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Native plantings for beneficial insects in Canterbury: scoping and researching economic, environmental, and social benefits in a simplified agricultural landscape

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Abstract: Loss of remnant vegetation and landscape complexity through agricultural intensification reduces the abundance and diversity of beneficial insects such as pollinators and natural enemies of pests (predators/parasitoids). The Canterbury Plains (CP), New Zealand, is a highly intensified agricultural region that has lost almost all remnant native woody vegetation. Establishing native semi-natural habitat (SNH) designed to increase the abundance and diversity of beneficial insects could offer farmers opportunity to reduce pest damage to crops and pastures, reduce insecticide use, and improve yields through increased pollination. While it is currently challenging to estimate the full potential benefits of establishing native SNH on CP farms, simple calculations suggest that eliminating just one insecticide application across frequently treated crops could save farmers over $NZ24.1 million p.a. collectively. We also calculate that CP farmers could potentially save more than $39.9 million p.a. through increased yields if pollination deficits could be eliminated. Designed native SNH may also deliver environmental benefits if it can support the functional service of beneficial insects and mitigate environmental effects such as climate change. Moreover, if economic and environmental benefits can be demonstrated, the transfer of this information to farmers and the broader community could increase knowledge and appreciation of native SNH that supports diverse beneficial insects. Here we outline research to evaluate the economic, environmental, and social benefits of insect-mediated ecosystem service contributions (pollination, pest suppression) across CP arable, dairy, sheep, and beef farms. The research partners include industry bodies, local and regional councils, and restoration trusts responsible for delivering knowledge to farmers and broader community catchment groups.

Keywords: climate change, crop yield, ecosystem services, insect diversity, insect natural enemies, insect predators, native habitat, New Zealand, pollinators, semi-natural habitat.

Introduction

Increasing the diversity of beneficial insects on farms can improve the resilience of ecosystem processes such as pollination and natural pest suppression (Carvalheiro et al. 2011; Feit et al. 2019). Pollinator diversity can improve crop yields (Garibaldi et al. 2016) and yield stability across seasons (Senapathi et al. 2021), while a diversity of natural enemies can improve pest suppression (Yang et al. 2021). To support populations of these beneficial insects, establishing or protecting semi-natural habitat (SNH, e.g. native plantings, remnant vegetation and floral strips) is promoted across a number of countries by scientists and through governmental policies (Bommarco et al. 2013; Kovacs-Hostyanszki et al. 2017; Howlett et al. 2023; Müller et al. 2024). In some cases this has resulted in improved pollination (Blaauw & Isaacs 2014) and pest control (Bianchi et al. 2006; Qian et al. 2021; Crowther et al. 2023) but outcomes have been inconsistent (Albrecht et al. 2020), even when insect diversity has increased (Nicholson et al. 2020).

A lack of guaranteed economic benefits from establishing and maintaining SNH have left some farmers sceptical of this strategy for promoting beneficial insects (Kleijn et al. 2019; Osterman et al. 2021). Farmers may also be reluctant to establish or protect SNH if it is perceived to support pests (Maseyk et al. 2017). Indeed, unmanaged SNH can be a source of pest insects (Tscharntke et al. 2016) that are poorly controlled by natural enemies emanating from the same habitat (Blitzer et al. 2012). Designing SNH to support targeted beneficial insects but not pests may improve outcomes (Tschumi et al. 2016; Lundin et al. 2019; Nichols et al. 2019; Howlett et al. 2021; Windsor et al. 2021). Such designs typically aim to identify a mix of plant species to establish within a SNH that supports targeted beneficial insects for a specific crop (Howlett et al. 2021; Windsor et al. 2021). However, the implementation of these designed SNHs is often constrained by limited knowledge

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about the most effective insect species to target for many crops (Rader et al. 2020; Howlett et al. 2023). This is further complicated in that the optimal composition of SNH plant species is constrained by the farming system (e.g. cultural practices, land use, local climate) and the different beneficial insect species that are, or could be, present across various locations (Howlett et al. 2022; 2023).

In New Zealand, research has focussed on creating SNH to support on-farm beneficial insects using exotic (Stephens et al. 1998; Berndt et al. 2006) and also native species (Davidson & Howlett, 2010; Tompkins 2010; Curtis et al. 2019; Howlett et al. 2021). Given native SNH is being widely established across New Zealand farmland for a number environmental and social benefits (e.g. reduced nutrient run-off, prevention of soil erosion, increased native biodiversity, aesthetics, intergenerational equity; Maseyk et al. 2017; Maseyk et al. 2018), there is opportunity to further design these to include additional benefits such as beneficial on-farm insects (Fiedler et al. 2008; Wratten et al. 2012; Howlett et al. 2023). However, the economic benefit to New Zealand farmers from native SNH that supports pollination and pest control services remains poorly understood. Goldson et al. (2020) expressed scepticism that native insects that are natural enemies (predators and parasitoids) that consume pests will readily migrate from native SNH into adjacent farmland to manage exotic pests on non-native crops and pasture plants, as these natural enemies have co-evolved with insect herbivores within native habitats. New Zealand native and exotic ecosystems can, however, interact in impactful ways. Several native insects are important natural enemies of farmland pests (Early 1984) while others are significant farm pests (Ferguson et al. 2019; Fig. 1). Moreover, the adult life-stages of various introduced natural enemies readily utilise the floral resources of native plant species (Tompkins 2010; Howlett et al. 2021).

As one of the most agriculturally intensified regions in New Zealand, the Canterbury Plains (CP) presents a significant opportunity to evaluate how establishing on-farm native SNH can support beneficial insects, potentially offering measurable benefits to farmers, land managers, and the broader community. Land-use is dominated by livestock (dairy, sheep, and beef) and crop farming with less than 1.0% natural vegetation remaining (Leathwick et al. 2002; Meurk 2008). Farmers rely heavily on pesticide use to control insect pests (Hageman et al. 2019; Mansfield et al. 2019) and managed honey bees to pollinate crops (Goodwin 2012). Despite this, much is known about the diversity of beneficial insect species that contribute pollination and pest control services across this region (Rader et al. 2009; Howlett et al. 2021; Fijen et al 2022) including their relationship with on-farm native plantings (Table 1). In this context, we describe several anticipated economic, environmental, and social benefits that could be achieved by designing and establishing native SNH to support beneficial insects on the Canterbury Plains. We then outline research to evaluate these benefits and describe our strategy for knowledge transfer to farmers, land managers, and the broader community.

