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SPIDER DISTRIBUTION IN AGROECOSYSTEMS

IN CANTERBURY, NEW ZEALAND

A thesis

submitted in partial fulfilment

of the requirements for the Degree of

Doctor of Philosophy

at

Lincoln University

by

A.R.G. McLachlan

Lincoln University

2000

This thesis is dedicated to the memory of

Ellen Annie Tricker

20.i.1922 – 22.ix.1996

Nana... naturalist... hardcase

and

Josephus Joannes Schepers

17.ii.1931 – 21.i.2000

friend

I am glad I did it, partly because it was well worth it, and chiefly because I shall never have to do it again.

Mark Twain

Intriguing paradoxes define the spider persona as presently understood. The spider is food limited, yet does not compete for prey. Thus spiders do not consume enough prey to lower the prey availability substantially for other spiders. This suggests that spiders do not limit population densities of their prey. Furthermore, the foraging behavior of spiders and their life history characteristics lead to the prediction that spiders should not regulate prey populations, i.e. should not inflict pronounced density-dependent mortality on their prey. Thus individual species of spiders should not be good biocontrol agents in agroecosystems. Indirect evidence, based on estimates of energy flow through the entire community, and direct evidence from field experiments contradict these expectations. However, experimental studies are too few in number to support firm generalizations about the role of spiders in limiting insect numbers. Results so far lead to an enigmatic portrait of the spider persona; its role is clear in some scenes, but only dimly perceived in other acts. Many scripts it follows are still obscure.

David Wise, 1993.

Spiders in ecological webs. Cambridge University Press. p. 262.

Abstract

The spider assemblage from four shelterbelts and their adjacent grazed pastures in South Island, New Zealand was suction sampled from August 1994 to July 1995 and from March 1996 to March 1997. Spider density decreased rapidly with distance from the field margin (mean 241/m²) to 72.5/m² at 2.5 m and 10.3/m² at 5 m into the pasture. Fenced shelterbelts had 6.7 times more spiders and 3-10 more species than did the adjacent pasture. The most common pasture species was the European linyphiid *Lepthyphantes tenuis* (Blackwall) (37% of individuals) but, in shelterbelts, *L. tenuis* was equally common at 26% with an unidentified endemic theridiid species at 25%.

Eleven shelterbelts were suction sampled in November 1995 and had spider densities ranging from 62/m² to 369/m², and species richness ranging from 6 to 12 from a 1 m² sample area at each site. Twenty-three species were recorded; three were introduced European linyphiids, the rest were native or endemic to New Zealand.

Spider density was compared in three pasture types (cocksfoot and clovers, lucerne, and ryegrass and clovers) both in open and agroforestry pasture (between rows of *Pinus radiata* trees). There were no differences between either open and agroforestry pasture, or the three pasture types. Spider density was not correlated with vegetation height or cover, although *L. tenuis* density was positively correlated with vegetation height characteristics in open pasture.

Mowing ungrazed pasture plots reduced both spider density and species richness. Unmown plots had a fauna and density similar to those of shelterbelts, but mown plots had a density similar to those in grazed pasture.

Field cage experiments in a lucerne (*Medicago sativa* L.) crop and in broad bean (*Vicia faba* L.) plots to investigate the effects of spider density on pea aphid (*Acyrtosiphon pisum* (Harris)) abundance, showed that a large number of replicates (46 or more) were needed to detect differences in aphid abundance between spider density treatments. Aphid densities reached unnaturally high levels due to the sheltered cage conditions.

The results are discussed in the context of the effects of pastoral agricultural practices in New Zealand on spider density, distribution, species composition, and potential in pest management.

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Chapter 1: General introduction

In modern intensive agriculture, there is an increasing need for diminished use of chemicals to control plant pests and diseases. This reduction is driven both by consumer resistance to products grown using pesticides, hence the growth of the 'organic' food industry (e.g., Snowden and Wratten, 2000), and pesticide resistance in target organisms, either requiring newer (and thereby expensive to develop) pesticides or alternative practices to control the pests (van Emden and Peakall, 1996). Alternative non-chemical means of pest control are encouraged in integrated pest management (IPM) which seeks to combine cultural, chemical, and biological control methods to manage pest numbers with a resulting reduction in pesticide use (Ruberson *et al.*, 1998).

Classical biological control usually involves the release of a pest-specific predator, parasite, or pathogen (usually exotic to the region) to control or diminish the pest numbers (Bugg and Pickett, 1998). But, classical biological control may have negative effects on non-target organisms, including extinction of native species – see examples in Howarth (2000), and there may be government regulations that restrict the importation and release of exotic organisms. However, already present in many agroecosystems are predator species which themselves are usually suppressed by agricultural practice (often even more so than the plant pests). Predatory beetles, mites, and spiders are found in agroecosystems throughout the world, and occur as natural enemies of the plant pests.

Known as conservation biological control (Ehler, 1998; Landis *et al.*, 2000), recent work has concentrated on conserving these natural enemies so that their numbers or presence is augmented and they attack the pests and reduce their effect on the crop (Landis *et al.*, 2000). For example, in Europe, Thomas *et al.* (1992b) created 'beetle banks' that were populated by over-wintering predatory beetles (Carabidae and Staphylinidae) that preyed on aphids in the neighbouring cereal crop. The 'beetle bank' is a raised bank, within a paddock, planted in cocksfoot (*Dactylis glomerata* L.), which was shown to be important for over-wintering beetles (Thomas *et al.*, 1992a; Dennis *et al.*, 1994). In north-western China, artificial bird houses were built for the native rosy starling (*Sturnus roseus*) which suppressed grasshopper numbers in a 500 m radius around the nest area before migrating (Olkowski and Zhang, 1998). Prune trees planted next to Californian vineyards provide an over-

wintering refuge for an egg parasitoid (*Anagrus* spp., Hymenoptera) that attacks grape leafhoppers (*Erythroneura elegantula*, Homoptera: Cicadellidae) (Corbett and Rosenheim, 1996). This egg parasitoid is a significant cause of mortality (up to 100%) of leafhoppers, and the amount of parasitism is related to early season parasitoid density in the prune trees (Murphy *et al.*, 1998)

Spiders are amongst the most abundant predators in agroecosystems (Riechert and Lockley, 1984), but are often not considered important in the management of pests for a number of reasons: (1) they are generalist (polyphagous) predators and will usually eat any arthropod of suitable size that they can attack (Riechert and Luczak, 1982; Nyffeler *et al.*, 1986, 1987), including other predators (Wise, 1993; Nyffeler and Sterling, 1994) and natural enemies of plant pests (Nyffeler *et al.*, 1994); and (2) they are generally annual or biennial species (Schaefer, 1987) and are thus long-lived compared with many pest species, and do not track the prey population (Riechert and Lockley, 1984).

In spite of this, Riechert and Bishop (1990) have shown that the numbers of spiders in a vegetable garden could be manipulated to increase predation on vegetable pests and, as a result, reduce plant damage by insect pests. In south-eastern United States, these authors added treatments of mulch, flowering weeds (to attract pollinators and as a nectar source for predators and parasitoids), and mulch+flowers to their replicated vegetable plots, and found that adding mulch alone increased the densities of spiders. By both adding mulch and hand removing spiders in another treatment, they were able to show that it was spiders that caused a reduction in plant damage. Presumably, the spiders were attracted to the humid, shaded microclimate provided by the mulch. Similarly, in New Zealand, Lövei and Bycroft (1992) found that 10 cm depth of wheat straw mulch added to cauliflower plots reduced the numbers of aphids and slightly reduced leaf damage. The authors suggest that natural enemies were responsible for this decrease. However, in this case, the mulch treatment reduced rather than increased the number of spiders on the plants compared with the untreated control, and the total numbers of predators (including mainly lacewings and syrphid larvae) and parasitoids were not affected by the mulch treatment.

Wyss (1995) and Wyss *et al.* (1995) provided weedy strips in apple orchards in Switzerland and found both an increase in spider density (along with other aphid predators) in the trees beside the strips, and a decrease in aphid numbers in the apple

trees compared with trees without the strips. Orb-web building spiders (Araneidae) were the organisms implicated in the aphid reduction.

Mansour and others have studied the impact of spiders in citrus (Mansour, 1988b) and apple (Mansour *et al.*, 1983) orchards in Israel. Spiders were removed from three branches on a citrus tree by shaking the branch (other arthropods were collected and returned to the branch) then the branches were enclosed in cloth bags. After 14 days, the branches from which spiders had been removed had more scale insects, *Ceroplastes floridensis* (Hemiptera: Coccoidae), and greater sooty mould infestation (the mould grows on the honeydew exuded by the scale insect) than the undisturbed control branches. However, because the branches were enclosed in bags, the microclimate for the experimental branches could have been modified and, by enclosing the spiders, these animals may have increased encounters with the scale insect because the spiders were prevented from leaving the branch when prey numbers were low (Wise, 1993). In an earlier experiment on apples, bags were not used (Mansour *et al.*, 1983). Spiders were removed from branches on three trees, then bands of sticky substance were placed on the trunks to prevent re-colonisation by spiders. Egg masses of *Spodoptera littoralis* (Lepidoptera: Noctuidae), an important pest, were placed on the apple leaves. After five days, the branches from which spiders had been removed showed greater egg survival, more pest larvae, and more damage to the leaves than the undisturbed control branches. This experiment was repeated eight days later with similar results. The effect of spiders on *S. littoralis* may not have been only predation. Mansour *et al.* (1981b) showed that the presence of spiders disrupted feeding aggregations of *S. littoralis* larvae on apple leaves, causing the larvae to fall from the leaf. Yamanka *et al.* (1972) found a similar disturbance effect by a linyphiid spider on first-instar *Spodoptera littura* in taro (*Colocasia*) fields in Japan.

Unlike the specialist predators of classical biological control, numerous species of spiders were involved in these studies (Riechert and Bishop, 1990; Wyss *et al.*, 1995). Riechert, in particular, argued that the 'spider assemblage' acts to control prey numbers, with each spider species a generalist predator with different prey-catching tendencies and individually not displaying a functional response, but collectively depressing prey numbers (Riechert and Lockley, 1984; Riechert and Bishop, 1990). However, Wise (1993) argued against this by pointing out that the evidence is relatively weak, and that spiders should be considered as a density-

independent cause of prey mortality, rather like abiotic factors, and that rather than regulating prey numbers, spiders limit prey numbers to fewer than there would be in the absence of spider predation.

Kobayashi (1975) tried augmenting spider numbers in Japanese rice paddies by adding *Drosophila* as a food source. *Drosophila* were released on dykes between the rice paddies, and this led to an increase in spider numbers both on the dyke and in the adjacent paddies. Numbers of hoppers (*Nephotettix cincticeps* Uhler and *Laodelphax striatellus* Fallen), pests of rice crops, were reduced in the paddies, but only late in the season, after the hoppers had caused considerable damage to the rice plants.

In Switzerland, 1.5 m wide weed strips in winter cereal crops had higher numbers of predatory beetles and spiders than the cereal crop (Lys and Nentwig, 1994), and the number of spider species and spider pitfall trap catches decreased with distance away from weed strips into maize, rape, and wheat crops (Frank and Nentwig, 1995), which demonstrates that the weed strips can influence spider communities in adjacent crops. The number of spider species and pitfall trap catch were highest in a two year old weed strip compared with one year old strips and a mown 10 year old boundary (Frank and Nentwig, 1995). Heidger and Nentwig (1989) released a dictynid spider into a wheat field where this web-building species preyed on insect pests. These spiders moved into adjacent successional strips over winter, but their density was very low, and the authors estimated that only 1% of the released spiders would return to the wheat crop the next summer.

In China, straw bundles are used to provide shelter for spiders, then moved from field to field as required for control (Jones, 1981 in Riechert and Lockley, 1984). This led to a 50-60% reduction in pesticide use.

Other studies have investigated manipulating the habitat to increase predator numbers. For example, Alderweireldt (1994) showed that making 10-12 cm deep holes of various diameters in the soil created web-building sites for linyphiid spiders in Belgian pasture. Making holes of 5 cm diameter increased numbers at least 13 times compared with control plots. These holes were particularly colonised by *Bathyphantes gracilis* (Blackwall) (Linyphiidae) while 9.5 cm diameter holes were mostly (45-67% of holes) colonised by *Lepthyphantes tenuis* (Blackwall) (Linyphiidae), showing that habitat manipulation can alter both spider density and species composition.

Habitat management can occur on several scales (within-crop, within-farm, and landscape) and can involve introducing plants, or management of existing plant species (Landis *et al.*, 2000). In South Island, New Zealand, exotic trees are commonly planted within farms around paddock margins to provide shelter for livestock during inclement weather. These shelterbelts, as they are known, are often fenced on both sides so that livestock cannot enter. Such a shelterbelt is not disturbed by grazing or tillage and, thus, may provide a refuge from disturbance for arthropod predators. The value of such shelterbelts in New Zealand as a refuge for predators is not currently known.

The above mentioned studies began with a good knowledge of the fauna and densities of spiders in agroecosystems. Examples of studies that provided such information are given in Table 1-1 below. (See Nyffeler and Benz (1987) for a more extensive list.)

Table 1-1. Examples of studies of spiders in agroecosystems.

Reference	Country	Crop	Fauna	Duration, method(s)
Agnew and Smith, 1989	U.S.A.	peanut	134 spp., 18 fam.	3 yr, pitfall, visual
Alderweireldt, 1989a	Belgium	ryegrass, maize	25-70 spp.	1 yr, pitfall
Bishop, 1980	Australia	cotton	25 spp., 10 fam.	5 yr, pitfall, sweepnet, destructive sampling
Dean <i>et al.</i> , 1982	U.S.A.	cotton	97 spp., 18 fam.	3yr, suction, sweepnet, pitfall, whole plant
Delchev and Kajak, 1974	Bulgaria, Poland	pasture	31-36 spp., 7-9 fam.	2 yr, turf, hand search
Doane and Dondale, 1979	Canada	wheat & border	24-39 spp.	2 yr, pitfall
Feeney and Kennedy, 1988	Ireland	wheat	~43 spp., ~6 fam.	~1 yr, pitfall, suction, quadrat
Howell and Pienkowski, 1971	U.S.A.	alfalfa	112 spp., 14 fam.	~1 yr, D-Vac, sweepnet
Kromp and Steinberger, 1992	Austria	wheat & margin	80 spp., 16 fam.	2 seasons, pitfall
Luff and Rushton, 1989	U.K.	grassland	11-40 spp.	2 yr, pitfall
Nyffeler and Benz, 1988c	Switzerland	grassland	22 spp., 11 fam.	summer, sweepnet
Peck and Whitcomb, 1979	U.S.A.	pasture	40 spp., 14 fam.	2 yr, pitfall
Putman, 1967	Canada	peach orchards	21 spp., 8 fam.	1 yr, beating
Thornhill, 1983	U.K.	sugar beet	11 spp.	4 yr, hand search, pitfall
Turnbull, 1966	Canada	pasture	40 spp., 11 fam.	summer, suction
Wheeler, 1973	U.S.A.	alfalfa	78 spp., 11 fam.	4 yr, visual, pitfall

In New Zealand, very little is known about spiders in agroecosystems. Martin (1983) listed species caught in pitfall traps in a Nelson pasture, but some taxonomic revision since then (especially Forster *et al.*, 1988) means that the species list is now somewhat out of date. More recently, Topping and Lövei (1997) provided the first density estimates and species lists for spiders in North Island, New Zealand, pastures. This thesis concerns spiders in pastures in South Island, New Zealand, and concentrates on the following objectives.

