



REVIEW

Harnessing spider biodiversity for sustainable horticulture: A call for research and conservation in Aotearoa New Zealand

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Abstract: The world is facing many pressing issues around food production and environmental sustainability. We are living in the sixth mass extinction event, driven by human activities including agricultural intensification, which has significantly affected invertebrate biodiversity. To address these issues, many scientists, growers, and policy makers are moving towards Integrated Pest Management (IPM) and restoring or creating natural or semi-natural habitats adjacent to or within food production ecosystems to conserve biodiversity whilst maintaining agricultural production. Despite spiders being the dominant, most abundant, and most diverse natural enemies of pests in horticultural ecosystems, their potential contribution to pest management has been understudied in Aotearoa | New Zealand. Internationally, many studies have shown the positive effects that spider abundance and diversity have on economically important food production systems, and many studies have demonstrated that enhancing adjacent habitat can conserve the biological control provided by spiders in these productive ecosystems. We highlight international studies that show positive effects of spider conservation on biological control in agroecosystems and discuss the few studies that have been completed on spiders in agriculture in Aotearoa | New Zealand. To date, only eight studies of spiders in agroecosystems have been published from Aotearoa | New Zealand and only a single study published on spiders in New Zealand horticultural ecosystems despite horticulture being a significant export market to countries that demand low chemical residue practices. All eight of these studies have been surveys of spider abundance and richness found in these systems, with a gap remaining in measuring the ecosystem functions they provide. We call for greater investment into research on spider conservation for biological control in Aotearoa | New Zealand to maximise the potential for ecologically friendly productive systems.

Keywords: Araneae, biological control, Integrated Pest Management (IPM)

Introduction

Since the end of World War II, chemical inputs into monoculture systems have become the standard way of growing food in the majority of countries around the world (Fountain 2022). The use of pesticides in these systems has been justified by economic gains in the form of increased yields; however, these increased yields have come at costs that are often difficult to measure economically. As well as costs to human health, the costs of pesticide use have been environmental: ecosystem degradation and biodiversity loss (Marc et al. 1999). This includes the loss of beta-diversity, which reduces the resilience in a system and leaves it more vulnerable to disturbances such as by invasive species and disturbance events, which are exacerbated by climate change (Ruberson et al. 1998; Cardoso et al. 2020; Blaise et al. 2022; Fountain 2022).

There is a growing body of evidence that we are in a sixth mass extinction event, driven by human activities, including agricultural intensification and broad-spectrum pesticide use (Barnosky et al. 2011; Ceballos et al. 2015; Hochkirch 2016; El Bilali et al. 2019; Cardoso et al. 2020; Blaise et al. 2022). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2019) states that at least one million species will face extinction in the coming decade, half of those species being insects (Cardoso et al. 2020). Although there is some disagreement on the degree of biodiversity loss due to the complexity of data collected, there is a consensus among experts that these losses are significant (Saunders et al. 2025). In order to reduce this decline, many scientists, growers, and policy makers are moving towards restoring or creating adjacent natural or semi-natural habitats alongside food production ecosystems (Cardoso et al. 2020; Blaise

et al. 2022; Rocher et al. 2024), and using Integrated Pest Management (IPM) as a way to conserve biodiversity whilst maintaining agricultural production (Allison 2017; Fountain 2022; Beaumelle et al. 2023; Hatteland et al. 2023).

Integrated Pest Management, defined as “combining knowledge of pests and plants with biological, cultural and chemical measures” (Ruberson et al. 1998) was a practice first conceptualised in the 1960s in response to observations of secondary pest outbreaks and increasing pest resistance to pesticides used in agriculture (Ruberson et al. 1998; Hatteland et al. 2023). Integrated Pest Management was adopted by many, including in Aotearoa | New Zealand, particularly in the pome (apples, pears, etc.) fruit industry (Walker et al. 2013). It is a voluntary practice in Aotearoa | New Zealand and elsewhere. However, recently IPM was made mandatory for all professional pesticide users in the European Union (EU) by the EU directive 2009/128/EC on sustainable use of pesticides (European Parliament and Council 2009). Regulations such as these and increasing withdrawals of pesticide approvals in many countries (Fountain 2022), alongside consumer pressure to reduce the amount of pesticide used in food production, are leading to an increased use of IPM and Conservation Biological Control (supporting populations of natural pest enemies) in agricultural production (Shaw et al. 2021).