Economic benefits

Reduction in insecticide use

On-farm SNH can increase the abundances of natural enemies that reduce the intensity of crop pest outbreaks (Thomson & Hoffmann 2013; Lu et al. 2022), and hence the need for pesticides (Gardiner et al. 2009; Meehan & Gratton 2015). For example, rice farmers in Asia required 70% fewer pesticide sprays to fields neighbouring diverse flowering plants (Gurr et al. 2016). In Canterbury, farmers rely heavily on insecticides to control insect pests within seed and forage crops and pasture

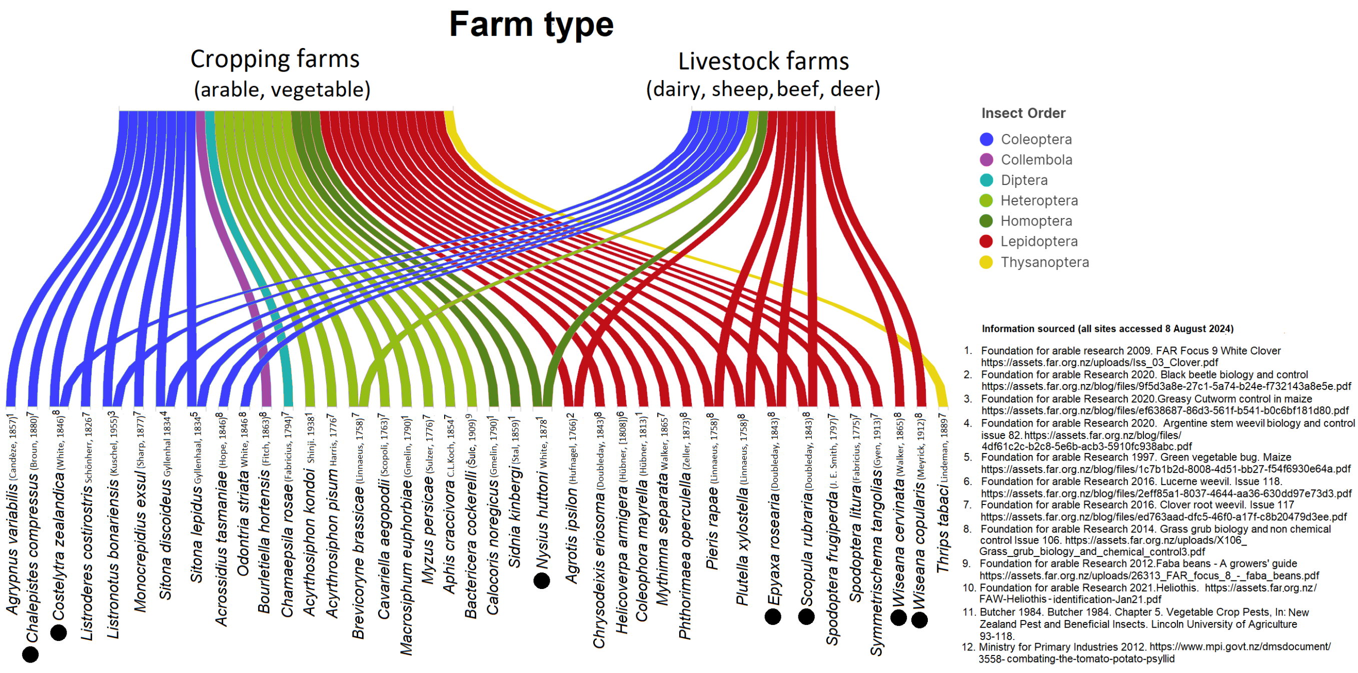


Figure 1. Pest insects of Canterbury cropping and livestock farms. For all species, applications of insecticide are recommended to control economically damaging populations. Insects preceded by black circles are native species. Cited information for each insect is numbered (superscripted after each insect) with reference details provided at the right of the figure.

Table 1. Examples of studies having assessed native plantings and their influence on or interactions with beneficial insect pollinators and natural enemies (predators, parasitoids) on Canterbury farms.

Research	Key findings relevant to insect pollinators and natural enemies	Study
Species interactions	Native plant species supporting diverse verified beneficial insects.	Davidson et al. 2010; Tompkins 2010; Schmidlin et al. 2018; Howlett et al. 2021; Davidson & Howlett 2023
Support of adult and immature life-stages	Life histories support strategies for population maintenance.	Howlett et al. 2021
Influence on diversity and distributions	Native plantings alter abundances and diversity.	Rader et al. 2014; Shields et al. 2016; Macdonald et al. 2018; Curtis 2019; Fijen et al. 2022
Movement across habitat types	Diverse insects move into surrounding farmland	Schmidlin et al. 2021

(Ferguson et al. 2019). Crop and pasture pests are diverse within the region (Fig. 1) and several species are multivoltine (Mansfield et al. 2021), hence farmers may need to apply multiple insecticide applications per annum to control a myriad of species (van Toor et al. 2008; 2013).

Native plant species on CP farms are known to support natural enemies. These include the adult stages of aphid and caterpillar eating hover flies (e.g. *Melanostoma fasciatum* and *Melgangyna novaezelandiae*), pest attacking parasitoid wasps (Tompkins 2010) and tachinid flies (e.g. *Protohystricia alcis* and *Pales marginata* that attack pasture damaging *Porina* moths, and *Proscissio cana*, a parasitoid of the crop and pasture damaging grass grub; Howlett et al. 2021). While we are unaware of any scientific studies specifically from Canterbury investigating whether on-farm native SNH can reduce insecticide use, anecdotal evidence suggests this can be the case (Rural News Group 2019). Moreover, practices (i.e. Integrated Pest Management) that support natural enemies on CP farms have proven to reduce the need for insecticide applications without impacting yield (Foundation for Arable Research 2015). We therefore anticipate that designing on-farm native SNH that support natural enemies could also contribute to the reduction of on-farm insecticide usage. Even if each CP farmer could eliminate a single insecticide application per annum by establishing native SNH that support insect natural enemies, we calculate >$22.4 million per annum could be saved through reduced insecticide applications across CP arable, dairy, sheep and bee farms collectively (Table 2).

Yield increases through pollination

Canterbury Plains farmers who establish native plantings designed to support diverse crop-pollinating insects could also achieve increased crop yields. In Canterbury, pollination by honey bees is relied upon for vegetable and clover seed production (export value $NZ100 million; Ministry for Primary Industries 2023), apples (on-farm $58.2 million), summerfruit (on-farm $7.1 million) and berryfruit (on-farm $96.9 million) (Aitken & Warrington 2018). Based on these data, these crops earn $262.2 million p.a. collectively. As with other intensively farmed regions worldwide, sub-optimal pollination has resulted in crop yield deficits within the Canterbury region. For example, white clover yields could potentially be doubled if pollination services were optimised (Goodwin et al. 2011) and carrot yields increased by 31.1% (mean yield deficit across 13 fields) (Howlett et al. 2021). Elsewhere, enhanced pollinator diversity resulting from the presence of neighbouring native vegetation has been shown to increase crop yields throughout adjacent paddocks by 15–30% (Garibaldi et al. 2016). If diversified pollination services emanating from designed native SNH adjacent to fields increased crop yields by 15%, we estimate

Table 2. Calculations of potential savings if Canterbury Plains arable, dairy, and sheep and beef farmers were able to eliminate one insecticide application per annum across crops that typically require applications. Farm area and numbers of farms were obtained from the Ministry for the Environment (2018). The proportion of a farm treated with at least one insecticide has been based on the types of crops grown in these farming systems (e.g. arable farm systems predominantly grow seed (vegetable and forage) and cereal crops (Dynes et al. 2010); dairy, sheep and beef farm systems grow forage brassicas, cereals, or fodder beets). One or more insecticide application(s) are often applied to control a myriad of insect pests (Fig. 1). To determine the mean proportional land area established in these crops per farm system, satellite imagery (March 2023) was assessed for 18 Canterbury farms (six per system, each >5 km apart), with land area between 145 and 431 ha) and, where necessary, farmers were contacted to verify crop type (B. Howlett, unpublished data).