Research objectives of this thesis

- To determine the taxonomic composition and abundance of spiders in pasture and shelterbelt habitats (Chapters 3 & 4).
- To determine the effect of distance from the field margin on the constitution of the pasture spider assemblage (Chapter 3).
- To investigate the effects of the following management practices:
 1. Different pasture types (including agroforestry) (Chapter 5),
 2. Mowing (Chapter 6).
- To investigate habitat correlates with spider density in several pasture types (Chapter 5).
- To investigate the feasibility of a field cage method for investigating effects of spider predation on aphids (Chapter 7).

Chapter 2: Sampling methods

Introduction

The main methods of collecting spiders are pitfall traps, suction sampling, habitat searching, sweep netting, and beating (Turnbull, 1973; Wise, 1993), although few methods allow density estimates to be made (Sunderland *et al.*, 1995). This study focussed on the density of spiders in pastures and shelterbelts and a method was therefore required that would allow density estimates to be made. Three methods, habitat searching, fenced pitfall traps, and suction sampling have all been used to estimate densities of spiders (Sunderland *et al.*, 1995). Of these, habitat searching is labour intensive, especially in dense vegetation such as that found in some shelterbelts (Sunderland *et al.*, 1995), and fenced pitfall traps are likely to be disturbed by livestock in grazed pasture. There are several suction sampling devices that have been used for sampling terrestrial invertebrates (Dietrick, 1961; Arnold *et al.*, 1973; Summers *et al.*, 1984; Holtkamp and Thompson, 1985; De Barro, 1991; MacLeod *et al.*, 1994; Stewart and Wright, 1995), but only two were available to the author, the D-Vac (Dietrick, 1961) and the Vortis (Arnold, 1994). The Vortis differs from the D-Vac in that no net, filter, or bag is used to collect the material. Instead, the material collects into a removable plastic cup. Also, the Vortis is carried by hand rather than as a backpack. Unpublished data (student class exercise, Lincoln University) had shown that the Vortis was more efficient at collecting spiders from short grass than was the D-Vac, as well as being lighter, easier to operate, and faster to use. Thus, the Vortis was used in this study, but because it is a relatively new design it was necessary to obtain some measure of the collection efficiency of the machine. This chapter details evaluations of the spider collection efficiency of the Vortis in pasture and describes the standard sampling method used throughout this study.

Methods

Standard Vortis sample

The Vortis machine used was powered by a 21 cc McCulloch Super AirStream IV Gas Blower/Vac motor (McCulloch Corporation, U.S.A.). The *standard Vortis sample* used in this study covered an area of 0.1 m² and consisted of

five placements, about 1 metre apart, of the Vortis on the ground for 5 seconds of suction at maximum engine revolutions at each placement. Thus, each standard Vortis sample totalled 25 seconds of suction. After the five placements, the sample was labelled and 70% ethanol added to kill and preserve any spiders in the sample. In the laboratory, the samples were sieved through a 2 mm mesh to separate plant and soil debris, and the debris trapped on the sieve was searched for spiders attached to it. The material which had passed through the sieve was sieved again, this time with a 250 μm mesh. The remaining material was sorted under a stereo microscope (up to 125 \times magnification) and all spiders identified to species where possible. Species names follow Forster (1959), Forster (1970), Forster and Forster (1973), Forster and Wilton (1973), Forster and Platnick (1977), Forster and Blest (1979), Millidge (1984), Forster *et al.* (1988), Vink and Sirvid (1998), and Forster and Forster (1999).

Efficiency test 1

The study site was a grazed sheep pasture (Lincoln University Sheep Breeding Unit paddock S2) referred to in this thesis as Shands Road Site (see Appendix C for details of location) with a ryegrass (*Lolium perenne* L.) clover (*Trifolium* spp.) mix and vegetation height of *c.* 10 cm. To test the efficiency of the Vortis at collecting spiders, a suction sample was taken, then the turf area that had been suction-sampled was collected for later hand searching for any spiders that remained in the turf. To do this, a sheet metal cylinder with a height of 55 mm and a diameter just large enough that the Vortis nozzle could fit inside it (an area of 0.02 m^2) was placed on the ground and quickly pressed into the soil 1-2 cm. Without delay (within about 5 seconds of pressing the cylinder into the soil), a Vortis sample of 5 seconds duration was taken from within the cylinder. This was defined as a *suction sample*. The spiders in the suction sample were killed with 70% ethanol for later sorting and identification. Immediately after the suction sample was completed, the cylinder was completely dug out of the ground by a field assistant and all the soil within the cylinder was placed into a sealed plastic bag. This was known as a *turf sample*. Thirty five pairs of 0.02 m^2 suction and turf samples were taken. Ten standard 0.1 m^2 Vortis samples were taken for comparison.

Within 1-2 hours of collection, the turf samples were returned to the laboratory and each turf shaken on to a white plastic tray (46 \times 30 cm) and searched for spiders. All vegetation was clipped from the turf, and the turf again shaken on to

the tray and the search repeated. All spiders collected were placed in 70% ethanol for later identification under a stereo microscope (up to 125× magnification). Collection efficiency for each turf and suction pair was calculated as the number of spiders collected in the suction sample divided by the sum of the turf+suction. To see if the spiders were distributed randomly at this sampling scale, the observed frequencies of spiders in the 35 turf+suction samples were compared with a Poisson distribution using a Kolmogorov-Smirnov one-sample test (Siegel and Castellan, 1998).

Following analysis of these samples, it was discovered that the suction samples contained many fewer spiders per sample area than the standard Vortis samples (see Results, Table 2-1 below). Because of this, a second method was devised whereby the suction samples and turf samples were not paired.

Efficiency test 2

Because the suction samples taken inside the metal cylinder in Test 1 did not reflect the numbers of spiders from standard Vortis samples, suction samples were not taken in Test 2. Instead, only standard Vortis samples were taken, and turf samples, this time without first suction-sampling the turf, were taken for comparison.

A different site was used to carry out the second test because it was thought that the slightly longer vegetation (c. 10-20 cm) would yield more spiders which, in turn, would enable the efficiency to be measured with more precision than if only few spiders were collected. The study site was a grazed dairy pasture (Lincoln University Dairy Farm, paddock 12) referred to in this thesis as Dairy Farm Site (see Appendix C for details of location) with a ryegrass (*Lolium perenne* L.) clover (*Trifolium* spp.) mix.

Fifty turf samples and 10 standard Vortis samples were taken over a six-day period (10-15 April 1997). The samples were sorted and identified in the laboratory as before. To enable comparison with standard Vortis samples, descriptive statistics of turf samples were calculated using the sum of each five consecutive turf samples (summed area = 0.1 m²). A two-sample t-test was used to compare mean densities, and a G test was used to compare frequencies of spiders from each species (Zar, 1984). The observed frequencies of spiders in the turf samples were compared with a Poisson distribution using a Kolmogorov-Smirnov one-sample test (Siegel and Castellan, 1998).

Effect of sample duration

To determine the effect of sample duration, a trial was carried out to compare the spider catch using the Vortis with four different sampling durations. These were 5, 10, 20, and 40 s. Ten samples (5 placements of the machine with the same duration for each placement) were taken using each of the four durations. The durations were ordered randomly in a randomised block design to obtain good interspersions of treatments (Hurlbert, 1984). Samples were taken from the Dairy Farm Site on 7 April 1997. The mean spider densities were analysed using randomised block ANOVA, and Dunnett's test (Zar, 1984) was used to compare the 10, 20, and 40 s means with the 5 s, or standard, Vortis sample mean.

Results

Efficiency Test 1

The suction and turf samples contained 14.5% and 85.5% of total spiders, respectively (Table 2-1). The collection efficiency for each sample pair was calculated as $\text{Suction} / [\text{Turf} + \text{Suction}]$ (excluding sample pairs that did not contain any spiders). The mean collection efficiency was 15.7% (s.d.=33.4%, $n=27$). Unexpectedly, the suction samples contained only 32.6% of the density of spiders found in the standard Vortis samples. The standard Vortis samples contained 44.5% of the spider density found in the turf+suction samples (Table 2-1).

The frequency distribution of spiders in the turf+suction samples (Table 2-2) was not significantly different from a Poisson distribution ($\text{KS-D}_{\max} = 0.0485$, $P > 0.20$). The mean number of spiders per turf+suction was 1.57 (s.d. = 1.220, $n = 35$).

Table 2-1. Frequencies of spiders collected using three different collection methods, Shands Road Site, February 1997. Samples sizes were 35 turf and suction pairs (35 placements), and 10 standard Vortis samples (50 placements). Mean and standard deviation for Turf and Suction were calculated using the sums of each five consecutive placements. See Appendix A for species name authorities.

Species	Method			
	Turf	Suction	Turf+Suction	Standard
<i>Lepthyphantes tenuis</i>	1	2	3	1
<i>Erigone prominens</i>	4	1	5	4
<i>Erigone wiltoni</i>	13	1	14	3
<i>Araeoncus humilis</i>	1	0	1	0
Unidentified Araneoidea immatures	21	3	24	26
Unidentified Lycosidae	6	0	6	1
Unidentified Salticidae	0	1	1	0
Unknown family	1	0	1	0
Total	47	8	55	35
Mean/0.1 m ²	6.71	1.14	7.86	3.5
s.d.	3.59	1.46	3.34	2.27

Table 2-2. Frequency distribution of spiders in 35 Turf+Suction samples.

Number	0	1	2	3	4
Frequency	8	9	11	4	3

Efficiency Test 2

The sampling methods were not significantly different in their mean densities of spiders (Table 2-3) (two sample t -test, $t = 0.16$, $df = 18$, $P = 0.88$). The standard Vortis samples collected 97.0% of the Turf numbers. The two methods (Table 2-3) collected significantly different frequencies of species ($G=29.28$, $df=8$, $P = 0.0003$). Calculation of cell chi-square values showed that *Lepthyphantes tenuis* immatures and *Erigone wiltoni* contributed much of the significant difference in frequencies, with the standard Vortis sample collecting more *L. tenuis* immatures and fewer *E. wiltoni* than expected under a null hypothesis of independence. The frequency distribution of spiders in the turf samples (Table 2-4) was not significantly different from a Poisson distribution ($KS-D_{max} = 0.0803$, $P > 0.20$). The mean number of spiders per turf was 1.32 (s.d. = 1.491, $n = 50$).

Table 2-3. Frequencies of spiders collected using two different collection methods, Dairy Farm Site, April 1997. Fifty Vortis placements, total area = 1.0 m², for each method.

Species	Method	
	Turf	Standard
<i>Lepthyphantes tenuis</i>	8	15
<i>L. tenuis</i> immatures	2	11
<i>Erigone prominens</i>	1	0
<i>Erigone wiltoni</i>	19	6
<i>Diploplecta</i> sp.	4	9
<i>Haplina mundenia</i>	0	1
Unidentified Mynogleninae immatures	9	3
Theridiidae sp. 'a'	1	0
Unidentified Araneoidea immatures	18	19
Unidentified Lycosidae	4	0
Total	66	64
Mean/0.1 m ²	6.6	6.4
s.d.	3.37	2.27

Table 2-4. Frequency distribution of spiders in 50 turf samples.

Number	0	1	2	3	4	5	6
Frequency	17	18	5	6	2	0	2

Effect of duration

The mean spider catch/0.1 m² (Table 2-5) was not significantly different between sampling durations (randomised block ANOVA, $F=1.94$, $df=3,27$, $P = 0.148$), and longer duration sample means (10, 20, and 40 s) were not higher than the standard Vortis sample (5 s), (Dunnett's $q_{.05(1),27,4}=1.949$) (Figure 2-1).

Table 2-5. Numbers of spiders collected from Vortis samples using different sampling durations at the Dairy Farm Site, April 1997. Each sample consisted of five placements of the Vortis at the stated duration. Ten samples were taken at each duration.

Species	Duration			
	5 s	10 s	20 s	40 s
<i>Lepthyphantes tenuis</i>	6	12	12	8
<i>Erigone wiltoni</i>	8	13	10	7
<i>E. prominens</i>	1	3	0	0
<i>Diploplecta</i> sp.	5	3	9	3
<i>Haplisis fucatina</i>	1	0	0	0
Unidentified Mynogleninae	0	1	1	2
Unidentified Araneoidea	9	18	17	18
Unidentified Lycosidae	2	1	0	1
Total	32	51	49	39
Mean/0.1 m ²	3.2	5.1	4.9	3.9
s.d.	1.81	1.73	2.69	2.02

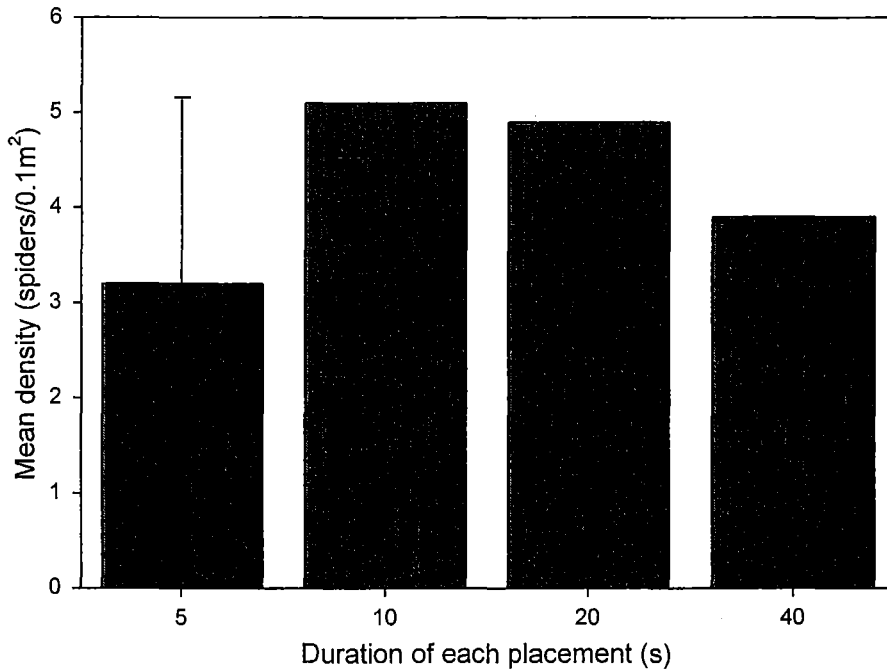


Figure 2-1. Mean density of spiders collected in Vortis samples of different sampling durations, with a line indicating Dunnett's test value for comparison of control mean (5 s) with the other means. Sample size is $n = 10$ for each mean with five placements in each sample.