Using natural enemies to control pests offers a pest control system that is low residue and increases biodiversity in a system. To maintain plant and soil biodiversity, while also supporting invertebrate biodiversity, natural habitats can be established and/or maintained within food production systems (Beaumelle et al. 2021; Blaise et al. 2022; Rocher et al. 2024). Increased biodiversity can increase ecosystem resilience to disturbance events and potential future environmental changes (Fountain 2022), increase carbon sequestration by increasing the number of trees planted on land, and provide aesthetic incentives for farmers to employ environmentally friendly practices (Maseyk et al. 2021). Importantly, increased invertebrate biodiversity can also increase pest regulation in food production systems, providing economic benefit to the grower while simultaneously reducing a reliance on chemical interventions (Shaw et al. 2021). For example, Fountain (2022) found that in apple orchards with wildflower alleys and no pesticides applied for five years, only 9.2% of the fruit was damaged compared with the 32.5% of fruit damaged in orchards with no wildflower alleys.

Horticulture is a significant export market for Aotearoa | New Zealand to countries that demand low-residue practices (horticultural exports totalled NZ\$5.09 billion in 2024; United Fresh 2024). Pest insects are a big cost to horticulture. For example, the passionvine hopper (*Scolypopa australis*) costs the Aotearoa | New Zealand kiwifruit industry an estimated \$77 million per year (Wilson & Barker 2020). The brown marmorated stink bug (*Halyomorpha halys*) has been estimated to have the potential to cost Aotearoa | New Zealand \$2–30 billion over 20 years if it establishes (NZIER 2017). The apple industry was an early adopter of IPM in Aotearoa, which produced economic benefits of NZ\$113 million between 2008 and 2011 (NZ\$165 million in today’s dollars [December 2024] when accounting for inflation) (Walker et al. 2017) and these benefits still continue today. If New Zealand can maintain a negligible risk of pest insects on export fruit, as well as no chemical residues on fruit, there are lucrative opportunities to access markets such as Japan and Europe, which have stringent phytosanitary requirements (Walker et al. 2013).

Of the natural enemies found in horticultural systems,

spiders (Araneae) are the dominant, most abundant, and most diverse (Sunderland 1999; Benamú et al. 2017; Michalko et al. 2019b; Blaise et al. 2022). Almost all spiders are generalist predators distributed across multiple trophic levels. They occupy a wide variety of spatial niches, employ a diverse range of hunting strategies, and can kill all life-stages of a pest (Sunderland 1999). As well as direct consumption of prey, spiders also reduce pest populations via non-consumptive effects (Sunderland 1999; Hogg et al. 2014; Michalko et al. 2019a). Spiders will often over-kill, partially feed on, or wound prey items, which still results in preventing the pest from damaging the crop. Spider webs kill small pests (e.g. thrips, aphids, midges) that are sometimes ignored by the spider, thus removing more pests from the crop system than are removed by feeding alone. These qualities set them apart from other beneficial arthropod predators that rarely have non-consumptive behaviours (e.g. Dermaptera and predatory Coleoptera).

Due to the generalist predatory nature of spiders, some intraguild predation does occur, and quantifying the impact of intraguild predation is complex, with some studies indicating intraguild predation has a negative effect on the biological control of pests (Snyder & Ives 2001; Finke & Denno 2002), and other studies indicating a negligible effect (Janssen et al. 2006; Gontijo et al. 2015). Intraguild predation can be reduced by providing complex habitats for spiders to live in (Finke & Denno 2002; Gontijo 2019). When heterogeneous vegetation is included within or adjacent to a crop system, the chance of direct encounters between predators is reduced, which in turn reduces antagonistic interactions (Finke & Denno 2002). Heterogeneous vegetation can also provide a niche for alternative prey, which has been found to reduce intraguild predation (Gontijo 2019). This mitigation for intraguild predation aligns with conservation biological control practices.