Farming activity	Arable	Sheep and beef	Dairy
Farm number	1248	5034	1788
Mean farm size (ha)	206	422	385
Proportion treated with insecticide	0.67	0.05	0.18
Mean area per farm treated with an insecticide (ha)	138	21	69.30
Cost of insecticide per farm p.a.*	$8281.00	$1266.00	$4158.00
Insecticide cost saving p.a. across Canterbury farms**	$10,334,688.00	$6,373,044.00	$7,434,504.00

*Based on mean cost ($NZ60) of a single insecticide application per ha at lower estimate (Ferguson et al. 2019)
** Cost of insecticide per farm multiplied by insecticide use per ha

this would add $39.3 million p.a. in yield above the current estimate of $262.2 million p.a. Furthermore, pastoral systems could receive flow-on benefits since many use species requiring insect pollination for seed production (e.g. clovers, chicory, lucerne).

Costs and benefits from establishing designed SNH for beneficial insects

To conduct a thorough cost-benefit analysis for CP farmers considering the establishment of designed native SNH, further evaluation is necessary to determine the optimal extent of SNH required to effectively reduce pesticide usage and enhance pollination (Table 2). The estimated cost of establishing native SNH on-farm is $NZ30 thousand per hectare (Dewes et al. 2022). If, for example, establishing a 5-metre wide native SNH strip (similar to on-farm floral strips established elsewhere; Korpela et al. 2013; Mei et al. 2021) along one side of each paddock was successful in delivering the outlined benefits to farms, the estimated establishment cost to each farmer would range between $46 thousand and $67 thousand (Table 3). Projecting this cost across all CP farms would amount to approximately $416.3 million (sum of all farming systems in Table 3). In this scenario, arable farmers would benefit the most, with an estimated annual gain of $21.9 million from insecticide savings and increased seed yield (Table 1: pesticide savings + seed yield gains of $15 million p.a.). At an establishment cost of $64.9 million (Table 3), the potential payback period for arable farmers could be 2.9 years. In contrast, we calculate the payback periods for dairy farms and sheep and beef farms to be 16.1 years and 36.3 years respectively. These calculations have not considered costs associated with the loss of productive land through the establishment of SNH, which under the scenario provided would cover on average <3% of farm area. Estimates of this cost vary greatly ($100–13 000 per hectare of native SNH (Forbes 2022), depending on the land productivity. On the other hand, establishment costs of native SNH could be lowered substantially if farmers received financial support through partnerships with council and trusts. Beyond establishment costs (approximately 3 years), native plantings are generally considered to require low long term maintenance costs <$600 ha^{-1} p.a. (Forbes 2022).

Environmental benefits

The re-establishment of native plantings on farms can help to reverse New Zealand's declining native biodiversity as well as benefitting agri-ecosystems. A net loss of 71 000 ha of native landcover was estimated for 1996–2012, with a further loss of nearly 13 000 ha between 2012 and 2018 (StatsNZ 2018; Ministry for the Environment & StatsNZ 2022). Contributing to this loss includes conversion to pastural farming, exotic forests, and urban landscapes (Ministry for the Environment & StatsNZ 2019). Native re-vegetation on the CP is considered to be of particularly high priority to improve biodiversity and water quality, provide habitat, and protect soil (Case et al. 2023). It is recognised globally that achieving resilient and stable crop production requires diversifying the numbers of beneficial insects that provide pollination and pest control services (Potts et al. 2016; Dicks et al. 2021). Beneficial insect diversity increases functional service complementarity (e.g. having a range of species active under different weather conditions) and redundancy (e.g. loss of the service of one insect is replaced by others) (Hooper et al. 2005). These buffer ecosystem services to environmental impacts such as climate change (Howlett et al. 2013). Climate change is expected to increase outbreaks of some insect crop pests (Deutsch et al. 2018), favour the establishment of new invasive pest species (Paini et al. 2016), negatively affect the efficacy of certain insect natural enemies (e.g. through constraints to their thermal sensitivities and dispersal abilities; Gerard et al. 2013), and reduce the predictability of crop pollination services delivered by managed pollinators (Howlett et al. 2013).

The loss of native SNH across the Canterbury region has already had a negative impact on the diversity and distributions of insects that provide beneficial on-farm services such as pollination (Donovan et al. 2010; Fijen et al. 2022). Reliance on a limited number of beneficial insect species for pollination or pest suppression leaves sustainable production vulnerable to the impacts of climate change (Andrew & Hill 2017). With increasingly intense weather events (as predicted across much of New Zealand), Howlett et al. (2013) believe this could negatively affect the delivery of honey bee pollination services by affecting their foraging activity. Designing SNH that supports pollinating species (e.g. bumblebees and certain fly species) which forage under conditions that make honey bees ineffective will help ensure pollination is maintained (Howlett et al. 2021).

Table 3. Calculated cost of establishing designed native SNH for beneficial insects along the edge of each paddock on arable, dairy, and sheep and beef farms. The mean proportional land area of each farm system was measured, along with the number of paddocks and the length of 5-metre wide SNH strip needed to border each paddock, as calculated using satellite imagery (as described in Table 2 header). Six Canterbury Plains farms from each system, located more than 5 km apart, were assessed to calculate the means ± standard deviations (B. Howlett, unpublished data).

Farm System	Farm size (ha)	Mean number of paddocks	Native SNH length (m)	Estimated establishment cost per farm ($NZ)*	Estimated cost for all Canterbury farms ($NZ)
Arable	252±63	19.2±3.4	3474±924	$52±14 thousand	$64.9 million
Dairy	268.1±62	32.5±3.0	4490±881	$67±13 thousand	$119.8 million
Sheep and Beef	354±80	30.3±7.1	3096±624	$46±09 thousand	$231.6 million

*establishment cost of $NZ30 thousand per hectare (Dewes et al. 2022)
**mean estimated cost per farm multiplied by total number of farms (Table 2)

Many New Zealand indigenous insect species can provide very effective crop pollination across farms (Rader et al. 2012; Howlett et al. 2021; Broussard et al. 2022) but abundances can be low and widely variable between fields (Howlett et al. 2005). The abundances of several of these pollinators are strongly linked to the presence of neighbouring native habitat (Stavert et al. 2018) and the lack of such habitats could explain why populations of these insect species are low or absent there. Designed native SNH offers opportunity to support and build populations of these insects through the provision of food (nectar and pollen) (Tompkins 2010), undisturbed nesting sites for ground nesting native bees (Howlett et al. 2021), and by supporting reliable alternative prey for insect predators as observed in other SNH (Alignier et al. 2014).

Social and cultural benefits

Farmer motivations for establishing or protecting native SNH in New Zealand's agricultural landscapes can be complex, driven by various socio-economic factors (such as aesthetics, intergenerational equity, and farm value), environmental considerations (like protecting native fauna and water quality), and practical concerns (including animal wellbeing) (Maseyk et al. 2021). Understanding these diverse values can allow the tailoring of on-farm native SNH that can deliver multiple benefits (Howlett et al. 2023). For instance, native habitats designed to reduce nutrient runoff or protect indigenous biodiversity can also be designed to support beneficial insects (Wratten et al. 2012). Moreover, opportunities to design this SNH to minimise negative consequences such as the establishment and movement of mammalian pests (Morse 2022) can also be considered. Farmers' motivations for establishing native SNH may evolve as more information on the potential benefits of these habitats becomes available (Maseyk et al. 2018). For instance, as the ecosystem services provided by beneficial insects associated with native SNH are verified and recognised, this could increasingly drive farmers to establish such habitats.