Discussion

Test 1

All suction methods give an underestimate of density (Sunderland *et al.*, 1995) (except for the over-sampling reported by Samu *et al.* (1997), discussed below). The spider collection efficiency in Test 1 was only 15% (comparing suction

with turf+suction), which is a considerable underestimate of density when suction followed by hand-searching (i.e., turf+suction) is known to give good estimates of spider density (Sunderland and Topping, 1995). However, the density of spiders suction-sampled from inside the cylinder was only one third the density obtained from standard Vortis samples (without a cylinder), and this collection efficiency inside the cylinder does not appear to represent that of standard Vortis samples. Possible reasons for this are: (1) the placement of the metal cylinder disturbed the spiders and enabled them to cling onto the substrate and be less likely to be sucked into the Vortis; (2) the cylinder prevented airflow underneath the bottom edge of the Vortis as may possibly occur during standard Vortis samples, thus maintaining the sampled area to 0.02 m² per placement rather than an “enlarged” area during standard samples. This “edge effect” was described by Samu *et al.* (1997) who found that using a D-Vac in a transect gave a 200% increase in density compared with sampling inside a barrier, and calculated that this increase would require an extra 4 cm sampling radius. To similarly increase the Vortis sampling area three times (0.02 m² to 0.06 m²) the sampling radius would have to increase from 8 cm to 14 cm. That is, the Vortis would have to be sampling spiders from a further 6 cm around the base. However, the Vortis design allows air to enter from the top rather than only underneath the base as is common with the D-Vac design, so that pressing the Vortis hard against the soil is unlikely to allow a significant amount of airflow underneath the bottom edge (Figure 2-2). Also, unlike Samu *et al.* (1997) who found that the D-Vac overestimated densities (assuming the samples inside the barriers reflected the true density), the standard Vortis samples gave a density lower than the turf samples.

Test 2

Test 2 gave an extremely high 97% collection efficiency. However, this efficiency measure assumes that the turf samples and standard Vortis samples were collecting from the same population, i.e., with the same total number of spiders. Given the variation in spider numbers from sample to sample, this equality is unlikely to occur. Thus, the measure of collection efficiency from Test 2 is an approximate one. Indeed, it could be possible to achieve an efficiency greater than 100% with the Test 2 method. The Test 2 results also show a possible bias in species collected. There were more *L. tenuis* immatures, and fewer *E. wiltoni* in the Vortis samples, than in the turf samples. This may be simply because of variation in the

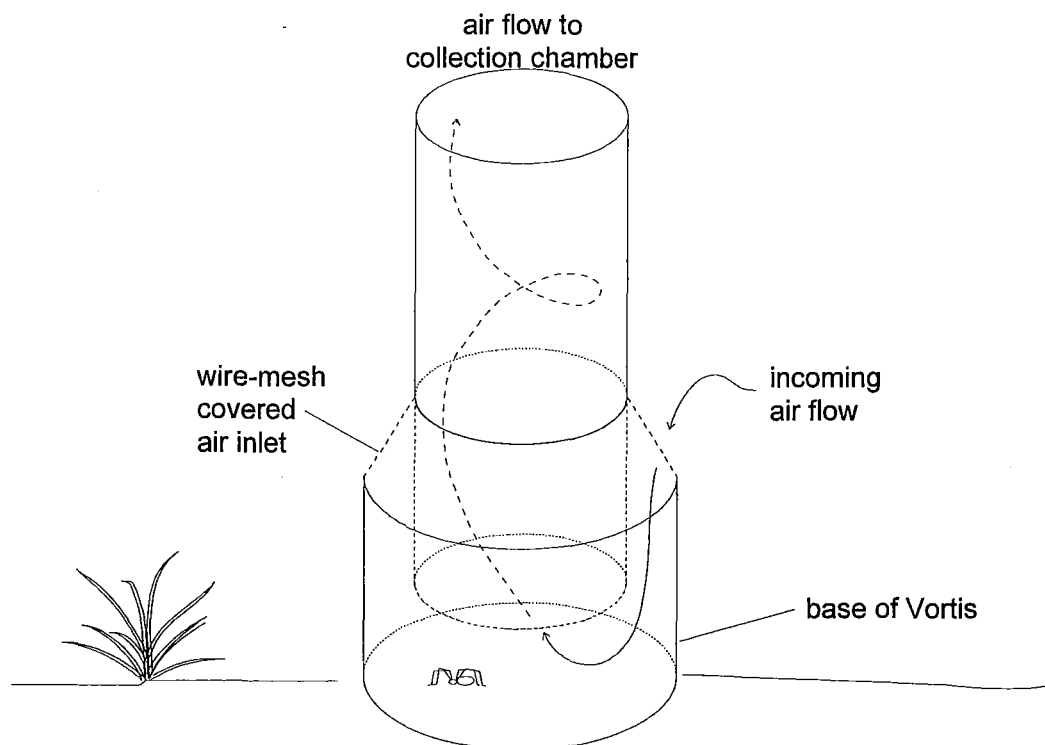


Figure 2-2. Air flow through the base of Vortis.

distribution of these species, but a similar result was found by Sunderland and Topping (1995) using a D-vac. These authors found that immatures were more efficiently collected, and that foliage-dwelling linyphiids, especially *L. tenuis*, were collected more efficiently than ground-dwelling Erigoninae linyphiids. The frequency distribution of total spiders from 0.02 m² turf samples was not different from a Poisson distribution, indicating that, at this sampling scale, spiders in these pastures are distributed randomly in space (Zar, 1984; Kuno, 1991).

Effect of duration

Although there is some suggestion that a 5 s duration collects lower numbers of spiders than do 10 s or 20 s durations, there was no statistical difference when only 10 samples are taken owing to the relatively large variation between samples.

No testing of collection efficiency was made in shelterbelts, which usually have longer vegetation. Some shelterbelts have short vegetation in parts, and the collection efficiency there should be considered similar to that obtained from pasture; however, most shelterbelt ground vegetation is tall and dense, which made it very difficult to use the Turf method for comparison with suction samples. In tall shelterbelt vegetation (>30 cm), the Vortis should be expected to collect less efficiently than in short vegetation, and density estimates from Vortis samples from

shelterbelts should be considered as underestimates of spider density. Hossain *et al.* (1999) found that vacuum-sampling was less effective in tall lucerne compared with short lucerne, and that cutting the tall lucerne and re-sampling improved the collection efficiency. Capture efficiency was affected by taxonomic group and reduced with increasing vegetation height in grassland (Henderson and Whitaker, 1977).

In very dense grass, vacuum samplers may not collect invertebrates trapped under a layer of vegetation (Sunderland *et al.*, 1995). Further, invertebrates in cracks in the soil may not be sampled (Sunderland and Topping, 1995).

Conclusions

Vacuum samples are expected to underestimate the population density of spiders (Sunderland *et al.*, 1995). In two grazed pastures, a standard Vortis sample collected approximately 44% and 97% of spiders. The cause of the variation in efficiency between the two pastures is unknown. Suction sampling inside a barrier produced unexpectedly low densities compared with standard Vortis samples, and made the use of the barrier impractical for efficiency measurement purposes.

The collection efficiency in tall shelterbelt vegetation is unknown, but likely to be lower than in short vegetation. The catch in a vacuum sample represents a combination of spider density and 'catchability', with catchability depending on the species' behaviour (e.g., positioned on foliage or on ground) and on the habitat structure (e.g., height and density of vegetation, presence of cracks and refuges in the soil). Thus, though results from standard Vortis samples are presented as densities in this thesis, they should be interpreted as relative, rather than absolute, density measures.

Chapter 3: Field-margin and pasture spider communities in Canterbury, New Zealand¹

Abstract

The density and species composition of ground-dwelling spiders were assessed using suction sampling from August 1994 to July 1995 at various distances from a field edge into a single grazed pasture, and from March 1996 to March 1997 in the same and three additional grazed pastures and adjacent fenced shelterbelts on the Canterbury Plains, New Zealand. Spider density declined rapidly with distance from the shelterbelt (mean 241 m⁻²) to 72.5 m⁻² at 2.5 m, and 10.3 m⁻² at 5 m into the pasture. Mean spider densities in the four pastures were 53.0 m⁻² while in the shelterbelts they reached 316 m⁻². The fauna in both habitats was dominated by the European linyphiid, *Lepthyphantes tenuis* (Blackwall). An unidentified theridiid was common only in the shelterbelt, while unidentified immature linyphiids and theridiids were common in both habitats. Of the 28 species collected, 25 were found in shelterbelts, and 13 in pasture. Thirteen endemic, one native, and one introduced species were found only in shelterbelts, while from pasture all but two endemic species were also recognised from shelterbelts. There was little evidence that the shelterbelts acted as refuges for spiders which could subsequently disperse to the adjacent paddocks.

Keywords Araneae; pasture; shelterbelt; suction sampling; Linyphiidae; *Lepthyphantes tenuis*; New Zealand

Introduction

Spiders are often the most abundant predators in agro-ecosystems (Turnbull, 1973; Wise, 1993). Spider communities in agro-ecosystems outside New Zealand have been well studied, including in the USA (Howell and Pienkowski, 1971; Dean *et al.*, 1982; Plagens, 1983; Agnew and Smith, 1989), Canada (Turnbull, 1966; Putman,

¹ This chapter has been submitted to *New Zealand Journal of Zoology* as: McLachlan, A.R.G.; Wratten, S.D. Field-margin and pasture spider communities in Canterbury, New Zealand. The text has been re-formatted to conform with the thesis style and some minor editorial changes made. References are not listed separately, but are combined with those from the entire thesis.

1967; Wheeler, 1973; Doane and Dondale, 1979), Belgium (Alderweireldt, 1987, 1989a; Maelfait and De Keer, 1990), Austria (Kromp and Steinberger, 1992), Switzerland (Nyffeler and Benz, 1988b, c), Ireland (Feeney and Kennedy, 1988), the United Kingdom (Thornhill, 1983; Luff and Rushton, 1989) and Australia (Bishop, 1980). Most of these studies were of fauna and phenology. However, in New Zealand, until recently, virtually nothing was known of the spider fauna in farmland. Forster (1975) noted that the New Zealand spider fauna as a whole comprised native and introduced species, and Martin (1983) recorded species from 15 families from pitfall traps in a Nelson pasture. Topping and Lövei (1997) provided the first density estimates and faunal lists from North Island, New Zealand, agricultural habitats. Still unknown in New Zealand is the actual or potential contribution made by spiders to biological control, the value of paddock-margin refuges for this group, and the extent to which spiders move from these refuges to the open field.

A knowledge of the densities, species-composition and dispersal of spiders has helped improve the contribution made by spiders to the biological control of pests. For example, in Europe, weed strips planted in an apple orchard (Wyss *et al.*, 1995) led to an increase in the numbers of aphidophagous predators, including spiders, which in spring reduced aphid numbers on trees near the weed strips. Also in Europe, within-field overwintering refuges have been established for polyphagous predatory invertebrates (Thomas *et al.*, 1992b), some of which disperse widely from the refuge in spring, colonising the adjacent field, and potentially contributing to enhanced levels of biological control. The faunal groups involved in that work were mainly Coleoptera (Carabidae and Staphylinidae) and spiders from a range of European families. Beetles from both families dispersed into the field, but the spiders either remained in the refuge (Lycosidae) or dispersed widely aerially (Linyphiidae) (Thomas *et al.*, 1992b).

In New Zealand, the margins of fields are commonly planted with trees to provide shelter for livestock. These shelterbelts may be fenced off from the pasture so that livestock can not enter them. In this study, the effect of distance from a shelterbelt on species richness and abundance of spiders is examined, based on sampling extending over 11 months. Species richness and abundance in the same and three additional pastures and in their adjacent fenced-off shelterbelts are also analysed, based on a further thirteen-month sampling period.

Methods

Spider densities in relation to distance from field margin

A 6 ha paddock referred to as the “Shands Road site” (see description below) on the Lincoln University Sheep Breeding Unit, was sampled every three to five months from August 1994 to July 1995 using a ‘Vortis’ vacuum sampler (Arnold, 1994). Sample dates were: 4 Aug 1994, 22 Oct 1994, 27 Mar 1995, and 7 Jul 1995. Suction samples of the invertebrate fauna were taken in the shelterbelt (within 0.5 m of the fence) and at 2.5, 5, 10, 25, and 50 m into the pasture. Ten samples were taken at each of the six distances (see Sampling procedures).

Spider densities in four pastures and shelterbelts

Four pastures near Lincoln University (see Site descriptions below) were sampled at one to three month intervals from March 1996 to March 1997. At each site, five suction samples were taken from the shelterbelt (within 1 m of the fence separating the shelterbelt and pasture) and from the pasture (25 m away from the fence).

Site descriptions

The four sites were within 4 km of each other, near Lincoln University, Canterbury, New Zealand (43° 39' S, 172° 28' E). The area receives an average of 55 cm of rainfall per year. Daily mean temperatures range from 6.1 °C in July to 17.0 °C in January.

Shands Road: This was a sheep pasture (Lincoln University Sheep Breeding Unit paddock S2, 6.0 ha) dominated by ryegrass *Lolium perenne* L. (Gramineae) with some clover *Trifolium* spp. (Fabaceae), rotationally grazed by sheep for ten months of the year, then set-stocked for two months (September-October) at an average stocking rate of 15 stock units per hectare. The paddock had been in pasture for eight years at the start of sampling, and was cultivated and sown in *L. perenne* and white clover *Trifolium repens* L. in March 1995. The shelterbelt comprised *Pinus radiata* (D. Don) G. Don (Pinaceae) trees *c.* 25 years old, trimmed to *c.* 9 m in height, planted 2 m apart in two rows 4 m apart. Inside the fence at its base was an almost-continuous stand of cocksfoot *Dactylis glomerata* L. (Gramineae) whereas underneath the trees only pine needles covered the ground.

Weedons Road: This was sheep pasture (Lincoln University Research Farm paddock R 28, 7.3 ha) of mainly ryegrass and white clover grazed from April-December at an average stocking rate of 12 stock units per hectare. The field had been in pasture for 12 years at the beginning of sampling. The shelterbelt was *Cedrus deodara* (D. Don) G. Don (Pinaceae) trees 6-8 m tall, planted 6 years previously, 2-3 m apart *c.* 3 m from the fence. *D. glomerata* was the main grass present, with some yarrow *Achillea millefolium* L., thistle *Cirsium vulgare* (Savi) Ten. (Asteraceae) and broom *Cytisus scoparius* (L.) Link (Fabaceae).