When observed as an entire group within an ecosystem, spiders consume a wide range of prey; whereas, when dividing spiders into separate guilds, or looking more specifically at an individual spider species’ hunting strategy and location within an environment, each species can be viewed as a fairly specialised predator (Marc & Canard 1997; Marc et al. 1999; Uetz et al. 1999; Cardoso et al. 2011). For this reason, not only is it important to investigate the contribution of spiders as a whole group to ecosystem function, but also to investigate spider foraging and diet behaviour for spider species individually to understand the relative importance of a particular species or functional guild of spiders in a horticultural setting.

Being in the midst of a mass extinction event, coupled with political and consumer pressure for reduced pesticide use and alternative pest management strategies, now is the time to focus research efforts on ecologically friendly biological control options to enhance IPM regimes in our productive systems. In this review, we set out to (1) explore international research on spiders as biological control agents that could provide valuable lessons to Aotearoa | New Zealand, (2) review the state of research on spiders as biological control agents within Aotearoa | New Zealand, and (3) highlight knowledge gaps and make recommendations for applied arachnological studies in New Zealand horticultural systems going forward.

International research

Internationally, there is an increasing body of evidence to show the importance of spiders in horticultural systems. Spiders

have been found to be the most abundant predators in both agricultural fields and in orchard systems (Hogg & Daane 2011; Nyffeler & Birkhofer 2017; Michalko et al. 2019b). In Chinese cotton fields, Zhang (1992) found that spiders make up 55–81% of the natural enemies present. Similarly, Costello & Daane (1999) found spiders constituted 98.1% of all predatory arthropods collected in a Californian vineyard. In Pakistani citrus orchards, Maqsood et al. (2016) found spider abundance to be at its highest during the months when prey insect numbers were also greatest, suggesting spiders are a large consumer of the prey insects in citrus.

Feeding guilds and ecological niches of spiders

Spiders are distributed across a wider range of spatial niches than any other generalist predators (Vink et al. 2017; Michalko et al. 2019b; Rezáč et al. 2023) and occupy many different functional guilds (Uetz et al. 1999; Cardoso et al. 2011). Spiders differ by foraging strategy, prey range, vertical stratification, and circadian activity (Cardoso et al. 2011). Uetz et al. (1999) proposed eight different spider guilds: foliage runners, ground runners, stalkers, ambushers, sheet web-builders, tangle weavers, orb weavers, and space web builders. Cardoso et al. (2011) also identified eight different spider guilds, although slightly different from Uetz et al. (1999): sensing web-builder, sheet web-builder, space web-builder, orb weaver, specialist, ground hunter, ambush hunter, and other hunter. The number and variety of guilds and spatial niches demonstrate that spiders are likely to have an even larger ecosystem role than we currently understand and are likely to provide key ecosystem services in agroecosystems.

Spider biodiversity and abundance affected by land use

Several studies have shown that increasing spider abundance in cropland is associated with adjacent non-crop habitat (Clough et al. 2005; Baba & Tanaka 2016; Havlova et al. 2017). Baba and Tanaka (2016) found that two major spider groups (*Tetragnatha* and *Lycosidae*) were more abundant in rice paddies throughout Japan where there was a forest area within a 200 m radius of the paddy field. Similarly, more spider species were found along natural field edges and in heterogeneous landscapes in German cereal crops (Clough et al. 2005). Blaise et al. (2021) used a sentinel prey experiment in Mediterranean vineyards to demonstrate that predation activity by spiders was higher in vineyards that had all inter-rows vegetated with grass-legume mixtures than in tilled vineyards. Both diurnal and nocturnal species showed a positive functional response to increasing non-productive vegetation within a growing system. In addition, Hogg and Daane (2018) found that establishment of spiders in crop habitats depended more on suitable habitat than the dispersal ability of the spider. Similarly, in pistachio orchards in South Africa, Haddad et al. (2005) found habitat structure to have an influence on spider colonisation rates, as well as on the presence of conspecifics, the abundance and availability of prey, and interspecific competition. Marin et al. (2016) showed that spider biodiversity and abundance in Mexican coffee plantations was strongly influenced by agricultural habitat, including canopy cover, shade tree richness, shade tree density, and the proportion of *Inga* trees (a shade tree often

found in coffee plantations). They highlighted the importance of conserving a diverse mosaic of plants in coffee plantations to provide refugia for spider biodiversity throughout the seasons and associated weather events.