At a regional level in New Zealand, landholding and land-managing stakeholders are typically diverse, including local, regional, and national government departments, primary industry organisations, restoration trusts, and rūnanga (iwi assembly) (Fig. 2). While these organisations often promote or engage in the establishment of native SNH, their motivations can vary significantly. For instance, Howlett et al. (2023) found that national government departments and restoration trusts are particularly driven to establish native SNH on farmland when it contributes to enhancing indigenous biodiversity. However, this issue holds only moderate importance for horticultural industries. On the other hand, horticultural industries prioritise the establishment of native SNH more highly when it supports the presence of natural insect enemies, a goal that is less critical for national and regional governments. Despite these differences, these organisations recognise the importance of collaboration in developing strategies that provide both valuable ecological benefits and economically important ecosystem services (Howlett et al., 2023).

The Canterbury region is home to a diverse group of landholders, land users, and governmental authorities, each identifying various key drivers for establishing or safeguarding native habitats (Fig. 2). Regional and district councils promote the restoration of native habitats in collaboration with community groups through a variety of programmes around common values. For example, Environment Canterbury work with local rūnanga with the goals of delivering mahinga kai, protecting and restoring rivers and wetlands, and supporting community-led biodiversity projects (Environment Canterbury Regional Council 2023). The Selwyn District Council provides funding to the native planting trust Te Ara Kākāriki, community groups, and private landholders, with the goals of protecting or restoring native habitat, creating ecological corridors for native wildlife, and protecting waterways from nutrient run-off (Selwyn District Council n.d.). The dairy company Synlait has a particular interest in restoring riparian and wetland areas that support wildlife (Fig. 2). To achieve this, they are working with dairy farmers through their Whakapuāwa programme (Synlait 2019).

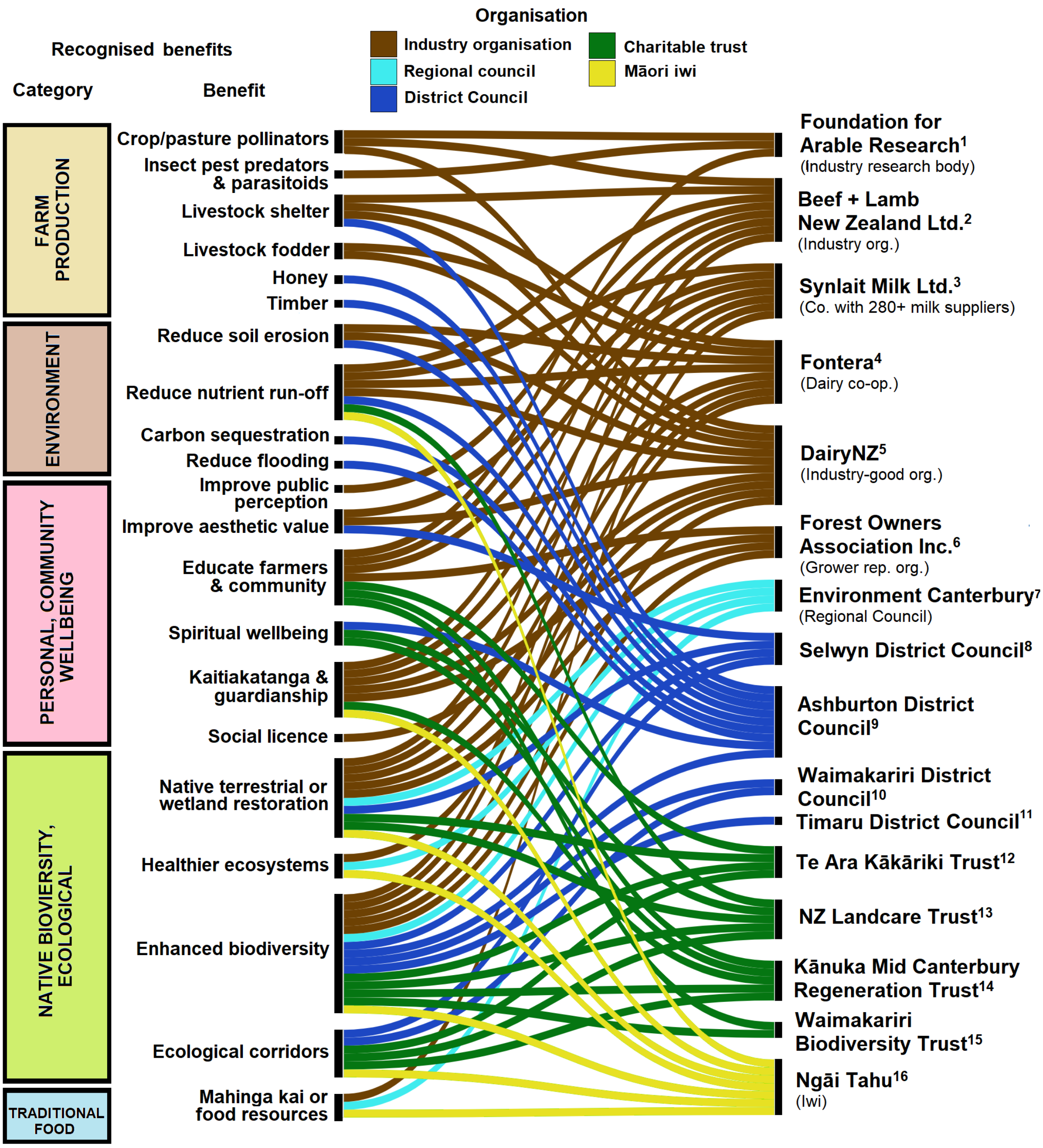
New research

To support land managers in making informed land-use decisions, further research is needed to fully understand the benefits of native plantings and beneficial insects. For plantings on the CP, we have identified three priority research objectives to build on current knowledge. These are: (1) evaluating associated temporal and spatial abundance and diversity of beneficial and pest insects, (2) measuring the contributions made by beneficial insect pollinators and natural enemies to on-farm ecosystem services (e.g. pollination and natural insect pest suppression), and (3) understanding how farmers and the broader community perceive native plantings and their connections to beneficial insects, and how these perceptions may evolve with the introduction of new knowledge.

These objectives have become the focus of a five-year research program, "Boosting Farm Yield Through Beneficial Insects" (Ministry for Primary Industries 2022), which began in August 2021. Data for objective 1 is being collected over five years (2021–2025) to provide robust information on temporal changes in insect abundances. Data for objective 2 has been gathered over a period of approximately three-years between 2021 and 2024 and is currently under analysis. For objective 3, data is being collected over four years (2021–2024), with a current emphasis on sharing information with farmers and land-managers.