Boundary Road: This was dairy pasture (privately owned, 0.6 ha, adjacent to Lincoln University Mixed Cropping Farm paddock A18) sown in permanent pasture (ryegrass and clover) 5 years previously, and irrigated in summer. The shelterbelt comprised poplar trees *Populus* sp. (Salicaceae) and willow trees *Salix* sp. (Salicaceae) 6-8 m tall, *c.* 5 years old. The roadside fence had gorse *Ulex europaeus* L. and broom *C. scoparius* growing in it. Ground cover consisted of the grasses *D. glomerata* and *Arrhenatherum elatius* (L.) J. Presl et C. Presl, some yarrow *A. millefolium*, clover *Trifolium* sp., with occasional vetch *Vicia sativa* L. (Fabaceae).

Dairy Farm: This was dairy pasture (Lincoln University Dairy Farm paddock 12, 3.2 ha) sown in permanent pasture (ryegrass and clover) *c.* 30 years previously, and irrigated in summer. The shelterbelt comprised poplar trees *Populus* sp. *c.* 30 years old, trimmed to *c.* 7 m, planted *c.* 1 m apart in two rows *c.* 3 m apart. Ground cover was mainly *Phalaris aquatica* L. with some *D. glomerata*, *Holcus lanatus* L., and *A. elatius* (Gramineae) and *Rumex obtusifolius* L. (Polygonaceae), *Plantago lanceolata* L. (Plantaginaceae), *Cirsium vulgare*, and *C. arvense* (L.) Scop. (Asteraceae). Plant names follow Edgar and Connor (2000), Webb *et al.* (1988), and Vidaković (1991).

Sampling and identification procedures

Each 0.1 m² suction sample consisted of five, 5-second suctions taken approximately 1 m apart. Ethanol (70%) was added to the sample container to kill and preserve the specimens. The samples often contained soil and plant debris, so they were sieved through a 2 mm mesh in the laboratory. The debris trapped on the sieve was then searched for any spiders attached to it. The material that had passed through the sieve was sieved again, this time with a 250 µm mesh. Samples from one pasture that had recently been cultivated (Shands Road, 27 Mar 1997) were

processed differently. Owing to the large amount of soil in the samples, flotation separation (Southwood, 1978) was used instead of sieving to sort the spiders from the debris.

The individual spiders were transferred to 70% ethanol and examined under a dissecting microscope (up to 125x magnification). Identification was usually to family or species and the names followed Forster (1970), Forster and Forster (1973), Forster and Wilton (1973), Forster and Blest (1979), Millidge (1984), Forster *et al.* (1988), and Vink and Sirvid (1998). Some species could not be named because of limitations of the current taxonomic literature, or because of the absence of adult specimens.

Results

Spider densities in relation to distance from field margin

Spider density declined rapidly with distance into the pasture from the shelterbelt (Figure 3-1), with little effect of season on this pattern of decline, although the densities in the shelterbelt did vary from season to season.

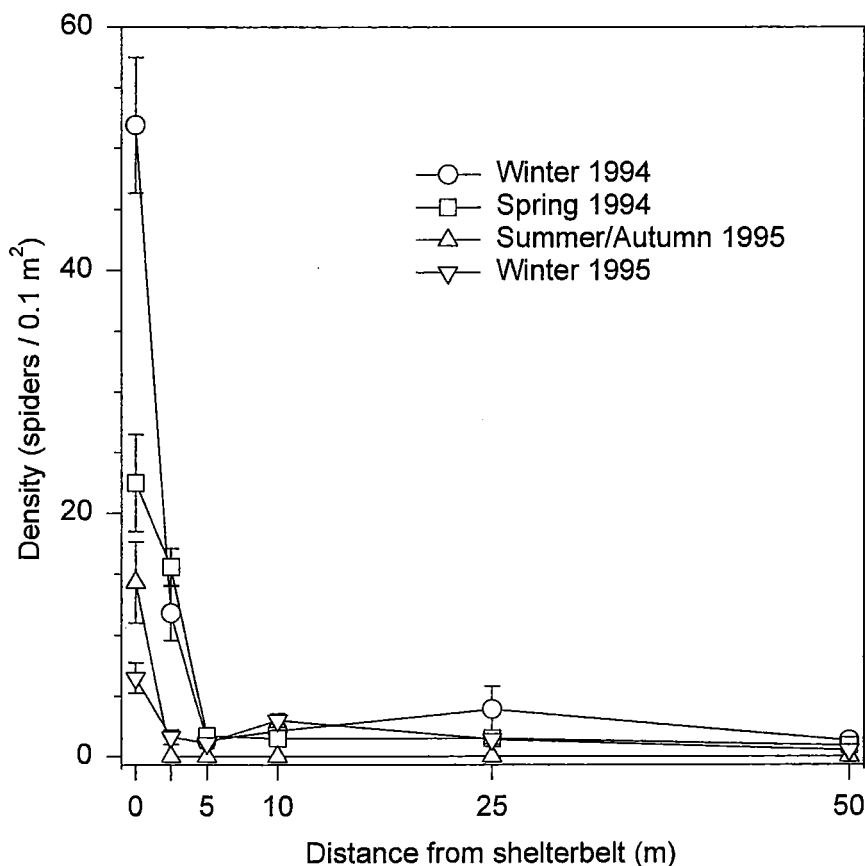


Figure 3-1. Density of spiders (mean/0.1 m² ± S.E.) below a fenced-off *Pinus radiata* shelterbelt and in an adjacent sheep pasture in four seasons in Canterbury, New Zealand.

The mean density/0.1 m² (\pm S.E.) of spiders was 24.1 \pm 3.38 in the shelterbelt (four sample dates combined), and 1.3 \pm 0.21 in the pasture away from the shelterbelt (samples from 10 m, 25 m, and 50 m combined from four sample dates). Thirteen species of spider from seven families were recognised (Table 3-1), with ten species and six families in the shelterbelt, and eight and four, respectively, in the pasture.

Table 3-1. The spider fauna in a grazed sheep pasture at various distances from an adjacent fenced-off *Pinus radiata* shelterbelt in Canterbury, New Zealand. Data are pooled from four sample dates in 1994 and 1995. * = introduced species, ⁿ = native; all others are endemic. † = immatures from the superfamily Araneoidea (*sensu* Coddington and Levi, 1991) comprise Linyphiidae and Theridiidae in this case.

Species	Distance from field margin						Total
	0m	2.5m	5m	10m	25m	50m	
LINYPHIIDAE							
<i>Lepthyphantes tenuis</i> *	31	77	4	11	11	1	135
<i>L. tenuis</i> immatures*	231	96	12	33	30	10	412
<i>Microctenonyx subitaneus</i> *	28	2	0	0	0	0	30
<i>Erigone wiltoni</i> ⁿ	0	5	3	6	2	8	24
<i>Araeoncus humilis</i> *	1	3	0	0	0	0	4
<i>Haplisis fucatina</i>	0	0	0	0	1	2	3
<i>Pseudafroneta incerta</i>	2	0	0	0	0	0	2
Unidentified Mynogleninae immatures	39	2	1	0	0	0	42
THERIDIIDAE							
Unidentified sp. 'a'	172	0	0	0	2	0	174
Unidentified sp. 'b'	3	0	0	0	0	0	3
ARANEOIDEA†							
Unidentified immatures	274	103	18	12	18	4	429
LYCOSIDAE							
Unidentified immatures	4	1	3	2	4	1	15
AGELENIDAE							
Unidentified immatures	1	0	0	0	0	0	1
SYNOTAXIDAE							
<i>Pahora</i> sp.	1	0	0	0	0	0	1
SALTICIDAE							
Unidentified immatures	97	0	0	0	0	0	97
MICROPHOLCOMMATIDAE							
<i>Parapua punctata</i>	0	1	0	0	0	0	1
UNKNOWN FAMILY							
Unidentified immatures	54	0	0	0	0	1	55
TOTAL	938	290	41	64	68	27	1428
Density, individuals/0.1 m ²	24.1	7.25	1.03	1.64	1.70	0.68	6.00
Number of species	10	7	4	3	5	4	13
sampled area (m ²)	3.9	4.0	4.0	3.9	4.0	4.0	23.8

Of the seven taxonomic groups found in both the pasture and the shelterbelt, three were species of European Linyphiidae, while the others were an unidentified

species of Theridiidae (species 'a'), one unidentified Lycosidae species (only immatures were present, but probably *Lycosa hilaris* Koch, C.J. Vink *pers. comm.*), immature Mynogleninae (Linyphiidae), and immature Araneoidea (*sensu* Coddington and Levi, 1991). Of these, *Lepthyphantes tenuis* (Blackwall) and immature Araneoidea dominated the fauna shared between the two habitats, and *L. tenuis* was the most abundant identified species overall.

Spider densities in four pastures and shelterbelts

Twenty-eight species of spider were collected from the four sites, 13 from pasture and 25 from shelterbelts (Table 3-2). At all four sites, the shelterbelt had higher species richness (3-10 spp. more), and higher density of spiders (average 6.7 times more) than the adjacent pasture. Introduced species contributed 41% of numbers in pasture, and 29% in shelterbelts (Table 3-2).

Over all the sites, the most abundant species were *L. tenuis*, theridiid sp. 'a', and Araneoidea immatures (which may have included both these species, but also other linyphiids and theridiids). Much of the variation in spider numbers at the four sites (Figure 3-2) can be attributed to these three groups. Much of the variation in the shelterbelt spider densities at Shands Road can be attributed to changes in numbers of Araneoidea immatures, *L. tenuis* immatures, and to a lesser extent theridiid sp. 'a', while Shands Road pasture spider numbers were mainly Araneoidea immatures. The high numbers of spiders in the Weedons Road shelterbelt in March 1996 comprised mainly *L. tenuis* adults, Araneoidea immatures, and theridiid sp. 'a' in similar proportions, while the March 1997 numbers comprised Araneoidea immatures, and theridiid sp. 'a' only. Weedons Road pasture numbers fluctuated little during the year. At the Dairy Farm shelterbelt, peak numbers occurred in April 1996 and April 1997 and were dominated by theridiid sp. 'a', with Araneoidea immatures the second-most dominant group. An April 1996 peak in numbers in pasture was due mainly to a high number of *E. wiltoni* adults (40 out of 71 spiders collected).

With the exception of *Oxyopes gracilipes* (White) (Oxyopidae) and the occasional lycosid or salticid, all the spiders collected were small enough to pass through a 2 mm sieve. Sample numbers differ slightly between sites (Table 3-1, Table 3-2) because some samples dried out in storage and the material could not then be identified.

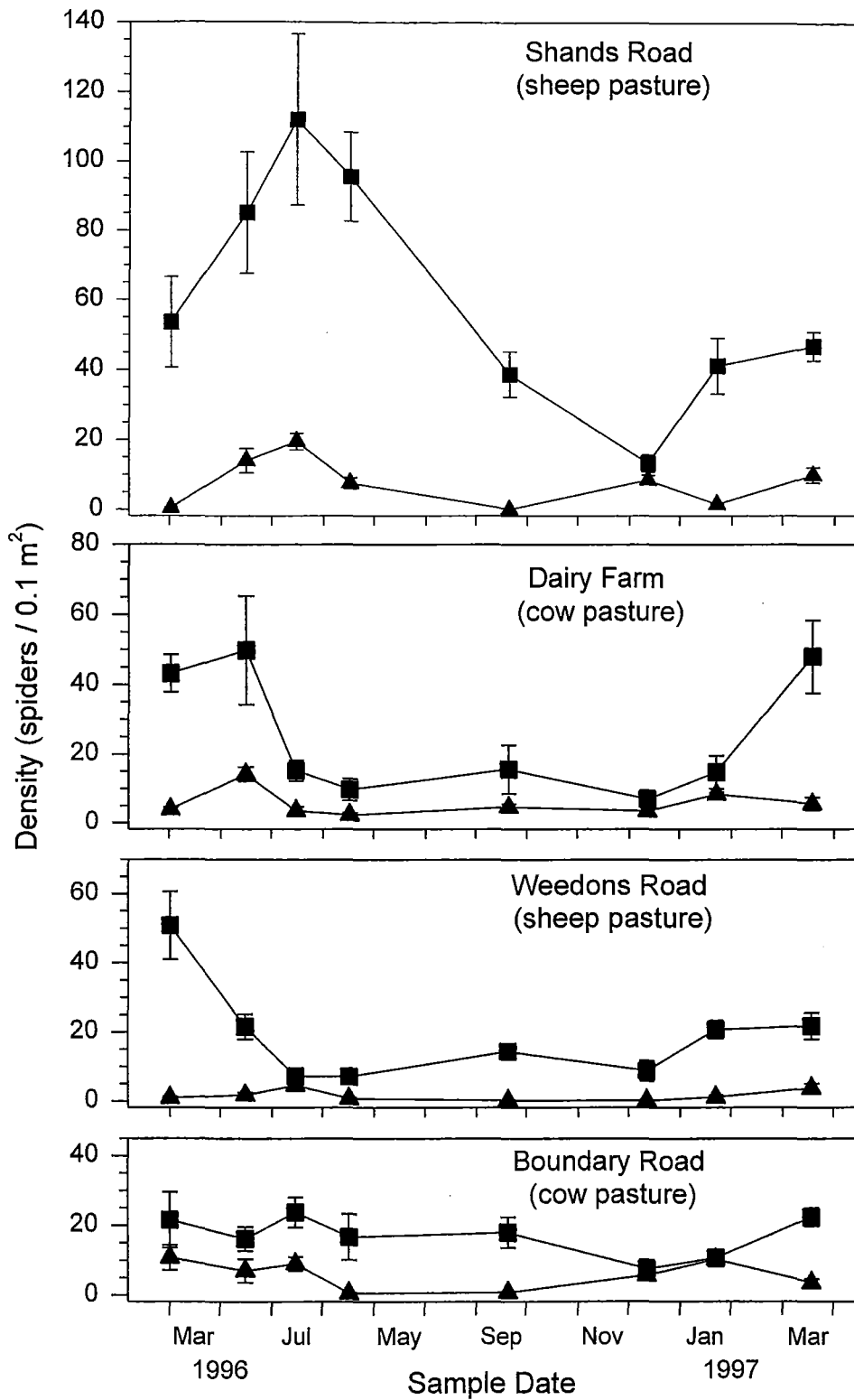


Figure 3-2. Density of spiders (mean/0.1 m² ± S.E.) in four pastures and adjacent fenced-off shelterbelts. See Methods section for site descriptions. ■ = shelterbelt, ▲ = pasture.