Spider abundance and biodiversity has been found to be influenced not only by local vegetation, but also by land-use management (Argañaraz et al. 2020). In a review of management practices to shelter natural enemies, Gontijo (2019) found the following management techniques enhanced conservation of spider-mediated biological control in field crops: intercropping, no-till farming, preservation of non-crop vegetation, flower-strip cultivation, increasing connectivity between cropland and unmanaged habitats, and the use of selective insecticides. These practices helped natural enemies by providing them with alternative food sources, suitable microclimates, and protection from intraguild predation and direct contact with pesticides (Gontijo 2019).

Positive functional effects of spiders

It has been estimated that spiders consume up to 800 million tons of (mostly) invertebrate prey globally per year (Nyffeler & Birkhofer 2017). Although currently only 2% of this occurs in annual crops, this presents an immense potential for spider-based biological control in food production systems if spiders can be conserved and encouraged into these systems. In laboratory trials, Zhang (1992) found that *Hylyphantes graminicola* (Sundevall, 1830) can consume 20–45 cotton aphids per day. These small, abundant linyphiid spiders overwinter as adults in wheat, bean, or rape fields, then move into cotton fields before summer and increase in density, with a peak of 50 spiders per plant. At this density spider:aphid ratios were between 1:0.13 and 1:0.34 and cotton aphid populations were kept under control. Hooks et al. (2003) used natural colonisation of lepidopteran caterpillars in broccoli to assess the role of spiders and birds in the predation control of these economic pests. By excluding either spiders, birds, spiders and birds, or neither, the authors determined that both spiders and birds, alone or together, suppressed pest caterpillar numbers and reduced plant damage by up to 89%. Similarly, in Californian orchard systems, Hogg et al. (2014) found two hunting spiders reduced the population of a key horticultural pest *Epiphyas postvittana* (Lepidoptera: Tortricidae) below a damage threshold. In addition, Nakasuji et al. (1973) experimentally investigated the role spiders play in controlling *Spodoptera litura* (Lepidoptera: Noctuidae) in avocado orchards and found that spider predation greatly limited damage. In their review of spiders' role in pest limitation, Marc et al. (1999) conclude that the efficacy of spiders as pest control agents has been demonstrated unambiguously. The authors do caution that not all spiders are effective against all pests in all agroecosystems, so individual spider species, or at least guilds, need to be studied and understood to produce the most effective biological control, and they note that spiders' efficacy in controlling invertebrate pests is most obvious in orchards compared with other agroecosystems. This has significant implications for Aotearoa | New Zealand where our greatest export earners are orchard fruits i.e. kiwifruit, apples, and wine grapes (United Fresh 2024).

A recent study (Wilder et al. 2024) has demonstrated that the positive functional effects of spiders go beyond pest suppression. The nutrient content of soil in the presence

and absence of two different spider functional groups (web-builder and wandering spider) was analysed for soil nutrient content, soil respiration, soil microbial communities, and plant growth. The waste from both functional groups of spiders was found to have a positive effect on soil nutrient content, soil respiration, and plant growth, and had a large effect on the composition of the soil microbial community (Wilder et al. 2024). Microbial communities have been shown to have large impacts on plant growth and soil health (Williams et al. 2013; Wicaksono et al. 2017; Purushotham et al. 2018) but there are still large knowledge gaps around microbial communities and the functional effects they have. Now that the science capability is available, Aotearoa | New Zealand should investigate how spiders affect microbial communities in agroecosystems, given that spiders are a largely mobile and ubiquitous occupier in these environments and could potentially add growth and value to our key economic crops.