Future impact

If designed native SNH for beneficial insects can be demonstrated to deliver economic (e.g. pollination, pest suppression), environmental (e.g. indigenous biodiversity, resilient ecosystem services), social (e.g. intergenerational equity, aesthetics), and cultural (e.g. enhanced mauri through maintaining and enhancing the life-force of the land for future Māori generations) benefits, farmers will have increased incentive to establish native SNH. Regional communities may also be enriched socially, particularly if designs also consider the requirements of local iconic, rare species. Farmers' awareness and motivation have already initiated restoration projects focused on protecting specific indigenous species or habitats (Williams n.d.). To drive uptake, we believe working with organisations responsible for transferring knowledge to farmer catchment groups is key. These include primary industry bodies, local and regional councils, trusts that promote native plant establishment, and experts who can establish on-farm native plantings. We believe this approach provides an opportunity to shift farmer perceptions of native SNH from being a 'nice-to-have' to being recognised as an integral component of



Citations

1. Foundation for Arable Research 2018. FAR Focus Biodiversity https://www.far.org.nz/resources/far-focus-13-biodiversity (Accessed: 18 July 2024); 2. Beef + Lamb New Zealand n.d. Improving biodiversity https://beeflambnz.com/knowledge-hub/environmental-management/improving-biodiversity (Accessed 18 July 2024); 3. Synlait 2019. Whakapuāwai fact sheet. https://www.synlait.com/wp-content/uploads/2019/12/Synlait-Whakapuawai-Fact-Sheet_11122019.pdf (accessed 18 July 2024); 4. Fonterra n.d. Vegetation on farm, What Fonterra Does. https://indd.adobe.com/embed/e75cbd02-7f3f-4b7d-a7ca-1dac75cd5340?startpage=24&allowFullscreen=true (Accesssed 18 July 2024); 5. DairyNZ (n.d.). Riparian Planting. https://www.dairynz.co.nz/environment/waterbodies-and-wetlands/riparian-planting/ (Accessed18 July 2024); 6. Forest Owners Association n.d. Rare species, Guidance for mananging rare species in plantation forests. https://rarespecies.nzfoa.org.nz/ (Accessed 15 July 2024); 7. Environment Canterbury Regional Council 2023. Biodiversity Funding. https://www.ecan.govt.nz/your-region/your-environment/our-natural-environment/biodiversity-funding/ (29 June 2023); 8.Selwyn District Council n.d. Restoration Planting Projects. https://www.selwyn.govt.nz/community/our-natural-environment/restoration-planting-projects (Accessed 29 June 2023); 9. Ashburton District Council 2023. Biodiversity: Why native trees? https://www.ashburtondc.govt.nz/news/2023-news/biodiversity-why-native-trees (Accessed 15 July 2024); 10. Waimakariri District Council n.d. Significant Natural Areas. https://www.waimakariri.govt.nz/environment/significant-natural-areas (Accessed 15 July 2024); 11. Timaru District Council n.d. Biodiversity Policy https://www.timaru.govt.nz/council/publications/policies/biodiversity-policy (Accessed 15 July 2024); 12. Te Ara Kākāriki Greenway Canterbury Trust n.d. Our vision. https://kakariki.org.nz/about-us/#vision (Accessed 18 July 2024); 13. NZ Landcare Trust n.d. Farming with Native Biodiversity https://landcare.org.nz/project/farming-with-native-biodiversity/ (Accessed 15 July 2024); 14. Kānuka Mid Canterbury Regeneration Trust (n.d.) Draft Biodiversity Strategy Submission https://www.ashburtondc.govt.nz/__data/assets/pdf_file/0029/82487/KANUKA-MID-CANTERBURY-REGENERATION-TRUST-Rushton,-Claire.pdf (Accessed 15 July 2024); 15. Waimakariri biodiversity Trust n.d. https://www.wbt.org.nz/about (Accessed 15 July 2024); 16. Te Rūnanga o Ngāi Tahu 2023. Iwi farm's native planting 'intergenerational' https://ngaitahu.iwi.nz/connect-2/connect/media/former-pine-plantation-turning-native/ (Accessed 18 July 2024)

Figure 2. Stated benefits of establishing native SNH on Canterbury farmland identified within websites of different organisations. The node size of each benefit (left axis) corresponds with number of times the benefit was identified across organisations, while the node size of each organisation (right axis) corresponds with the total number of benefits recognised by that organisation. Lines connect the benefits promoted by each organisation. Primary industry organisations were selected based on major land uses across Canterbury (beef, sheep, and non-dairy livestock (1 547 317 ha), dairy (326 1352 ha), grain (229 257 ha) and forestry (89 077 ha) (StatsNZ 2021). Industry organisations that provide extension services to farmers were identified using the google search query: "Canterbury Plains" *(organization OR cooperative OR company) AND (farming OR agriculture) AND (information OR support OR resources), with the first ten pages reviewed. Google was used to search each council district, with the additional terms "biodiversity" and "native planting" and "trust" to identify native planting trusts from the first page results from each search. Website searches of each organisation were conducted using the terms "biodiversity", "native plantings", and "sustainability" to identify relevant material.

the agricultural landscape, delivering multifunctional farm/agricultural and community benefits

Application of the outlined research may also be transferrable to other regions and farming systems. In New Zealand, research is currently aiming to apply designed SNH to increase verified pollinators of kiwifruit (Howlett et al. 2022). However, the approach could be similarly applied across many other agricultural systems, throughout New Zealand and globally (Howlett et al. 2023).

There is also significant opportunity to re-evaluate existing native SNH to determine its value for supporting beneficial insects and their services. For example, New Zealand dairy farmers have established many thousands of kilometres of riparian plantings to reduce nutrient runoff into streams (Maseyk et al. 2017). Although this has not been designed to support beneficial insects, there may be unrecognised benefits from such plantings. Likewise, similar assessments of on-farm remnant vegetation provide opportunities for farmers to further value the presence of this SNH within their farming system.

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References

Aitken AG, Warrington IJ 2018. Fresh facts New Zealand horticulture. The New Zealand Institute for Plant & Food Research Ltd. 40 p.

Albrecht M, Kleijn D, Williams NM, Tschumi M, Blaauw BR, Bommarco R, Campbell AJ, Dainese M, Drummond FA, Entling MH, Ganser D, Arjen de Groot G, Goulson D, Grab H, Hamilton H, Herzog F, Isaacs R, Jacot K, Jeanneret P, Jonsson M, Knop E, Kremen C, Landis DA, Loeb GM, Marini L, McKerchar M, Morandin L, Pfister SC, Potts SG, Rundlöf M, Sardiñas H, Sciligo A, Thies C, Tscharntke T, Venturini E, Veromann E, Vollhardt IMG, Wäckers F, Ward K, Westbury DB, Wilby A, Woltz M, Wratten S, Sutter L 2020. The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: a quantitative synthesis. Ecology Letters 10: 1488–1498.

Alignier A, Raymond L, Deconchat M, Menozzi P, Monteil C, Sarthou JP, Vialatte A, Ouin A 2014. The effect of semi-natural habitats on aphids and their natural enemies across spatial and temporal scales. Biological Control 77: 76–82.

Andrew NR, Hill SJ 2017. Effect of climate change on insect pest management. In: Coll M & Wajnberg E eds. Environmental pest management: challenges for agronomists, ecologists, economists and policymakers. John Wiley & Sons Ltd., Oxford. Pp. 195–223.