Table 3-2. The spider fauna from suction samples in four grazed pastures and their adjacent fenced-off shelterbelts. Data are pooled from eight sample dates (March 1996 to March 1997). * = introduced species, ⁿ = native; all others are endemic. † = *sensu* Forster and Forster (1999).

Habitat type: Species	Site										
	Shands		Weedons		Boundary		Dairy		TOTAL		
	Pasture	S/belt	Pasture	S/belt	Pasture	S/belt	Pasture	S/belt	Pasture	S/belt	Both
LINYPHIIDAE											
<i>Lepthyphantes tenuis</i> *	27	250	3	122	24	23	24	10	78	405	483
<i>L. tenuis</i> immatures	56	763	31	52	108	38	41	38	236	891	1127
<i>Microctenonyx subitaneus</i> *	2	74	1	21	0	0	0	1	3	96	99
<i>Erigone wiltoni</i> ⁿ	17	1	8	0	7	1	67	1	99	3	102
<i>Erigone prominens</i> *	19	1	2	0	2	0	1	0	24	1	25
<i>Araeoncus humilis</i> *	2	0	0	1	2	2	0	0	4	3	7
<i>Diplocephalus cristatus</i> *	0	0	0	0	0	0	0	4	0	4	4
<i>Diploplecta</i> sp.	1	0	0	0	3	1	5	0	9	1	10
<i>Haplina mundenia</i>	0	0	0	0	0	0	1	0	1	0	1
<i>Haplina titan</i>	1	0	0	0	0	0	0	0	1	0	1
<i>Laetesia minor</i>	0	1	0	0	0	0	0	0	0	1	1
<i>Maorineta tumida</i>	0	2	0	0	0	0	0	0	0	2	2
<i>Maorineta</i> sp.	0	1	0	0	0	0	0	0	0	1	1
THERIDIIDAE											
Unidentified sp. 'a'	15	247	4	243	3	194	0	525	22	1209	1231
Unidentified sp. 'b'	2	12	2	1	0	16	1	28	5	57	62
<i>Rhomphaea</i> sp. †	0	0	0	0	0	1	0	17	0	18	18
ARANEIDAE											
Unidentified immatures	0	0	0	1	0	1	0	1	0	3	3
ARANEOIDEA											
Unidentified immatures	140	1012	12	241	68	108	93	317	313	1678	1991
LYCOSIDAE											
<i>Lycosa hilaris</i>	4	0	0	0	2	0	0	0	6	0	6
Unidentified immatures	12	1	3	1	6	117	3	1	24	120	144
OXYOPIDAE											
<i>Oxyopes gracilipes</i> ⁿ	0	0	0	4	0	1	0	0	0	5	5

Habitat type: Species	Site											
	Shands		Weedons		Boundary		Dairy		TOTAL			
	Pasture	S/belt	Pasture	S/belt	Pasture	S/belt	Pasture	S/belt	Pasture	S/belt	Both	
AGELENIDAE												
Unidentified immature	0	0	0	1	0	0	0	0	0	1	1	
SYNOTAXIDAE												
<i>Pahora</i> sp.	0	2	0	0	0	11	0	1	0	14	14	
PSECHRIDAE												
<i>Poaka graminicola</i>	1	23	1	7	0	57	0	14	2	101	103	
CLUBIONIDAE												
<i>Clubiona contrita</i>	0	0	0	0	0	2	0	0	0	2	2	
Unidentified immatures	0	1	0	1	0	7	0	3	0	12	12	
GNAPHOSIDAE												
Unidentified immatures	0	0	0	0	0	2	0	0	0	2	2	
SALTICIDAE												
Unidentified sp. 'a'	0	4	0	2	0	0	0	2	0	8	8	
Unidentified sp. 'b'	0	2	0	3	0	1	0	0	0	6	6	
Unidentified immatures	0	57	1	36	0	26	0	11	1	130	131	
MICROPHOLCOMMATIDAE												
<i>Parapua punctata</i>	0	0	0	0	0	4	0	0	0	4	4	
HAHNIIDAE												
<i>Rinawa otagoensis</i>	0	0	0	0	0	0	0	1	0	1	1	
THOMISIDAE												
Unidentified immatures	0	0	0	0	0	2	0	3	0	5	5	
UNKNOWN FAMILY												
Unidentified immatures	9	29	0	5	4	32	2	50	15	116	131	
TOTAL	308	2483	68	742	229	647	238	1028	843	4900	5743	
Density, individuals/0.1m ²	7.70	63.7	1.70	19.0	5.87	17.5	5.95	25.7	5.30	31.6	18.3	
Minimum number of species	11	14	9	13	7	17	7	15	13	25	28	
sampled area: (m ²)	4.0	3.9	4.0	3.9	3.9	3.7	4.0	4.0	15.9	15.5	31.4	

Discussion

The density of spiders in the grazed pasture was similar to that reported elsewhere for this habitat in mainland Europe (Delchev and Kajak, 1974), the United Kingdom (Salt *et al.*, 1948; Cherrett, 1964), North America (Wolcott, 1937; Turnbull, 1966), and New Zealand (Topping and Lövei, 1997), and for hay meadows in Europe (Kajak, 1978; Alderweireldt, 1987). Pasture spider density varied little during the year, but there was more variation in numbers in the adjacent shelterbelts (Figure 3-2). The spider density in the Shands Road shelterbelt declined by 90% from winter 1994 to winter 1995 (Figure 3-1). This could have been due to differences in the shelterbelt understorey or to differences in the winter weather between years.

The relative difference between the field margin and the pasture in spider density and species richness was similar to that found in other studies, although the species richness found in these pastures was much lower than that found in other countries. Studies of pasture (Wolcott, 1937; Salt *et al.*, 1948; Cherrett, 1964; Turnbull, 1966; Delchev and Kajak, 1974; Peck and Whitcomb, 1978; Martin, 1983; Maelfait and De Keer, 1990; Topping and Lövei, 1997) and meadows (Kajak, 1978; Alderweireldt, 1987; Nyffeler and Benz, 1988c) showed that as many as 45 species of spider from 15 families may be present in this type of habitat. Because the sampling effort and method varied between these studies, only general comparisons of species numbers can be made with the data in this study. However, Topping and Lövei (1997) used vacuum-sampling followed by hand-searching (Sunderland and Topping, 1995) and recorded fewer species in grazed pasture in North Island, New Zealand than were found in the current study (4-5 cf. 7-11). While these authors sampled only during one month (November) they sampled a larger total area (5 m² cf. 4 m²) per site. In North Island pastures, *L. tenuis* is also a commonly encountered species.

The differences in relative density between the pasture and shelterbelt understorey could be caused by differences in vegetation structure (Greenstone, 1984) and height (although not recorded, shelterbelt understorey vegetation could reach 60 cm or more compared with pasture of *c.* 10-20 cm), or disturbance by grazing (Delchev and Kajak, 1974; Topping and Lövei, 1997), or differences in prey abundance. Delchev and Kajak (1974) found that sheep grazing reduced numbers of web-building spiders in Polish pasture, and Topping and Lövei (1997) found that

spider numbers decreased in agricultural habitats (wheat, pasture, and roadside verge) with increased disturbance. Numbers of possible prey were not recorded in this study so the effects of prey availability remain unknown in this study. Suction sampling can underestimate spider densities (Sunderland *et al.*, 1987b, 1995; MacLeod *et al.*, 1994; Sunderland and Topping, 1995) (but see Samu *et al.* (1997) for an exception). Vegetation density (Hand, 1986; Sunderland and Topping, 1995) and height (Henderson and Whitaker, 1977; Hossain *et al.*, 1999) can also reduce arthropod collection efficiency. The shelterbelts had taller herbaceous vegetation than did the pastures and, as a consequence, the density estimates from the former may have been underestimated more than those from the pasture. Therefore, the relative difference in densities between these two habitats may be even more extreme than this study shows.

The Canterbury Plains region of New Zealand was largely covered in trees and shrubs before European settlement in the 19th century (Molloy, 1969). Little of this vegetation remains today, as most of the available land is used for agriculture. This extreme habitat modification has led to a largely non-native pasture spider fauna. The most common species found in this study, *L. tenuis*, is also dominant in European fields (Sunderland, 1996). The ballooning habit (Forster and Forster, 1973) of linyphiid spiders probably explains their prevalence in disturbed agro-ecosystems, because this high dispersal ability would allow re-colonisation from distant undisturbed habitat (Meijer, 1977; Thomas and Jepson, 1997). In contrast, endemic species are more common in the relatively undisturbed field margin.

According to Chapman (1984) the main pests of pasture in New Zealand are Argentine stem weevil *Listronotus bonariensis* (Kuschel) (Coleoptera: Curculionidae) and grass grub *Costelytra zealandica* (White) (Coleoptera: Scarabaeidae). Neither of these Coleoptera are likely to be important prey items of spiders. Grass grub adults are too large, and their larvae are subterranean. Argentine stem weevil larvae feed within grass stems, while the adults are probably too robust to be attacked by the mostly small spiders found in this study. However, other pasture types include legumes on which aphid pests can be abundant (Chapman, 1984), therefore, the spider population and faunal data presented in this paper may be of value in helping interpret spiders' potential for controlling pests in other pasture types.

Bishop and Riechert (1990) showed that spiders colonising a vegetable garden came not from nearby woodland sources, but from further away. While most of the pasture species listed in the four study sites here were also present in the shelterbelt, a few were not, and probably came from further afield to colonise newly cultivated fields. They may, however, have already been present as unidentified immatures (either in the shelterbelt or pasture or both). The possibility of manipulating the density of spiders in a pasture by creating habitat for them in the field or in the margin seems remote, because spider density declined rapidly away from the shelterbelt (Figure 3-1), and the fauna was dominated by highly-mobile Linyphiidae.

Acknowledgments

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Chapter 4: Spider fauna and abundance in fenced-off shelterbelts

Introduction

Agricultural systems are highly disturbed by processes such as cultivation, harvesting, and grazing by livestock (Heidger and Nentwig, 1989; Marc *et al.*, 1999). For spiders to re-colonise after such disturbance events, there need to be populations or meta-populations living in undisturbed areas (Topping and Sunderland, 1994). Many farm paddocks in New Zealand have trees planted around the margins to provide a windbreak and shelter for livestock in what are known as shelterbelts. Often these shelterbelts are fenced off and, thereby, could represent a undisturbed refuge habitat next to the disturbed paddock habitat.

Other workers have investigated the spiders in the margins of fields, for example, in Belgium (Desender and Alderweireldt, 1988; Alderweireldt, 1989b; Maelfait and De Keer, 1990), and Canada (Doane and Dondale, 1979). The aim of this chapter was to investigate the fauna and abundance of spiders living in fenced-off shelterbelts for the first time in New Zealand in order to determine which species of spiders are available to potentially colonise and re-colonise farm paddocks.

Methods

Eleven fenced-off shelterbelts and woodlots located on or near the Lincoln University farms were used. From each, ten standard Vortis samples were taken on 22-29 November 1995. Samples were stored in 70% ethanol until ready for sorting under a stereo microscope (125× magnification), and spiders identified to species where possible. The number of species at a site was determined as the minimum number of species present. This was calculated by counting the number of recognised species plus the minimum number of species that were present as immatures only. For example, if a family is only represented by immatures (possibly from several species that cannot be determined) this was counted as a minimum of one species.

Site descriptions

See Appendix C for maps detailing the location of the following sample sites. Site A: beside *Eucalyptus* sp. trees 6-8 m high planted 4 years ago (1991) next to dairy pasture (Lincoln University Dairy Farm, L.U.D.F., paddock 33). The

main ground cover was cocksfoot (*Dactylis glomerata* L.), clover (*Trifolium* sp.), yarrow (*Achillea millefolium* L.), and Californian thistle (*Cirsium arvense* (L.) Scop.).

Site B: under willow (*Salix* sp.) trees 7-9 m high, fenced off from pasture (L.U.D.F. paddock 25) planted *c.* 30 years ago (*c.* 1965). The main ground cover was cocksfoot, clover, and tall oat grass (*Arrhenatherum elatius* (L.) Beauv. ex. J & C. Presl), with some dock (*Rumex obtusifolius* L.), catsear (*Hypochoeris* sp.) and Scotch thistle (*Cirsium vulgare* (Savi) Ten.).

Site C: under poplar (*Populus* sp.) trees trimmed to *c.* 7 m high planted *c.* 30 years ago or more (*c.* 1965 or earlier) beside dairy pasture (L.U.D.F. paddock 12). The main ground cover comprised *Phalaris aquatica* L., with some cocksfoot, yorkshire fog (*Holcus lanatus* L.), tall oat grass, dock, and thistles (*C. arvense*, *C. vulgare*). This site was referred to as 'Dairy Farm' in Chapter 3.

Site D: *Eucalyptus* sp. woodlot 6-8 m high planted 6 years ago (1989) (next to L.U. Mixed Cropping Farm paddock A11). The main ground cover was cocksfoot, with some yarrow and tall oat grass, and areas of eucalypt leaves.

Site E: conifer trees 3-4 m high planted 7 years ago (1988) beside sheep pasture (L.U. Research Farm paddock R27). The main ground cover was cocksfoot, tall oat grass, and yarrow with some browntop (*Agrostis capillaris* L.).

Site F: *Cedrus deodara* (D. Don) G. Don (Pinaceae) conifer trees *c.* 6-8 m high planted *c.* 6 years ago (*c.* 1989) beside sheep pasture (L.U. Research Farm paddock R28). The main ground cover was cocksfoot, with some yarrow, scotch thistle, and broom (*Cytisus scoparium* (L.) Link). This site was referred to as 'Weedons Road' in Chapter 3.

Site G: unfenced grassy strip, uncultivated for 10-15 years, between crop (L.U. Mixed Cropping Farm paddock A12) and *Eucalyptus* sp. and wattle (*Racosperma* sp.) trees, with main ground cover of dense cocksfoot.

Site H: under *Pinus radiata* (D. Don) G. Don trees trimmed to *c.* 9 m high planted *c.* 20 years ago (*c.* 1975) beside sheep pasture (L.U. Sheep Breeding Unit paddock S2) with mainly cocksfoot and pine needles as ground cover. This site was referred to as 'Shands Road' in Chapter 3.

Site I: *C. deodara* conifer trees *c.* 4 m high planted *c.* 6 years ago (*c.* 1989) beside sheep pasture (L.U. Sheep Breeding Unit, between paddocks S2 and S10).

The main ground cover was meadow foxtail (*Alopecurus pratensis* L.), with some cocksfoot, browntop and yarrow.

Site J: under *P. radiata* trees trimmed to c. 9 m high planted c. 20 years ago (c. 1975) beside sheep pasture (L.U. Sheep Breeding Unit paddock S12) with mainly meadow foxtail and pine needles with some cocksfoot as ground cover.