Spiders negatively affected by agrichemicals

When assessing the role spiders play in agroecosystems, it is important to recognise the effects horticultural management practices have on spider populations. Many agrichemicals (e.g. acaricides, insecticides, fungicides, herbicides) have been shown to have both lethal (Mansour & Nentwig 1988; Pekár 2002) and non-lethal but still harmful (Hanna & Hanna 2014; Schmidt-Jeffris et al. 2022; Reiff et al. 2024) effects on spiders, including on feeding performance, which influences the effectiveness of spiders as biological control agents (Pekár 2012; Benamú et al. 2017; Boyd et al. 2022). Spiders may consume intoxicated prey, or be directly sprayed with the agrichemical, or contact agrichemicals via contact with a potential prey item (without consumption). The effect of these chemicals ranges in severity depending on the spider species and what type of agrichemical is used. Insecticides, acaricides, fungicides, and herbicides have been shown to each have a different effect on the spider *Theridion impressum* (L. Koch, 1881) (Pekár 2002), with insecticides and acaricides having the most lethal effect, followed by fungicides and then herbicides. The type of insecticide can also have a large effect. Broad-spectrum insecticides more frequently have a lethal effect whereas some selective insecticides have been found not to harm spiders (Pekár 2002; Lacava et al. 2020). Agrichemicals have a large effect on web-building, which again affects invertebrate suppression ability; the higher the agrichemical dose, the more detrimental the effect on web building (Pekár 2012; Benamú et al. 2013; Benamú et al. 2017). Samu et al. (1992) showed the spider webs of the orb weaver *Araneus diadematus* (Clerck, 1757) readily accumulated agrichemicals under lab conditions, demonstrating that web-building spiders are very exposed to these sprays in agroecosystems via contact with their webs. Benamú et al. (2013) found the web-building spider *Alpaida veniliae* (Keyserling, 1895) was adversely affected by insecticides in several ways: prey consumption ability, web-building, abnormal egg sacs, and decreased fecundity and fertility.

In addition to feeding performance, pesticides have been found to affect the abundance and diversity of spiders, with different guilds being affected to different extents. When assessing the abundance of spiders in Uruguayan lemon crops with different management strategies, Benamú et al. (2017) found 62.08% of the total abundance of spiders came from insecticide-free lemon crops compared with 37.92% in

conventional lemon crops. Likewise, Beaumelle et al. (2023) found spider abundance was 86% higher in organic viticulture. Moreover, species richness was 36–51% higher in spider and other ground- and foliage-dwelling arthropods in organic vineyards compared with conventional vineyards (Beaumelle et al. 2023). Furthermore, an interaction with adjacent land-use was observed. In organic vineyards, species richness of foliage spiders increased with the percentage of semi-natural habitat present, and ground spiders increased with decreasing distance from semi-natural habitat. However, in conventional vineyards the opposite was observed: species richness of foliage spiders decreased with the percentage of semi-natural habitat present, and ground spiders decreased with increasing distance from semi-natural habitat (Beaumelle et al. 2023).

Because of spiders' sensitivity to many agrichemicals, spiders have been used as disturbance bioindicators related to acaricides, insecticides, fungicides, and herbicides (Benamú et al. 2017). In a recent study, Michalko et al. (2024) investigated how pesticides permeate through food webs in Czech Republic food crops using four different trophic levels: soil, plants, rodents, and spiders. The authors found levels of insecticide and fungicide bioaccumulation increased with trophic level, making spiders an appropriate organism to study for pesticide residues. This study uncovered a disturbing but important finding that some harmful pesticides that were banned from use in Europe several years ago can still be detected in food webs now.

Spider studies in Aotearoa | New Zealand

There have been no published studies to date that have directly estimated the role of spiders in pest management in Aotearoa | New Zealand. The published studies of spiders in New Zealand's agroecosystems (Table 1) have been predominantly in arable crop or pasture systems (Topping & Lövei 1997; McLachlan & Wratten 2003; Clark et al. 2004; Vink et al. 2004; Curtis 2019) with just one study in carrots (Sivasubramaniam et al. 1997), one in beans (Hodge & Vink 2000), and one study in horticultural systems (vineyards, apples, and kiwifruit; Table 2) (Sullivan et al. 2023). These studies have essentially been surveys of spiders found in these systems, with a gap remaining in measuring the ecosystem functions they provide.