Berndt LA, Wratten SD, Scarratt SL 2006. The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards. Biological Control 237: 50–55.

Bianchi FJJA, Booij CJH, Tscharntke T 2006. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society B: Biological Sciences 273: 1715–1727.

Blaauw BR, Isaacs R 2014. Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. Journal of Applied Ecology 51: 890–898.

Blitzer EJ, Dormann CF, Holzschuh A, Klein AM, Rand TA, Tscharntke T 2012. Spillover of functionally important organisms between managed and natural habitats. Agriculture Ecosystems & Environment 146: 34–43.

Bommarco R, Kleijn D, Potts SG 2013. Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution 28: 230–238.

Broussard MA, Howlett BG, Evans LJ, McBrydie H, Cutting BT, Read SFJ, Pattemore DE 2022. Pollinator identity and behavior affect pollination in kiwifruit (*Actinidia chinensis* Planch.). Peerj 10: e12963.

Carvalheiro LG, Veldtman R, Shenkute AG, Tesfay GB, Pirk CWW, Donaldson JS, Nicolson SW 2011. Natural and within-farmland biodiversity enhances crop productivity. Ecology Letters 14: 251–259.

Case BS, Forbes AS, Stanley MC, Hinchliffe G, Norton DA, Suryaningrum F, Jarvis R, Hall D, Buckley HL 2023. Towards a framework for targeting national-scale, native revegetation in Aotearoa New Zealand's agroecosystems. New Zealand Journal of Ecology 47: 3504.

Crowther LI, Wilson K, Wilby A 2023. The impact of field margins on biological pest control: a meta-analysis. BioControl 68: 387–96.

Curtis K, Bowie MH, Hodge S 2019. Can native plantings encourage native and beneficial invertebrates on Canterbury dairy farms? New Zealand Entomologist 42: 67–78.

Davidson MM, Howlett BG 2010. Hedging our bets: choosing hedgerow plants to enhance beneficial insects to optimise crop pollination and pest management on Canterbury farms The New Zealand Institute for Plant & Food Research Limited. 21 p.

Davidson MM, Howlett BG 2023 Native plants support more insect pollinator species than expected. The Wētā: 57: 23–28.

Deutsch CA, Tewksbury JJ, Tigchelaar M, Battisti DS, Merrill SC, Huey RB, Naylor RL 2018. Increase in crop losses to insect pests in a warming climate. Science 361: 916–919.

Dewes A, Burke J, Douglas B, Kincheff S 2022 Retiring Farmland into Ngahere. National Science Challenges, Our land and Water. 42 p.

Dicks LV, Breeze TD, Ngo HT, Senapathi D, An JD, Aizen MA, Basu P, Buchori D, Galetto L, Garibaldi LA, Gemmill-Herren B, Howlett BG, Imperatriz-Fonseca VL, Johnson SD, Kovacs-Hostyanszki A, Kwon YJ, Lattorff HMG, Lungharwo T, Seymour CL, Vanbergen AJ, Potts SG 2021. A global-scale expert assessment of drivers and risks associated with pollinator decline. Nature Ecology & Evolution 5: 1453–1461.

Donovan BJ, Howlett BG, Walker MK 2010. Relocation and establishment of nesting populations of the native bee *Leioproctus huakiwi* Donovan (Hymenoptera: Colletidae). New Zealand Entomologist 33: 109–113.

Dynes RA, Burggraaf VT, Goulter CG, Dalley DE 2010. Canterbury farming: production, processing and farming systems. Proceedings of the New Zealand Grassland Association 72: 1-8.

Early JW 1984. Parasites and predators. In: Scott RR ed. New Zealand pest and beneficial insects. Christchurch, Lincoln University of Agriculture. Pp. 271–308.

Environment Canterbury Regional Council 2023. Biodiversity funding. https://www.ecan.govt.nz/your-region/your-environment/our-natural-environment/biodiversity-funding/ (accessed 29 June 2023).

Feit B, Blüthgen N, Traugott M, Jonsson M 2019. Resilience of ecosystem processes: a new approach shows that functional redundancy of biological control services is reduced by landscape simplification. Ecology Letters 22: 1568–1577.

Ferguson CM, Barratt BI, Bell N, Goldson SL, Hardwick S, Jackson M, Jackson TA, Phillips CB, Popay AJ, Rennie G 2019. Quantifying the economic cost of invertebrate pests to New Zealand's pastoral industry. New Zealand Journal of Agricultural Research 62: 255–315.

Fiedler AK, Landis DA, Wratten SD 2008. Maximizing ecosystem services from conservation biological control: the role of habitat management. Biological Control 45: 254–271.

Fijen TPM, Read SFJ, Walker MK, Gee M, Nelson WR, Howlett BG 2022. Different landscape features within a simplified agroecosystem support diverse pollinators and their service to crop plants. Landscape Ecology 37: 1787–1799.

Foundation for Arable Research 2015. FAR focus integrated pest management https://assets.far.org.nz/uploads/FAR_Focus_12_-_IPM_-_Final.pdf (Accessed 7 August 2024).

Forbes A 2022. Review of actual forest restoration costs, 2021. Te Uru Rākau – New Zealand Forest Service. 23 p.

Gardiner MM, Landis DA, Gratton C, DiFonzo CD, O'Neal M, Chacon JM, Wayo MT, Schmidt NP, Mueller EE, Heimpel GE 2009. Landscape diversity enhances biological control of an introduced crop pest in the north-central USA. Ecological Applications 19: 143–154.

Garibaldi LA, Carvalheiro LG, Vaissiere BE, Gemmill-Herren B, Hipolito J, Freitas BM, Ngo HT, Azzu N, Saez A, Astrom J, An JD, Blochtein B, Buchori D, Garcia FJC, da Silva FO, Devkota K, Ribeiro MD, Freitas L, Gaglianone MC, Goss M, Irshad M, Kasina M, Pacheco AJS, Kiill LHP, Kwapong P, Parra GN, Pires C, Pires V, Rawal RS, Rizali A, Saraiva AM, Veldtman R, Viana BF, Witter S, Zhang H 2016. Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science 351: 388–391.

Gerard P, Barringer J, Charles J, Fowler S, Kean J, Phillips C, Tait A, Walker G 2013. Potential effects of climate change on biological control systems: case studies from New Zealand. BioControl 58: 149–162.

Goldson SL, Barker GM, Chapman HM, Popay AJ, Stewart AV, Caradus JR, Barratt BI 2020. Severe insect pest impacts on New Zealand pasture: the plight of an ecological outlier. Journal of Insect Science. 20: 5823977

Goodwin RM 2012. Pollination crops in Australia and New Zealand 12/059. Rural Industries Research and Development Corporation. 121 p.

Goodwin RM, Cox HM, Taylor MA, Evans LJ, McBrydie HM 2011. Number of honey bee visits required to fully pollinate white clover (*Trifolium repens*) seed crops in Canterbury, New Zealand. New Zealand Journal of Crop and Horticultural Science. 39: 7–19.

Gurr GM, Lu Z, Zheng X, Xu H, Zhu P, Chen G, Yao X, Cheng J, Zhu Z, Catindig JL 2016. Multi-country evidence that crop diversification promotes ecological intensification of agriculture. Nature Plants 2: 16014.