Site K: under willow (*Salix* sp.) trees 6-8 m high planted 5 years ago (1990) beside dairy pasture. The main ground cover was cocksfoot, tall oat grass, with some yarrow and clover. This site was referred to as 'Boundary Road' in Chapter 3.

Results

In the 11 sites, the density/0.1 m² of spiders collected ranged from 6.2 to 36.9, with an average density of 16.5 (Table 4-1). Sample numbers differ slightly between sites because some samples dried out in storage and the material could not then be identified. Species found in every site were *Lepthyphantes tenuis* and theridiid sp. 'a', along with unidentified Araneoidea immatures, which could include any of the linyphiid and theridiid species. Other commonly collected species were *Poaka graminicola*, collected from all but two sites, and *Microctenonyx subitaneus*, collected from 7 of the 11 sites. Twenty-three species of spiders were recognised (Table 4-1), with between 6 and 12 species from any one site (1 m² sampled). For a list of species names and authorities, see Appendix A.

Discussion

Of the 23 species listed in Table 4-1, only the three most common linyphiids (*L. tenuis*, *M. subitaneus*, and *Diplocephalus cristatus*) are introduced species to New Zealand (Forster *et al.*, 1988). All other species except one are endemic to New Zealand, or assumed to be endemic. One species, *Oxyopes gracilipes*, is also found across Australia and is native rather than endemic to New Zealand (Vink and Sirvid, 2000). Although the gnaphosid *Nauheia tapa* is listed as endemic, Forster (in Forster and Blest, 1979) has doubts that the genus *Nauheia* Forster is endemic.

The number of species found at any one site seems low compared with some overseas studies, although it is difficult to directly compare species richness between studies when there is a different sampling effort and fauna involved in each study.

Table 4-1. Fauna and abundance of spiders in 11 fenced-off shelterbelts. Sites are arranged in order of decreasing spider density. * = introduced species, ⁿ = native; all others are endemic. See Methods section for site descriptions, and Appendix A for authorities of species names.

Species	Site											Total
	A	D	E	F	B	J	I	G	H	K	C	
LINYPHIIDAE												
<i>Lepthyphantes tenuis</i> *	11	11	0	1	7	6	1	1	3	0	0	41
<i>L. tenuis</i> immatures*	93	77	21	5	26	35	2	4	17	6	2	288
<i>Microctenonyx subitaneus</i> *	1	15	8	0	0	1	3	0	9	0	2	39
<i>Diplocephalus cristatus</i> *	0	3	0	0	0	0	0	0	0	0	2	5
<i>Haplisis fucatina</i>	0	1	0	0	0	0	0	0	0	0	0	1
<i>Pseudafroneta incerta</i>	0	0	0	0	0	1	0	0	0	0	0	1
<i>Laetesia trispathulata</i>	0	0	0	0	0	0	0	0	0	0	1	1
<i>Diploplecta</i> sp.	0	0	0	0	0	1	0	0	0	0	0	1
THERIDIIDAE												
Unidentified sp. 'a'	40	3	40	33	19	4	53	24	8	16	13	253
Unidentified sp. 'a' immatures	19	3	7	0	1	2	4	3	1	4	6	50
Unidentified sp. 'b'	0	4	0	0	0	0	0	0	0	0	0	4
Unidentified sp. 'b' immatures	6	9	6	0	1	0	0	0	0	1	1	24
ARANEOIDEA												
Unidentified immatures	137	126	63	9	74	31	8	63	13	19	26	569
LYCOSIDAE												
<i>Lycosa hilaris</i>	0	2	0	0	0	0	0	0	0	0	0	2
Unidentified immatures	6	9	3	0	1	0	0	0	0	14	0	33
OXYOPIDAE												
<i>Oxyopes gracilipes</i> ⁿ	11	0	12	0	0	0	0	0	0	0	0	23
AGELENIDAE												
Unidentified immatures	5	0	0	0	0	2	2	1	0	2	0	12
SYNOTAXIDAE												
<i>Pahora</i> sp.	10	0	0	1	0	0	0	0	0	3	0	14
possible <i>Runga akaroa</i>	0	1	0	0	0	0	0	0	0	0	0	1
PSECHRIDAE												
<i>Poaka graminicola</i>	10	7	6	1	1	0	5	7	17	4	0	58
CLUBIONIDAE												
<i>Clubiona clima</i>	0	0	0	2	0	0	0	0	0	1	0	3
<i>Clubiona huttoni</i>	0	0	0	0	0	0	0	0	0	0	2	2
Unidentified immatures	2	0	3	2	0	0	6	1	0	2	0	16
GNAPHOSIDAE												
<i>Nauhea tapa</i>	0	0	0	1	0	0	0	0	0	0	0	1
Unidentified immatures	0	0	2	0	0	0	1	2	1	0	0	6
SALTICIDAE												
Unidentified sp. 'a'	0	0	0	1	1	2	0	0	2	0	2	8
Unidentified sp. 'b'	0	1	0	1	0	1	0	2	0	0	0	5
Unidentified immatures	0	6	4	6	2	4	32	6	29	2	2	93
MICROPHOLCOMMATIDAE												
<i>Parapua punctata</i>	1	0	0	0	0	0	0	0	0	1	0	2
CTENIDAE												
Unidentified immature	1	0	0	0	0	0	0	0	0	0	0	1
IDIOPIDAE												
<i>Misgolas</i> sp. immature	0	0	0	1	0	0	0	0	0	0	0	1
UNKNOWN FAMILY												
Unidentified immatures	16	0	36	60	8	3	10	11	5	5	3	157
TOTAL	369	278	211	124	141	93	127	125	105	80	62	1715
Density, individuals/0.1 m ²	36.9	27.8	21.1	15.5	14.1	13.3	12.7	12.5	10.5	8.8	6.2	16.5
Minimum number of species sampled area: (m ²)	12	10	10	9	6	8	8	7	6	10	8	23
mean number of spp./0.1 m ²	1.0	1.0	1.0	0.8	1.0	0.7	1.0	1.0	1.0	0.9	1.0	10.4
	5.6	4.4	4.7	2.8	2.3	3.0	3.4	2.6	3.7	3.3	2.1	3.5

For example, in Canada, two years of pitfall trapping in a grassy field border gave 38 and 39 species (14 families) in each year (Doane and Dondale, 1979), and 21 and 24 species (10 families) in the adjacent wheat field. In Austria, four months of pitfall trapping in a grassy field margin next to a wheat field, yielded 48 species from 14 families (Kromp and Steinberger, 1992). In Belgium (Maelfait and De Keer, 1990), one year of pitfall trapping yielded 70 species in a pasture edge, compared with 37 species in the adjacent intensively grazed cow pasture. Most (60%) of the species recorded by Maelfait and De Keer (1990) were members of family Linyphiidae, which contrasts with the current results where 10-50% (mean 26.1%) of species at any one site were linyphiids.

It should be noted that Europe has a lot more species of Linyphiidae than New Zealand. Roberts (1987) listed 267 species in Britain alone, compared with 95 species in New Zealand (Forster and Forster, 1999). However, it should also be noted that immature Araneoidea in the current work may contain more linyphiid species than those listed, because it is often impossible to identify immature spiders to species. Samples taken from shelterbelt sites C, F, H, and K eight times during a year (Chapter 3) showed another five linyphiid species are present in Canterbury shelterbelts. However, two of those (*Erigone wiltoni*, *E. prominens*) are predominantly pasture species (Table 3–2) and the others (*Araeoncus humilis*, *Laetesia minor*, and *Maorineta tumida*) were represented by only a few specimens. Additionally, three linyphiid species (*Haplisis fucatina*, *Pseudafroneta incerta*, and *Laetesia trispathulata*) were found in the current shelterbelt sampling and not in the other work (Table 3–2). Linyphiids are prevalent in agroecosystems, especially in Europe, (Sunderland, 1987, 1991), possibly because their ballooning habit enables them to quickly colonise paddocks following disturbance (Thomas and Jepson, 1997).

Linyphiids are sheet-web builders and generally (the details vary from species to species) build a horizontal non-sticky web that the spider hangs beneath while waiting for prey (Wise, 1993; Nyffeler *et al.*, 1994; Foelix, 1996). Like other web-building spiders, their distribution is to some extent influenced by habitat structure and the need for suitable web attachments (Uetz, 1991). Other web-building families present in the shelterbelts were Theridiidae, Agelenidae, Synotaxidae, and Micropholcommatidae. Theridiids build an irregular tangle-web (Wise, 1993; Nyffeler *et al.*, 1994; Foelix, 1996), and together with linyphiids and Araneoidea

immatures make up 74.4% of the individuals collected. Wandering or hunting spiders do not build webs to snare prey, but instead actively hunt their prey or wait in ambush for it (Wise, 1993; Nyffeler *et al.*, 1994). Not strictly a wandering spider, a sole *Misgolas* sp. immature (Idiopidae) was found (Table 4-1). This spider does not build a web, but a trapdoor retreat from which it ambushes prey (Forster and Forster, 1999). Wandering spider families present in the shelterbelts were Lycosidae, Oxyopidae, Clubionidae, Gnaphosidae, Psechridae, Ctenidae, and Salticidae. Salticids (jumping spiders) use their excellent vision (for a spider) to search for prey (Wise, 1993; Nyffeler *et al.*, 1994) and made up 0-29.5% (mean 8.2%) of spiders collected at any one shelterbelt site, and 42% of wandering spiders collected. Notable hunting spider families that are also found in other agroecosystems are lycosids (wolf spiders) and oxyopids (lynx spiders) (Nyffeler and Benz, 1988a; Agnew and Smith, 1989; Wise, 1993; Nyffeler *et al.*, 1994). Spiders from these two families and Salticidae are particularly known to disperse by ballooning (Agnew and Smith, 1989) while Clubionidae and Gnaphosidae species do so to a much lesser extent (Salmon and Horner, 1977; Dean and Sterling, 1985).

The purpose of this survey of shelterbelts was to investigate a range of shelterbelts and determine the spider density and species composition in them. What is not known are the factors responsible for the *c.* six times difference in density of spiders between the 11 sample sites. The two highest density sites (A, D) were both *Eucalyptus* sp. woodlots, 4-6 years old, while the two lowest density sites (C, K) were beside willow and poplar trees, 5 years and 30+ years old, respectively. In the United Kingdom, detailed investigation into habitat factors in field boundaries (Thomas *et al.*, 1992a) led to the creation of habitat that increased predator numbers in fields (Thomas *et al.*, 1992b). At present, it would be premature to embark on such studies in New Zealand until the beneficial effects of shelterbelt-inhabiting spiders are known.

Chapter 5: Spider faunal composition and densities in pasture in the Lincoln University Agroforestry Experiment

Introduction

Although spiders are among the most abundant predators in agro-ecosystems (Turnbull, 1973; Wise, 1993) their role in agricultural systems is not well understood (Wise, 1993); their predatory role in New Zealand agro-ecosystems has yet to be studied. To understand the ecology of spiders in agro-ecosystems, their habitat requirements need to be better known. In New Zealand, some farmers are planting widely-spaced trees in pasture, in what is known as 'agroforestry pasture', for reasons of erosion control, shelter for livestock, or for timber harvest (Mead *et al.*, 1993). This chapter analyses the spider density and fauna inhabiting three pasture types in open and in agroforestry pasture in the Lincoln University Agroforestry Experiment (LUAE) (Mead *et al.*, 1993). It also investigates vegetation characters as possible correlates with spider density, and is the first investigation into the habitat of spiders in agroecosystems on the Canterbury Plains in New Zealand.

Methods

Plot design

The LUAE was established in 1990 on the Canterbury Plains near Lincoln University (details in Mead *et al.*, 1993; see Appendix C for site location). Six pasture treatments were established, both with *Pinus radiata* (D. Don) G. Don (Pinaceae) trees (agroforestry pasture) and without trees (open pasture). Of these six, three of the pasture treatments were investigated here: (1) cocksfoot (*Dactylis glomerata* L.) and clovers (*Trifolium repens* L., *T. subterraneum* L., *T. pratense* L.); (2) lucerne (*Medicago sativa* L.); and (3) ryegrass (*Lolium perenne* L.) and clovers. For details of cultivars used and sowing rates see Mead *et al.* (1993). These pasture types were chosen to provide a diverse range of plant structures, and to be representative of common pasture species grown locally. The trees were planted in rows 7 metres apart and the pasture treatments were arranged as shown in Figure 5-1

below. At the time of sampling, the trees were about 6 metres tall and had not yet been pruned.

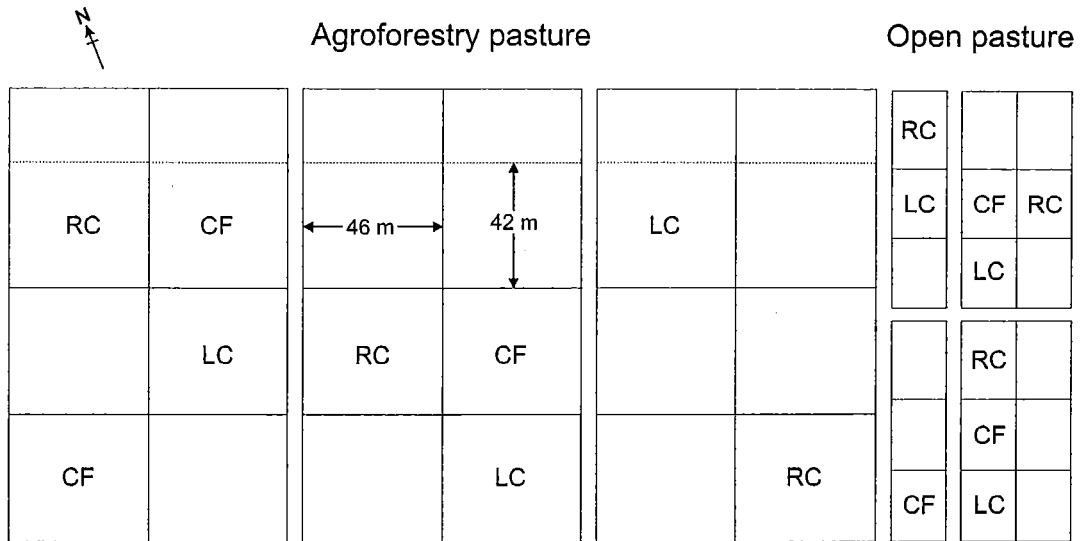


Figure 5-1. Design of the Lincoln University Agroforestry Experiment. RC = ryegrass-clovers pasture, LC = lucerne pasture, CF = cocksfoot-clovers pasture. Other pasture types (not investigated in this study) are not shown. Tree rows were aligned east-west (right-left).