Sampling methods

Sampling methods used to survey spiders can influence the species observed because spiders occupy many different niches within an ecosystem. Three of the eight studies mentioned above used suction sampling exclusively as the sampling method (Table 2). Vink et al. (2004) conducted suction sampling in cereal crops (ryegrass, fescue, cocksfoot, prairie grass, wheat, and barley) in Canterbury, while McLachlan & Wratten (2003) suction sampled pasture crops and adjacent shelter belts in Canterbury. Clark et al. (2004) looked at the effect of pasture cultivation on spider density and diversity. *Tenuiphantes tenuis* (Blackwall, 1852) was the dominant species caught in all three of these studies (McLachlan & Wratten 2003; Clark et al. 2004; Vink et al. 2004). Curtis (2019) sampled pasture crops in Canterbury using suction sampling, but in addition, employed several other sampling techniques (pitfall traps, ground hand collection, sweeping) to assess their relative

Table 1. A summary of the published studies of spiders in Aotearoa | New Zealand agroecosystems as of November 2024.

	Crop system	Sampling methods	Number of spider families caught	Number of spider species caught
Sivasubramaniam et al. (1997)	Carrot	Pitfall traps Malaise traps	5	6
Topping and Lövei (1997)	Pasture Wheat	Suction sampling Hand collection Pitfall traps	10	23
Hodge and Vink (2000)	Beans	Pitfall traps	7	Not assessed
McLachlan and Wratten (2003)	Pasture	Suction sampling	7	28
Clark et al. (2004)	Pasture	Suction sampling	11	16
Vink et al. (2004)	Cereal crops Grasses	Suction sampling	5	20
Curtis (2019)	Pasture	Suction sampling Hand collection Pitfall traps Sweep netting	12	28
Sullivan et al. (2023)	Vineyard Apple Kiwifruit	Hand collection Pitfall traps Sweep netting	17	31

effectiveness. Curtis (2019) found suction sampling collected only 22.5% of the estimated number of species in Canterbury pastures, compared with pitfall trap sampling collecting 92% and ground hand collection 80.7%. Therefore, the suction sampling method likely underestimated the number of species observed in the previous studies (McLachlan & Wratten 2003; Clark et al. 2004; Vink et al. 2004). Many spider species can hold on to vegetation and not be collected by the suction sampling method. Indeed, Clark et al. (2004) found 60–90% of spiders collected were from the family Linyphiidae. These are very small (1–6 mm; Paquin et al. 2010) dwarf sheet-web spiders that are able to be suction sampled effectively, and use ballooning as a dispersal method (Blandenier 2009). The remaining spiders observed were mostly juvenile Araneidae, Theridiidae, and Lycosidae. Araneidae and Theridiidae have also been found to commonly use ballooning as a dispersal method (Blandenier 2009). Future studies assessing spider populations should employ several different sampling methods to gain a full picture of the biodiversity present.

Common species observed in Aotearoa | New Zealand agroecosystems

All the Aotearoa | New Zealand agricultural spider studies have found Linyphiidae (predominantly the introduced species *Tenuiphantes tenuis*) and Lycosidae (predominantly the endemic *Anoteropsis hilaris*, L. Koch, 1877) as the dominant spiders in these ecosystems (Table 2). Linyphiidae and Lycosidae are both ground dwellers, do well in modified systems in other parts of the world, and are quick to colonise a habitat after a disturbance event (Noel & Finch 2010; Malumbres-Olarte et al. 2013). *Tenuiphantes tenuis* frequently balloons to allow movement over large distances (Blandenier 2009).

Due to international studies also commonly observing Linyphiidae and Lycosidae, these families are to be expected. However, suction sampling and pitfall traps, which have largely been used in Aotearoa | New Zealand studies, do catch

higher numbers of Linyphiidae and Lycosidae than other sampling methods such as active sampling, sweep netting or beating trays, potentially creating a sampling bias. Aotearoa | New Zealand also has a high endemic population of spiders (approx. 93%; Paquin et al. 2010), so one might expect a higher number of endemic species. *Anoteropsis hilaris* is an endemic species, but the only one frequently observed (Table 2). That few native species are numerically dominant may indicate effective isolation between agroecosystems and native areas.