Hageman KJ, Aebig CH, Luong KH, Kaserzon SL, Wong CS, Reeks T, Greenwood M, Macaulay S, Matthaei CD 2019. Current-use pesticides in New Zealand streams: comparing results from grab samples and three types of passive samplers. Environmental Pollution 254: 112973.

Hooper DU, Chapin III FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75: 3–35.

Howlett BG, Donovan BJ, McCallum JA, Newstrom LE, Teulon DA 2005. Between and within field variability of New Zealand indigenous flower visitors to onions. New Zealand Plant Protection 258: 213–218.

Howlett B, Butler R, Nelson W, Donovan B 2013. Impact of climate change on crop pollinator activity in New Zealand. Ministry for Primary Industries. 45 p.

Howlett BG, Todd JH, Willcox BK, Rader R, Nelson WR, Gee M, Schmidlin FG, Read SFJ, Walker MK, Gibson D, Davidson MM 2021. Using non-bee and bee pollinator-plant species interactions to design diverse plantings benefiting crop pollination services. Advances in Ecological Research 64: 45–103.

Howlett BG, Davidson MM, Logan DP, Gee M, Read SFJ, Todd JH 2022. Designing semi-natural perennial plantings to support targeted pollinators for kiwifruit orchards. Acta Horticulturae 1332: 179–186.

Howlett BG, Broussard MA, Bordes N, Graham S, Gee M, Davidson MM, Nelson WR 2023. A roadmap for designing semi-natural habitat: plantings that benefit pollinators and people, not pests. Advances in Ecological Research 68: 91–127.

Kleijn D, Bommarco R, Fijen TPM, Garibaldi LA, Potts SG, van der Putten WH 2019. Ecological intensification: bridging the gap between science and practice. Trends in Ecology & Evolution 34: 154–166.

Korpela EL, Hyvönen T, Lindgren S, Kuussaari M 2013. Can pollination services, species diversity and conservation be simultaneously promoted by sown wildflower strips on farmland? Agriculture, Ecosystems & Environment 179: 18–24.

Kovacs-Hostyanszki A, Espindola A, Vanbergen AJ, Settele J, Kremen C, Dicks LV 2017. Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. Ecology Letters 20: 673–689.

Leathwick J, Morgan F, Wilson G, Rutledge D, McLeod M, Johnston K 2002. Land environments of New Zealand: a technical guide. Ministry for the Environment and Manaaki Whenua Landcare Research. 184 p.

Lu A, Gonthier DJ, Sciligo AR, Garcia K, Chiba T, Juarez G, Kremen C 2022. Changes in arthropod communities mediate the effects of landscape composition and farm management on pest control ecosystem services in organically managed strawberry crops. Journal of Applied Ecology 59: 585–597.

Lundin O, Ward KL, Williams NM 2019. Identifying native plants for coordinated habitat management of arthropod pollinators, herbivores and natural enemies. Journal of Applied Ecology 56: 665–676.

Macdonald KJ, Kelly D, Tylianakis JM 2018. Do local landscape features affect wild pollinator abundance, diversity and community composition on Canterbury farms? New Zealand Journal of Ecology. 42: 262–268.

Mansfield S, Ferguson CM, White T, Hardwick S, Marshall SD, Zydenbos SM, Heimoana SC, Gorddard R, Whitehouse ME 2019. Barriers to IPM adoption for insect pests in New Zealand pastures. Journal of New Zealand Grasslands 81: 139–148.

Mansfield S, Ferguson C, Gerard P, Hodges D, Kean J, Phillips C, Hardwick S, Zydenbos S 2021. Climate change impacts on pest ecology and risks to pasture resilience. In: Douglas GB (ed). Resilient Pastures – Grassland Research and Practice Series 17. New Zealand Grasslands Association. Pp. 123–138.

Maseyk FJ, Dominati EJ, White T, Mackay AD 2017. Farmer perspectives of the on-farm and off-farm pros and cons of planted multifunctional riparian margins. Land Use Policy 61: 160–170.

Maseyk FJ, Dominati EJ, Mackay AD 2018. A case for integrating indigenous biodiversity into on-farm planning. Journal of New Zealand Grasslands 30: 55–60.

Maseyk FJ, Small B, Henwood RJ, Pannell J, Buckley HL, Norton DA 2021. Managing and protecting native biodiversity on-farm–what do sheep and beef farmers think? New Zealand Journal of Ecology 45: 3420.

Meehan TD, Gratton C 2015. A consistent positive association between landscape simplification and insecticide use across the Midwestern US from 1997 through 2012. Environmental Research Letters 10: 114001.

Mei Z, de Groot GA, Kleijn D, Dimmers W, van Gils S, Lammertsma D, van Kats R, Scheper J 2021. Flower availability drives effects of wildflower strips on ground-dwelling natural enemies and crop yield. Agriculture, Ecosystems & Environment 319: 107570.

Meurk C 2008. Vegetation of the Canterbury plains and downlands. The natural history of Canterbury. Christchurch, University of Canterbury Press. Pp. 195–250.

Ministry for Primary Industries 2022. Regenerating Aotearoa: investigating the impacts of regenerative farming practices. Agriculture & Investment Services, Ministry for Primary Industries. 25 p.

Ministry for Primary Industries 2023. Situation and outlook for primary industries. Ministry for Primary Industries. 154 p.

Ministry for the Environment 2018. Data services. Change in farm size, 2002–16. Table ID: 95342. Ministry for the Environment. 1 p.

Ministry for the Environment & Stats NZ 2019. New Zealand's Environmental Reporting Series: Environment Aotearoa 2019. Ministry for the Environment 2019. Theme 2: How we use our land. ME 1416, Ministry for the Environment and Stats NZ, 125 p.

Ministry for the Environment & Stats NZ 2022. New Zealand's Environmental Reporting Series: Environment Aotearoa 2022. ME 1634, Ministry for the Environment and Stats NZ, 90 p.

Morse H. 2022. Modelling endemic and invasive species' biodiversity corridors in the southern North Island of Aotearoa New Zealand. Unpublished Masters thesis, Victoria University of Wellington, Wellington, New Zealand.

Müller U, Bruninga-Socolar B, Brokaw J, Cariveau DP, Williams NM 2024. Integrating perspectives on ecology, conservation value, and policy of bee pollinator seed mixes. Frontiers in Ecology and the Environment 22: e2715.

Nichols RN, Goulson D, Holland JM 2019. The best wildflowers for wild bees. Journal of Insect Conservation 23: 819–830.

Nicholson CC, Ward KL, Williams NM, Isaacs R, Mason KS, Wilson JK, Brokaw J, Gut LJ, Rothwell NL, Wood TJ, Rao S, Hoffman GD, Gibbs J, Thorp RW, Ricketts TH 2020. Mismatched outcomes for biodiversity and ecosystem services: testing the responses of crop pollinators and wild bee biodiversity to habitat enhancement. Ecology Letters 23: 326–335.