Sampling design

Three replicate plots of each pasture treatment (cocksfoot-clovers, lucerne, and ryegrass-clovers) were sampled from both of the main pasture types (agroforestry pasture and open pasture) on 15-20 September 1994. Five 0.25 m² quadrats were placed at random in each plot and a sample was taken from each quadrat. From each quadrat, vegetation characteristics were recorded and a standard Vortis sample (see Chapter 2 for details) was taken for spiders. For the open pasture treatments, the quadrats were placed at random coordinates within the plots. For the agroforestry pasture treatments, a pasture row, between the rows of trees, was chosen at random and the five quadrats placed at random distances from the end of the row, on a transect along the centre of the row (3.5 metres from trees). The same row was used per replicate of each pasture type in the agroforestry pastures.

Vegetation characteristics

From each quadrat, the amount of plant cover (live material and dead material separately) and the amount of bare ground were assessed visually as belonging to a cover class ranging from 0 to 5. The cover classes were: 0, <5% cover; 1, 5-12%; 2, 12.5%-24%; 3, 25%-49%; 4, 50-74%; 5, 75-100%. Vegetation height was

measured using a ruler placed at nine regular positions (at the intersections of an imaginary 4x4 grid) within the quadrat. The height was recorded (to the nearest centimetre) as the maximum height that plant material touched the vertical ruler.

Spider density

Following recording of vegetation characteristics, a standard Vortis sample consisting of five 5-second suction samples (one from each of the four corners and one from the centre of the quadrat) was taken from within the quadrat. The total area suction-sampled was 0.1 m² per sample.

Analysis

The five quadrats within each plot were not true replicates (Hurlbert, 1984) but were sub-samples or pseudo-replicates. Analyses were done using plot means of these sub-samples. The spider density was analysed using a nested or hierarchical ANOVA design. From the nine vegetation heights recorded within each quadrat, maximum, mean, minimum, and vegetation height range were calculated. The mean of the five sub-sample values of each of these height characters was each correlated with spider density using Spearman's Rank Correlation. Vegetation cover class data were treated similarly.

Results

Density

The overall mean density was 3.5 spiders/0.1 m² (S.E. = 0.34, $n = 18$). The density of spiders did not differ between agroforestry and open pasture (Figure 5-2), or between the three pasture treatments (Figure 5-3)(Table 5-1).

Table 5-1. ANOVA table (nested design) showing analysis of spider density. TREE = pasture type (agroforestry or open pasture), PLANT = pasture species (cocksfoot-clovers, lucerne, or ryegrass-clovers), REP(TREE) = Replicates within TREE. Note: TREE effect is tested using REP(TREE) as an error term.

Source	d.f.	SS	MS	F	<i>P</i>
TREE	1	1.869	1.869	0.74	0.438
REP(TREE)	4	10.071	2.518		
PLANT	2	1.853	0.927	0.37	0.700
TREE*PLANT	2	0.778	0.389	0.16	0.857
ERROR	8	19.849	2.481		
TOTAL	17	34.42			

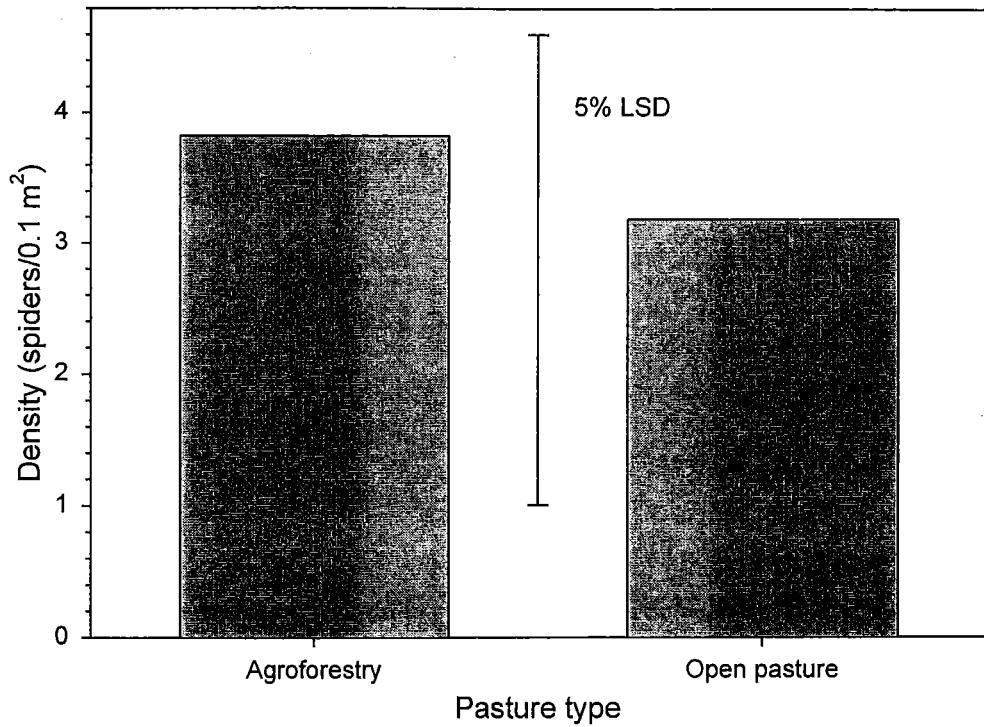


Figure 5-2. Mean density of spiders in agroforestry pasture and open pasture, with 5% LSD for comparison between means. Means include data from three pasture treatments. Sample size: $n = 9$ for each mean.

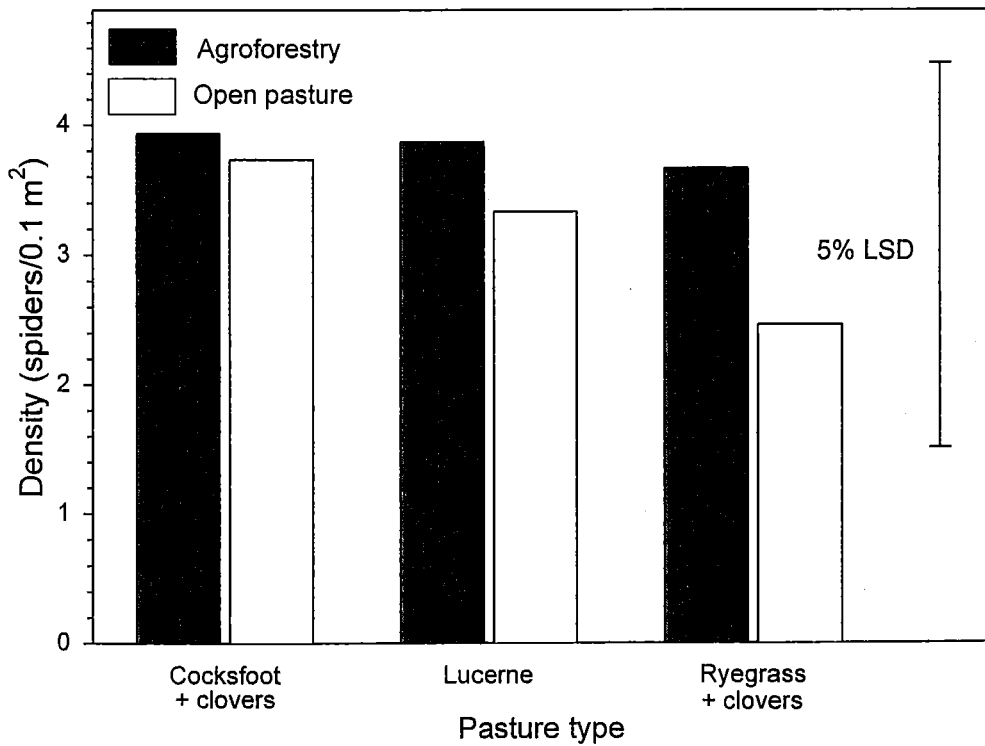


Figure 5-3. Mean spider density in three pasture types, both in agroforestry pasture and open pasture with 5% LSD for comparison between means. Sample size: $n = 3$ for each mean.

Correlates of spider density with vegetation characteristics

Spider density (all species combined) was not highly correlated with vegetation characters (Table 5-2). Plant cover characters were not correlated with spider density, but there is some suggestion that vegetation height was positively correlated with spider density in open pasture, but not in agroforestry pasture (Table 5-2). Mean vegetation characters are shown in Table 5-3. Correlations with the density of the most common species, *Leptyphantès tenuis* (adults and immatures), showed positive associations with vegetation height in open pasture but not in agroforestry pasture (Table 5-4, Figure 5-4).

Table 5-2. Spearman Rank Correlations between spider density per 0.1 m² and vegetation height and cover characters. Pasture species: CF = cocksfoot-clovers; LC = lucerne; RC = ryegrass-clovers.

vegetation height	All plots	pasture type		pasture species		
		open	agroforestry	CF	LC	RC
mean	0.39	0.70*	0.45	0.54	-0.17	0.20
minimum	0.25	0.61†	0.26	0.81	0.19	0.03
maximum	0.49	0.63†	0.45	0.60	0.00	0.60
range	0.37	0.51	0.23	0.43	-0.01	0.89*
cover						
bare ground	-0.24	-0.37	-0.10	-0.65	-0.19	0.06
live	0.02	0.01	-0.14	n.a.	-0.22	-0.31
dead	-0.07	-0.16	0.37	0.39	-0.31	-0.10
<i>n</i>	18	9	9	6	6	6

* $P < 0.05$, † $P < 0.10$. Note: coefficients are rounded to 2 decimal places, but probabilities were calculated from coefficients with 4 decimal place precision. "n.a." = correlation not able to be computed because all cover values were equal.

Table 5-3. Mean vegetation height characters (cm) and cover class (see Methods for cover classes) in agroforestry and open pasture, in three pasture treatments (mean/0.1 m² ± s.d.).

vegetation height	pasture type		pasture species		
	open	agroforestry	CF	LC	RC
mean	7.5±2.49	5.2±1.08	7.3±2.24	6.7±2.48	5.0±1.30
minimum	3.3±1.95	1.6±1.38	4.0±1.68	1.4±1.80	1.9±1.09
maximum	11.9±3.58	9.5±1.07	11.5±2.73	12.0±3.31	8.7±1.36
range	8.7±2.84	7.9±1.47	7.5±1.20	10.6±2.09	6.8±1.18
cover					
bare ground	0.47±0.520	0.49±0.649	0.03±0.082	0.53±0.589	0.87±0.575
live	4.7±0.27	5.0±0.0	5.0±0.0	4.7±0.24	4.8±0.29
dead	0.18±0.273	0.44±0.527	0.03±0.082	0.80±0.400	0.10±0.430
<i>n</i>	9	9	6	6	6

Table 5-4. Spearman Rank Correlations between *Lepthyphantes tenuis* density per 0.1 m² and vegetation height and cover characters. Pasture species: CF = cocksfoot-clovers; LC = lucerne; RC = ryegrass-clovers.

vegetation height	All plots	pasture type		pasture species		
		open	agroforestry	CF	LC	RC
mean	0.29	0.84**	0.22	0.70	-0.03	0.23
minimum	0.04	0.62†	-0.15	0.87†	0.32	0.06
maximum	0.51*	0.83*	0.39	0.75	0.14	0.67
range	0.55*	0.70*	0.55	0.63	0.06	0.93*
cover						
bare ground	-0.08	-0.29	0.17	-0.66	-0.23	0.09
live	-0.28	-0.18	0.04	n.a.	-0.09	-0.31
dead	-0.13	0.13	-0.11	0.00	-0.39	-0.10
<i>n</i>	18	9	9	6	6	6

** $P < 0.01$, * $P < 0.05$, † $P < 0.10$. Note: coefficients are rounded to 2 decimal places, but probabilities were calculated from coefficients with 4 decimal place precision. "n.a." = correlation not able to be computed because all cover values were equal.

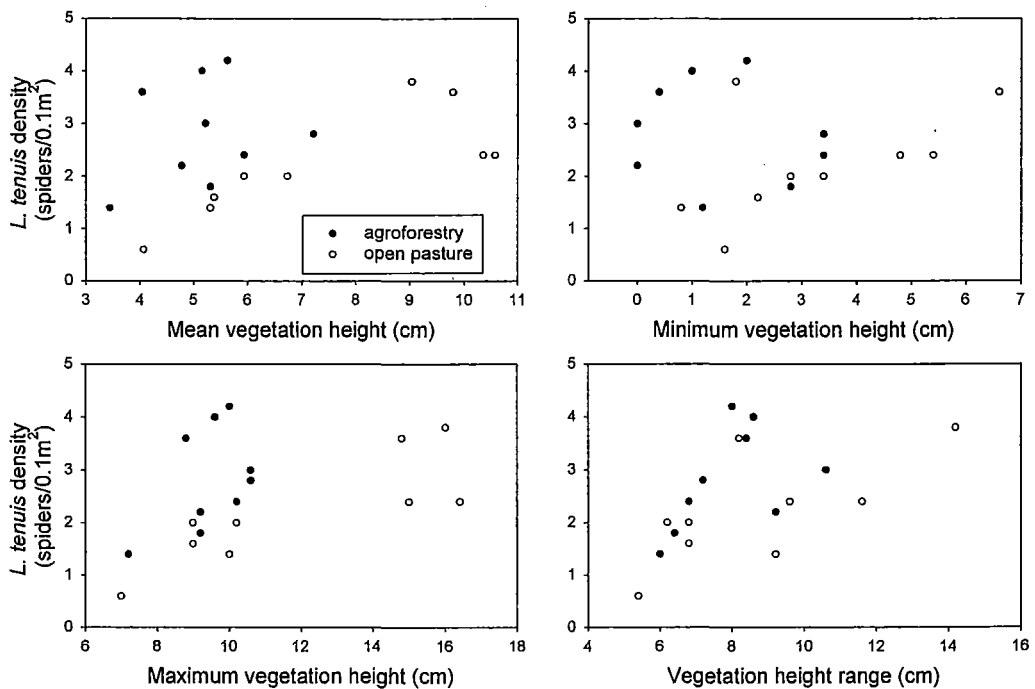


Figure 5-4. Scatterplots of *L. tenuis* density vs vegetation height characters in both agroforestry pasture (●) and open pasture (○).

Fauna

Six species of spider from three families were recognised (Table 5-5). The most common species was *Lepthyphantes tenuis*, which constituted 57% of adult spiders and 72% of all spiders. Of the six species recognised, four were linyphiids

recognised from adult specimens, and two other species, one theridiid and one lycosid were recognised from immatures. The lycosid specimens almost certainly belonged to a single endemic species, probably *Lycosa hilaris*, (C.J. Vink, *pers. comm.*). Other linyphiid and theridiid species may have been present as immatures, identified only as Araneoidea.

Table 5-5. Spider fauna and number of individuals of each species in agroforestry and open pasture types with three pasture treatments (CF = cocksfoot-clovers, LC = lucerne, RC = ryegrass-clovers). Sampled area: 1.5 m². See Appendix A for species name authorities.

