana*	
Hexatricha pulverulenta	*Platypus apicalis*	
Hierodoris atychioides	*Pseudocoremia suavis*	
Holocola zopherana	*Pyrgotis plagiatana*	
Hybolasius modestus	*Xyleborinus saxesenii*	
Hybolasius vegetus		
Liothula omnivora		
Microcryptorhynchus (Microcryptorhynchus) kronei		
Microcryptorhynchus (Microcryptorhynchus) vafer		
Mitrastethus baridioides		
Nesoptychias simpliceps		
Odontria sylvatica		
Pachycotes peregrinus		
Paedaretus hispidus		
Pasiphila inductata		

Herbivores	Pests	Pollinators
Phloeophagosoma dilutum *Phymatus phymatodes* *Planotortrix notophaea* *Poecilasthena pulchraria* *Pogonorhinus opacus* *Prionophus reticularis* *Proteuxoa comma* *Psepholax sulcatus* *Pseudocoremia fenerata* *Pseudocoremia leucelaea* *Rhopalomerus tenuicornis* *Shapius brouni* *Somatidia antarctica* *Stethaspis lineata* *Stethaspis sp.* *Stolotermes inopinus* *Stolotermes ruficeps* *Strongylopterus hylobioides* *Torostoma apicale* *Xylotoles laetus* *Zermizinga indocilisaria*		

Ulex europaeus

Herbivores	Pests	Pollinators
Lampides boeticus *Acanthoxyla* sp. *Aceria genistae* *Anisoplaca ptyoptera* *Chloroclystis filata* *Ctenoplectron fasciatum* *Declana floccosa* *Deinacrida* sp. *'Mahoenui'* *Dysnocryptus inflatus* *Hybolasius viridescens* *Mitophyllus arcuatus* *Planotortrix notophaea* *Pleosporius bullatus* *Pseudococcus hypergaeus* *Shapius brouni* *Zeamordella monacha*	*Ctenopseustis herana* *Ctenopseustis obliquana* *Epiphyas postvittana* *Heliothrips haemorrhoidalis* *Oemona hirta* *Planotortrix excessana* *Pseudocoremia suavis* *Pyrgotis plagiatana* *Thrips obscuratus*	*Apis mellifera* *Bombus terrestris*

Appendix 3: Some insect pollinator species and numbers of native (n, includes endemic species), and exotic (e) plant species they visit (Chinn 2005; Donovan 2007; Heine 1937; Howlett & Lankin 2005; Howlett et al. 2009; Lankin & Howlett 2005; Primack 1983; Rader et al. 2009; Walsh 1967). The number of vegetable or arable crops visited by pollinators is included in parentheses.

Insect Species	No. exotic plant species	No. native plant species
Apis mellifera	5 (4)	30
Bombus hortorum	3 (3)	5
Bombus terrestris	9 (7)	56
Calliphora spp.	5 (5)	8
Dilophus nigrostigma	4 (4)	6
Eristalis tenax	5 (5)	2
Euryglossina prototrypoides		2
Hylaeus agilis		9
Hylaeus asperithorax		2
Hylaeus capitosus		12
Hylaeus matamoko		2
Hylaeus relegatus		14
Lasioglossum cognatum		3
Lasioglossum mataroa		4
Lasioglossum maunga		11
Lasioglossum sordidum		43
Lasioglossum spp.	5 (5)	26
Leioproctus boltoni		10
Leioproctus fulvescens		9
Leioproctus huakiwi		13
Leioproctus hudsoni		9
Leioproctus imitatus		9
Leioproctus kanapuu		3
Leioproctus keehua		1
Leioproctus maritimus		4
Leioproctus metallicus		2
Leioproctus monticola		8
Leioproctus nunui		2
Leioproctus paahauma		1
Leioproctus paahaumaa		3
Leioproctus pango		20
Leioproctus pekanui		8
Leioproctus purpureus		5
Leioproctus spp.	6 (6)	14
Leioproctus vestitus		9
Leioproctus waipounamu		12
Lucilia sericata	4 (4)	4
Megachile rotundata	2 (2)	2
Melangyna novaezelandiae[1]	4 (4)	12
Melanostoma fasciatum[1]	4 (4)	4
Muscid spp.	4	7
Odontomyia spp.	4	3
Oxysarcodexia varia	4	3

Insect Species	No. exotic plant species	No. native plant species
Pollenia pseudorudis	4	
Scaptia sp.	1 (1)	3
Tachinid spp.	5 (5)	8

[1] Larval instars are predatory