Physical crop structure affects spider populations

Compared with crop and pasture systems, there is likely to be a higher abundance and diversity of spiders in horticultural systems, given that orchards present a more complex vegetative ecosystem structure, which has been found to positively influence spider diversity and abundance (Abdul et al. 2011; Benamú et al. 2017). Additionally, orchards are arguably a less disturbed productive system where orchard trees are left to stand for many years as opposed to the higher turnover of pasture and cereal crops. However, only one study has targeted spiders in Aotearoa | New Zealand horticultural systems (Sullivan et al. 2023). Sullivan et al. (2023) conducted spider surveys in Aotearoa | New Zealand vineyards, apple, and kiwifruit orchards using active searching, sweep netting, and pitfall sampling, and found 31 different species of spiders compared with 20 spider species found in arable crops and grasses by Vink et al. (2004), 13 spider species found in pasture by McLachlan and Wratten (2003), and 28 spider species in pasture by Curtis (2019). This aligns with international studies, such as Abdul et al. (2011), that found that the more complex the branch structure, the more spiders were present in citrus and guava crops in Pakistan. Haddad et al. (2005) looked at spiders in pistachio orchards and found spiders from the family Salticidae were dominant. They found the density of canopy spiders was typically correlated with an increase in density of branches. To obtain a full view of the spider fauna of

Table 2. A list of the spider species that have been found in Aotearoa | New Zealand agroecosystems, the functional guild they belong to according to Cardoso et al. (2011), and which of the eight published studies they were found in. The study system is noted in italics. Native to Aotearoa | New Zealand = (n), exotic = (x), unknown = (u).

Family	Functional guild	Species	Clark et al. (2004) <i>Pasture</i>	Curtis (2019) <i>Pasture</i>	McLachlan and Wratten (2003) <i>Pasture</i>	Topping and Lövei (1997) <i>Pasture/Cereal</i>	Vink et al. (2004) <i>Cereal/Grasses</i>	Sivasubramaniam et al. (1997) <i>Carrot</i>	Hodge and Vink (2000) <i>Beans</i>	Sullivan et al. (2023) <i>Orchards</i>
Amaurobiidae	Sheet web weaver	<i>Amaurobiidae</i> sp. (n)								*
Anapidae	Orb weaver	<i>Novanapis spinipes</i> (n) <i>Taphiassa punctata</i> (n)					*			
Araneidae	Orb weaver	<i>Arachnura</i> sp. (u) <i>Celaenia excavate</i> (x) <i>Novakiella trituberculosa</i> (x)	*							*
		<i>Salsa fuliginata</i> (x) <i>Socca pustulosa</i> (x)		*						*
Clubionidae	Other hunter	<i>Clubiona clima</i> (n)	*			*				
Corinnidae	Ground hunter	<i>Nyssus coloripes</i> (x)		*				*		*
Cyatholipidae	Sheet web weaver	<i>Tekelloides</i> spp. (n)				*				
Desidae	Ground hunter	<i>Badumna longinqua</i> (x) <i>Badumna insignis</i> (x)		*						*
Dysderidae	Specialist	<i>Dysdera crocata</i> (x)		*						*
Gnaphosidae	Ground hunter	<i>Anzacia gemmea</i> (n) <i>Hemicloea rogenhoferi</i> (x) <i>Intruda signata</i> (x) <i>Nauhea tapa</i> (n)	*	*		*				*
Idiopidae	Sensing web weaver	<i>Cantuaria dendyi</i> (n)		*						*
Lamponidae	Specialist	<i>Lampona cylindrata</i> (x)		*						*
Linyphiidae	Sheet web weaver	<i>Araeoncus humilis</i> (x) <i>Diploplecta communis</i> (n) <i>Diploplecta cristatus</i> (x) <i>Diploplecta simplex</i> (n) <i>Erigone prominens</i> (x) <i>Erigone wiltoni</i> (x) <i>Haplina exigua</i> (n) <i>Haplina fucatina</i> (n) <i>Haplina inexacta</i> (n) <i>Haplina mundenia</i> (n) <i>Haplina titan</i> (n) <i>Laetesia germana</i> (n) <i>Laetesia minor</i> (n) <i>Mermessus fradeorum</i> (x) <i>Microctenonyx subitaneus</i> (x) <i>Mynogleninae</i> (n) <i>Ostearius melanopygius</i> (x)		*	*		*	*	*	*

Aotearoa | New Zealand agroecosystems, it will be important to sample in horticultural systems and not extrapolate from pasture systems.