Osterman J, Landaverde-Gonzalez P, Garratt MPD, Gee M, Mandelik Y, Langowska A, Minarro M, Cole LJ, Eeraerts M, Bevk D, Avrech O, Koltowski Z, Trujillo-Elisea FI, Paxton RJ, Boreux V, Seymour CL, Howlett BG 2021. On-farm experiences shape farmer knowledge, perceptions of pollinators, and management practices. Global Ecology and Conservation 32: e01949.

Paini DR, Sheppard AW, Cook DC, De Barro PJ, Worner SP, Thomas MB 2016. Global threat to agriculture from invasive species. Proceedings of the National Academy of Sciences 113: 7575–7579.

Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J, Vanbergen AJ 2016. Safeguarding pollinators and their values to human well-being. Nature 540: 220–229.

Qian P, Bai Y, Zhou W, Yu H, Zhu Z, Wang G, Quais MK, Li F, Chen Y, Tan Y 2021. Diversified bund vegetation coupled with flowering plants enhances predator population and early-season pest control. Environmental Entomology 50: 842–851.

Rader R, Howlett BG, Cunningham SA, Westcott DA, Newstrom-Lloyd LE, Walker MK, Teulon DA, 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.

Rader R, Howlett BG, Cunningham SA, Westcott DA, Edwards W 2012. Spatial and temporal variation in pollinator effectiveness: do unmanaged insects provide consistent pollination services to mass flowering crops? Journal of Applied Ecology 49: 126–134.

Rader R, Cunningham SA, Howlett BG, Inouye DW 2020.

Non-bee insects as visitors and pollinators of crops: biology, ecology, and management. Annual Review of Entomology. 65: 391–407.

Rural News Group 2019. Native plantings paying dividends. https://ruralnewsgroup.co.nz/rural-news/rural-management/native-plantings-paying-dividends (Accessed 14 June 2023).

Schmidlin FG, Sullivan JJ, Bowie MH, Howlett BG 2018. Insect flower visitors of planted native species within the arable landscape on the Canterbury Plains, New Zealand. New Zealand Plant Protection 71: 198–206.

Schmidlin FG, Sullivan JJ, Bowie MH, Read SFJ, Howlett BG 2021. Small numbers of bee and non-bee pollinators detected moving between on-farm native plantings and neighbouring grass cropland. Journal of Asia-Pacific Entomology 24: 819–823.

Selwyn District Council n.d. Restoration planting projects. https://www.selwyn.govt.nz/community/our-natural-environment/restoration-planting-projects (accessed 29 June 2023).

Senapathi D, Frund J, Albrecht M, Garratt MPD, Kleijn D, Pickles BJ, Potts SG, An JD, Andersson GKS, Bansch S, Basu P, Benjamin F, Bezerra ADM, Bhattacharya R, Biesmeijer JC, Blaauw B, Blitzer EJ, Brittain CA, Carvalheiro LG, Cariveau DP, Chakraborty P, Chatterjee A, Chatterjee S, Cusser S, Danforth BN, Degani E, Freitas BM, Garibaldi LA, Geslin B, de Groot GA, Harrison T, Howlett B, Isaacs R, Jha S, Klatt BK, Krewenka K, Leigh S, Lindstrom SAM, Mandelik Y, McKerchar M, Park M, Pisanty G, Rader R, Reemer M, Rundlof M, Smith B, Smith HG, Silva PN, Steffan-Dewenter I, Tscharntke T, Webber S, Westbury DB, Westphal C, Wickens JB, Wickens VJ, Winfree R, Zhang H, Klein AM 2021. Wild insect diversity increases inter-annual stability in global crop pollinator communities. Proceedings of the Royal Society B-Biological Sciences 288: 20210212.

Shields MW, Tompkins JM, Saville DJ, Meurk CD, Wratten S 2016. Potential ecosystem service delivery by endemic plants in New Zealand vineyards: successes and prospects. PeerJ 4: e2042.

StatsNZ 2018. Land report highlights issues with soil degradation. https://www.stats.govt.nz/news/land-report-highlights-issues-with-soil-degradation#:~:text=192%20million%20tonnes%20of%20soil%20are%20lost%20every,the%20target%20range%20for%20phosphorus%20content%20and%20macroporosity. (accessed 27 November 2020).

StatsNZ 2021. Agricultural and horticultural land use. https://www.stats.govt.nz/indicators/agricultural-and-horticultural-land-use (accessed 5 July 2024)

Stavert JR, Pattemore DE, Bartomeus I, Gaskett AC, Beggs JR 2018. Exotic flies maintain pollination services as native pollinators decline with agricultural expansion. Journal of Applied Ecology 55: 1737–1746.

Stephens MJ, France CM, Wratten SD, Frampton C 1998. Enhancing biological control of leafrollers (Lepidoptera: Tortricidae) by sowing buckwheat (*Fagopyrum esculentum*) in an orchard. Biocontrol Science and Technology 8: 547–558.

Synlait 2019. Whakapuāwai fact sheet. 2 p.

Thomson LJ, Hoffmann AA 2013. Spatial scale of benefits from adjacent woody vegetation on natural enemies within vineyards. Biological Control 64: 57–65.

Tompkins JM 2010. Ecosystem services provided by native New Zealand plants in vineyards (New Zealand). Unpublished PhD thesis, Lincoln University, Lincoln, New Zealand.

Tscharntke T, Karp DS, Chaplin-Kramer R, Batary P, DeClerck F, Gratton C, Hunt L, Ives A, Jonsson M, Larsen A, Martin EA, Martinez-Salinas A, Meehan TD, O'Rourke M, Poveda K, Rosenheim JA, Rusch A, Schellhorn N, Wanger TC, Wratten S, Zhang W 2016. When natural habitat fails to enhance biological pest control - five hypotheses. Biological Conservation 204: 449–458.

Tschumi M, Albrecht M, Collatz J, Dubsky V, Entling MH, Najar-Rodriguez AJ, Jacot K 2016. Tailored flower strips promote natural enemy biodiversity and pest control in potato crops. Journal of Applied Ecology 53: 1169–1176.

van Toor RF, Viljanen-Rollinson SL, Teulon DA. 2008. Benchmarking of potato pesticide use in Canterbury. New Zealand Plant Protection. 61: 137–146.

van Toor RF, Viljanen-Rollinson SL, Rahman A, Teulon DA. 2013. Agrichemical use on wheat and barley crops in New Zealand in 2008–09. New Zealand Journal of Crop and Horticultural Science. 41: 9–22.

Williams K. n. d. Native plant communities of the Canterbury Plains. https://www.doc.govt.nz/globalassets/documents/conservation/native-plants/motukarara-nursery/canterbury-plains-plant-communities-book-full.pdf (accessed 20 August 2024).

Windsor FM, Tavella J, Rother DC, Raimundo RL, Devoto M, Guimarães Jr PR, Evans DM 2021. Identifying plant mixes for multiple ecosystem service provision in agricultural systems using ecological networks. Journal of Applied Ecology 58: 2770–2782.

Wratten SD, Gillespie M, Decourtye A, Mader E, Desneux N 2012. Pollinator habitat enhancement: benefits to other ecosystem services. Agriculture, Ecosystems & Environment 159: 112–122.

Yang F, Liu B, Zhu YL, Wyckhuys KAG, van der Werf W, Lu YH 2021. Species diversity and food web structure jointly shape natural biological control in agricultural landscapes. Communications Biology 4: 979.

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