Spiders negatively affected by agrichemicals

There is one published study on the effect of herbicides on spiders in Aotearoa | New Zealand (Evans et al. 2009). This study was to determine the effect of two herbicides and a surfactant on the spider *Steatoda capensis* as a proxy for the endemic Katipō spider (*Latrodectus katipo*). The herbicides were not found to have an effect on spider mortality, but the surfactant increased mortality by 35%. Research on the effect of agrichemicals in Aotearoa | New Zealand spider populations should be conducted to ascertain recommendations for growers on which agrichemicals would be safest to use to conserve spider populations and the ecosystem services they provide. Given it has been shown that different functional groups of spiders are affected differently by agrichemicals (Reiff et al. 2024), it is clear we have a long way to go when we do not have a robust knowledge of what spiders are present in Aotearoa | New Zealand agroecosystems.

Ecological spider studies in New Zealand with implications for agroecosystems

Using pitfall trapping and turf extraction, Malumbres-Olarte et al. (2013) studied the response of spider communities to fire in Aotearoa | New Zealand native grassland habitat. They found the number of functional groups and the diversity of spiders decreased after grassland burning events, and the density of individuals of generalist species increased. This could be a generalised response to a disturbance event and could have implications for spiders in crop ecosystems, which frequently experience disturbance events related to crop management. If crop disturbance events in Aotearoa | New Zealand lead to decreased diversity and higher abundance of generalist species, this would likely decrease complementarity which could in turn lead to higher intraguild predation and less effective biological control. Research to investigate this in a New Zealand context would be beneficial.

There have been several Aotearoa | New Zealand agricultural studies where spiders have been mentioned, but not focused on (Berry et al. 1996; Wardle et al. 1999; Todd et al. 2016; Malone et al. 2017, 2018). These studies do not separate spiders into detailed taxonomic units, and do not sample specifically for spiders, therefore it is likely many spider species and whole functional guilds have been omitted, as spiders occupy many different location niches within an environment and different sampling methods will catch different spider groups (Costello & Daane 1997; Curtis 2019).

Conclusions and Recommendations

Europe and the USA began investigating the role spiders play in the control of pests under experimental conditions in the 1970s (Marc et al. 1999). Research began by improving the knowledge of spider communities in agroecosystems. Marc et al. (1999), Uetz et al. (1999) and Fountain (2022) all emphasise the importance of understanding the biology,

ecology and interactions of spiders present before moving on to designing habitats to support biological control. These details include quantitative estimates, timing of hunting activity, details of predation and diet composition, and the population dynamics between predator and prey abundance.

To understand the potential spiders could have in Conservation Biological Control in horticulture in Aotearoa | New Zealand, we need to first establish a solid foundation of knowledge. We need to assess what spider species are present and in what numbers in Aotearoa | New Zealand's horticultural systems and understand the life history and functional traits of these species. We then need to go beyond that and address knowledge gaps for Aotearoa. Whilst international studies in Europe and the Americas have investigated interactions between spider populations and pesticides, landscape and local management factors, predation activity levels, ecosystem function, and soil network interactions, the eight spider studies in Aotearoa | New Zealand agroecosystems have focussed primarily on simply describing what spiders are present (richness and abundance). There is much room to expand our knowledge on the role of this important predator group in Aotearoa | New Zealand horticultural systems and the interactions they shape within these ecosystems. Future research should focus on the effectiveness of spiders as biological control agents, and whether this ecosystem service can be enhanced by local and landscape factors. Research should then go on to understand if and how spiders play a role in shaping the pesticide residues within a landscape. Interdisciplinary studies should be conducted to understand the network connections spiders make in agroecosystems, such as what microbial communities are being moved along with the spiders, and how spider waste affects the soil in these systems. Addressing these research questions will inform our practices around increasing biodiversity, increasing functional diversity, and creating more resilient systems, particularly in the face of climate change and increasing pest incursions. Further research will also enhance the ecosystem services that spiders can provide as biological control agents of pest invertebrates. The potential for spiders to contribute to a pressing problem of feeding the world in a sustainable way into the future is there. We need to invest in research to address these questions to maximise the potential for ecologically friendly productive systems in Aotearoa | New Zealand.

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