Species	pasture type						total
	agroforestry			open			
	CF	LC	RC	CF	LC	RC	
LINYPHIIDAE							
<i>Lepthyphantes tenuis</i>	5	8	12	6	6	5	42
<i>L. tenuis</i> immatures	30	38	34	32	32	18	184
<i>Erigone wiltoni</i>	1	6	2	4	7	8	28
<i>Araeoncus humilis</i>				2			2
<i>Haplina fucatina</i>				1			1
LYCOSIDAE							
Unidentified immatures	4	1	2	2			9
THERIDIIDAE							
Unidentified immature			1				1
ARANEOIDEA							
unidentified immatures	19	5	4	9	5	6	48
Total	59	58	55	56	50	37	315
Density, spiders/0.1 m ²	3.9	3.9	3.7	3.7	3.3	2.5	3.5
s.d.	1.50	1.17	1.79	2.00	1.53	1.33	1.42

Discussion

Spider density

The *P. radiata* trees did not appear to have an effect on the density of spiders in pasture. In the LUAE, the trees were planted in a 7 m wide spacing to allow sufficient light for adequate pasture growth. This wide spacing of the trees may mean that effects of the tree presence on ground-dwelling spider habitat are minimal. It should be noted, however, that because of the low replication (three replicates of each treatment combination) and high variability between plots, that the means would need to differ by at least 36 spiders/m² before a statistically significant difference would be found. This lack of significance does not mean there is no

ecological difference between agroforestry and open pasture mean spider densities. However, the small difference found of only 6 spiders/m² is not likely to be significant ecologically. In future studies, to reduce the sample variation, a larger area in each plot, say 2 m² or more, could be sampled.

There was a soil moisture gradient across the agroforestry pasture between the east-west tree rows. There was higher soil moisture on the shady (south) side of the trees and lower moisture on the sunnier (north) side (Keith Pollock, *pers. comm.*). The agroforestry samples were taken along the centre of the agroforestry pasture to avoid a possible confounding source of variation within the agroforestry plots. Thus, the effects of this moisture gradient on spider density were not investigated in this preliminary study, but soil moisture can affect spider distributions (Rushton *et al.*, 1987). However, soon after these samples were taken, the lower branches of the trees were pruned, which would have removed much of the shading near the tree bases and probably reduced the soil moisture gradient.

Spider density did not differ between the three pasture types (cocksfoot-clovers, lucerne, ryegrass-clovers). A similar result was found by Thomas *et al.* (1992b) who created 1.5 m wide ridges in fields in the U.K. and sowed them with various grass species (including cocksfoot and ryegrass). Though the authors found there were some differences between grass treatments in some ridges, there were no consistent differences in spider (mainly linyphiid) density between the pasture species over the entire three year study. Vegetation type in a field margin, however, did affect spider populations in Swedish farmland (Lagerlöf and Wallin, 1993) with a florally diverse field margin having a greater pitfall catch than did a margin dominated by couch-grass (*Elytrigia repens* (L.) Nevski), which had a greater catch than did a clover margin. Much of this difference, however, may have been caused by the age of the plots, as the clover plots were more recently cultivated than were the other vegetation types.

Correlates of spider density with vegetation characteristics

There were few significant correlations of spider density with vegetation characters (Table 5-2). Of the 42 correlation coefficients presented in Table 5-2, there were two (4.8 %) with $P < 0.05$, and four (9.5%) with $P < 0.10$. These results are what would be expected by chance alone, and should be interpreted with caution, especially considering the low sample sizes involved. Another reason for the lack of

significant correlations could be that several spider species are present, and although one or more species' density may correlate with a vegetation character, if the species are correlated in different ways, then when combined together, their respective species correlations could cancel each other out (Figure 5-5). For this reason, correlations were carried out for *L. tenuis*, the most common species present.

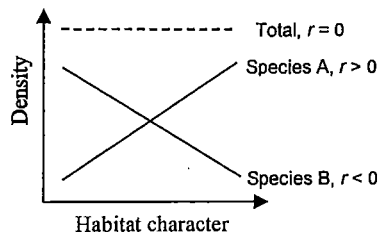


Figure 5-5. Theoretical habitat character that is significantly, but oppositely, correlated with two species, and is not correlated with the total density.

Significant correlations of *L. tenuis* density with vegetation characters were more numerous (six with $P < 0.05$, eight with $P < 0.10$, Table 5-4) than with total spider density. *L. tenuis* density was positively correlated with vegetation height in open pasture, but less so in agroforestry pasture. It is not clear why there were differences between these two types, although the vegetation was slightly higher in open pasture (mean heights: 5.2 cm in agroforestry; 7.5 cm in open pasture, Table 5-3), and the range of vegetation values was greater in open pasture plots than in agroforestry plots (Figure 5-4). The density of *L. tenuis* was not different between these pasture types.

In general, other studies suggest that spider numbers do not seem to be correlated with vegetation cover, but with habitat structure (in this case, crudely measured by the vegetation height characters). For example, Greenstone (1984) measured vegetational structural diversity in meadows and scrub in California and Costa Rica and found a positive correlation of web spider species diversity with vegetational structural diversity. Greenstone (1984) also measured prey availability using sticky traps, and found that spider diversity was not correlated with the sticky trap catch.

In contrast, Castro Schmitz (2000) found that wolf spider pitfall trap catch was correlated with both vegetation structure and cover. The wolf spider catch (males only) was positively correlated with vegetation height, and negatively correlated with percent plant cover and vegetation dry weight in farm habitats only several kilometres from the LUAE. However, pitfall trap catch can overestimate

abundance of Lycosidae (Dinter, 1995), and interpreting the results can be difficult (Sunderland *et al.*, 1995). This fact throws some doubt on the ecological interpretation of Castro Schmitz's results.

Habitat structure affected the distribution of linyphiid spiders in sugar beet fields (Thornhill, 1983) with some species building webs over shallow depressions in the soil, while others, including *L. tenuis*, were most often found in webs attached to beet plants. Alderweireldt (1994) demonstrated an effect of habitat structure on spider density by finding that, after digging holes of 2.8 to 9.5 cm diameter in soil, there was an increase in colonisation by web-building linyphiids of Belgian maize fields. Also in Belgium, variation in cattle pasture height influenced both the activity (as measured by pitfall trap catch) and density (quadrat samples) of spiders (De Keer *et al.*, 1989), and spiders were associated with clumps of taller vegetation within a grazed pasture in Canada (Turnbull, 1966).

Fauna

The spider fauna recorded from the LUAE is typical of that in other New Zealand pasture (Martin, 1983; Topping and Lövei, 1997) and clover crops (A. McLachlan, unpublished data) in New Zealand, being dominated by Linyphiidae, especially the sheetweb-building linyphiid, *L. tenuis*. This small spider (body length 3 mm) originated from Europe where it is also prevalent in agroecosystems (Sunderland, 1996) along with other linyphiids.

There appears to be little difference in spider species composition between the various pasture types, although most (7 of 9) of the lycosids collected were from the agroforestry plots. An adult of the native linyphiid *Haplinis fucatina* and two adults of the introduced linyphiid *Araeoncus humilis* were found only in the open cocksfoot-clovers pasture; however, these could have been present as Araneoidea immatures (Table 5-5) in the other plots.

Conclusions

There were no differences in spider density or species composition between three pasture types, or between open and agroforestry pasture. While total spider density was not correlated with vegetation cover or height characters, *L. tenuis* density was positively correlated with vegetation height in open pasture.

Chapter 6: Effect of mowing on spider density and species composition

Introduction

Agricultural ecosystems are highly disturbed compared with many natural ones. Farming practices such as harvesting, cultivation, grazing by livestock, and pesticide application disturb the habitat and are known to have major impacts on spider populations (Heidger and Nentwig, 1989; Marc *et al.*, 1999). For example, spider populations and species richness decreased with increasing management intensity (Luff and Rushton, 1989; Downie *et al.*, 1999), whereas less intensive production systems typically contained greater spider species richness than conventional crops (Fan *et al.*, 1993; Feber *et al.*, 1998).

Crop rotation also affected invertebrate populations in corn (Stinner *et al.*, 1986; Brust and King, 1994) as did planting date and row spacing in soybean (Buschman *et al.*, 1984). The density of weeds between crop rows influenced the number of web-building spiders in soybean plots (Balfour and Rypstra, 1998) with more spiders in plots of high compared with low weed density.

Tillage has negative effects on the numbers of invertebrates and species richness, especially that of soil arthropods (Edwards, 1977), but also of surface-dwelling spiders (Haskins and Shaddy, 1986; Stinner *et al.*, 1986; Everts *et al.*, 1989). Mechanical control of weeds by harrowing lowered species richness compared with the effects of chemical control of weeds (Everts *et al.*, 1989).

Insecticide use is generally detrimental to spiders, especially in orchards (Bostanian *et al.*, 1984; Mansour, 1988a). Although the treatments were not replicated, there was a 13-fold difference in spider numbers between sprayed and unsprayed citrus trees in Israel three days after spraying (Mansour, 1988a), and a 21-fold difference after 55 days. Dinter and Poehling (1992) used both D-Vac and pitfall traps to assess spider populations in German winter wheat, and found that pyrethroid insecticides reduced spider populations. However, the authors warned that pitfall traps may not adequately sample spider populations following insecticide application, and may give misleading results in studies of insecticide effects. Laboratory tests showed that spiders are susceptible to a number of insecticides and acaricides (Mansour *et al.*, 1981a; Mansour and Nentwig, 1988), although there is

evidence to suggest that some populations may be developing resistance to insecticide (Mansour, 1984).

Sheep grazing can reduce spider numbers and diversity, especially of those that build webs on vegetation (Delchev and Kajak, 1974; Gibson *et al.*, 1992). Mowing an old field reduced the density and diversity of spiders in it (Haskins and Shaddy, 1986). Mowing lucerne also reduced populations of some spider species, but led to an increase in Linyphiidae populations, possibly in response to the presence of higher numbers of prey insects in the mown vegetation (Howell and Pienkowski, 1971). Although Topping and Lövei (1997) found that spider numbers decreased with increasing levels of grazing in North Island, New Zealand, pasture, it is not known what changes, if any, to spider populations occur in New Zealand pasture following manipulations such as mowing.

In New Zealand, shelterbelts are commonly planted around field margins to provide shelter for livestock, and thus, also provide a spider habitat adjacent to pasture that is not disturbed by practices such as grazing and cultivation. Previous chapters (3 and 4) have shown that spider populations and faunas differ between the pasture and shelterbelt. The reasons for these differences are not known, but may be related to the amount of disturbance each habitat receives. To investigate the effects of a disturbance to pasture as a possible reason for the difference between pasture and shelterbelt spider communities, and the effects of mowing on New Zealand spider populations, this study investigates the effects of mowing on spider density and species richness in replicated pasture plots mown at different frequencies.

Methods

The study site was established in 1994 in a paddock adjacent to the Lincoln University Field Service Centre, and sown with red and white clovers (*Trifolium pratense* L. and *T. repens* L., respectively), perennial ryegrass (*Lolium perenne* L.) and cocksfoot (*Dactylis glomerata* L.). The study site was divided into 32 plots, each 4.5 m × 6.0 m, arranged in four randomised blocks of eight plots (Figure 6-1). There were four mowing treatments: (1) No mowing, (2) Infrequent mowing with clippings removed, (3) Infrequent mowing with clippings left, and (4) Frequent mowing with clippings left. 'Infrequent mowing' plots were mown 3-5 times per year to a 5 cm height. 'Frequently mown' plots were cut 6-10 times per year, to a 4 cm height. The

plots were mown at irregular intervals depending on the amount of plant growth, and were mown mainly in spring (September-November).

In October 1995, one standard Vortis sample (see Chapter 2) was taken from each plot, about 1 metre from the edge. Samples could not be taken further into the plots because it was not permitted to walk on them. Samples were stored in 70% ethanol until ready for sorting under a stereo microscope (125× magnification), and spiders were identified to species where possible. Treatments were compared using randomised block ANOVA, and data were transformed using \log_{10} where necessary to stabilise variances. Comparison of means was made using Tukey's Honestly Significant Difference (HSD) (Zar, 1984).

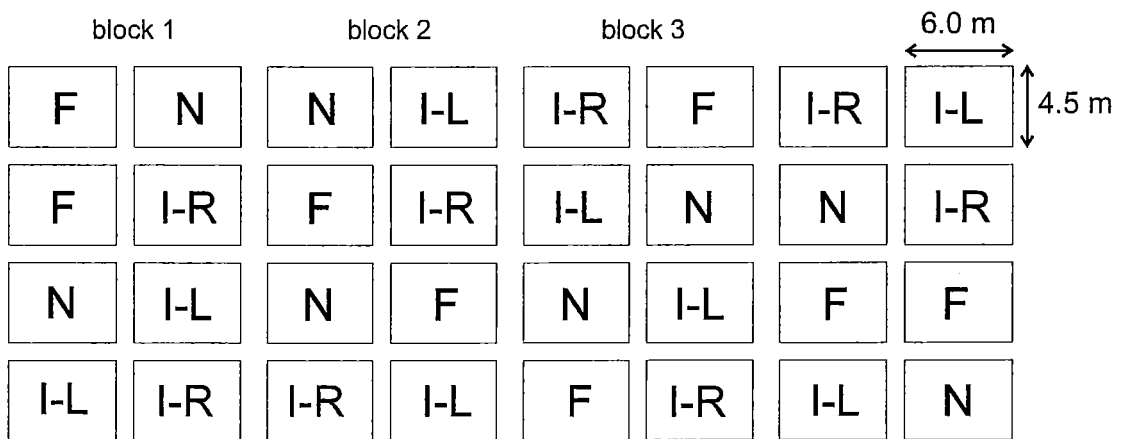


Figure 6-1. Layout of mowing treatments. N = No mowing, I-R = Infrequent mowing, clippings removed; I-L = Infrequent mowing, clippings left; F = Frequent mowing, clippings left. The 32 plots are arranged in four blocks of eight (each mowing treatment is repeated twice in each block).

Results

The density of spiders differed between the mowing treatments ($F=30.35$, $df=3,25$, $P<0.0001$) (Figure 6-2), as did the number of spider species ($F=5.45$, $df=3,25$, $P=0.0045$) (Figure 6-3). The 'No mowing' treatment contained more spiders than the other treatments (HSD; $P<0.05$), largely because of high numbers of *Lepthyphantes tenuis* immatures and Araneoidea immatures (Table 6-1). Two theridiid species were also more prevalent in the unmown treatment than the mown ones. The infrequently mown treatments had higher densities of spiders than did the frequently mown treatment (HSD; $P<0.05$, Figure 6-2), but did not differ in mean species richness (Figure 6-3). The 'No mowing' treatment had a higher species richness than did the other treatments (Table 6-2). There was no effect of removing clippings on either spider density or species richness.

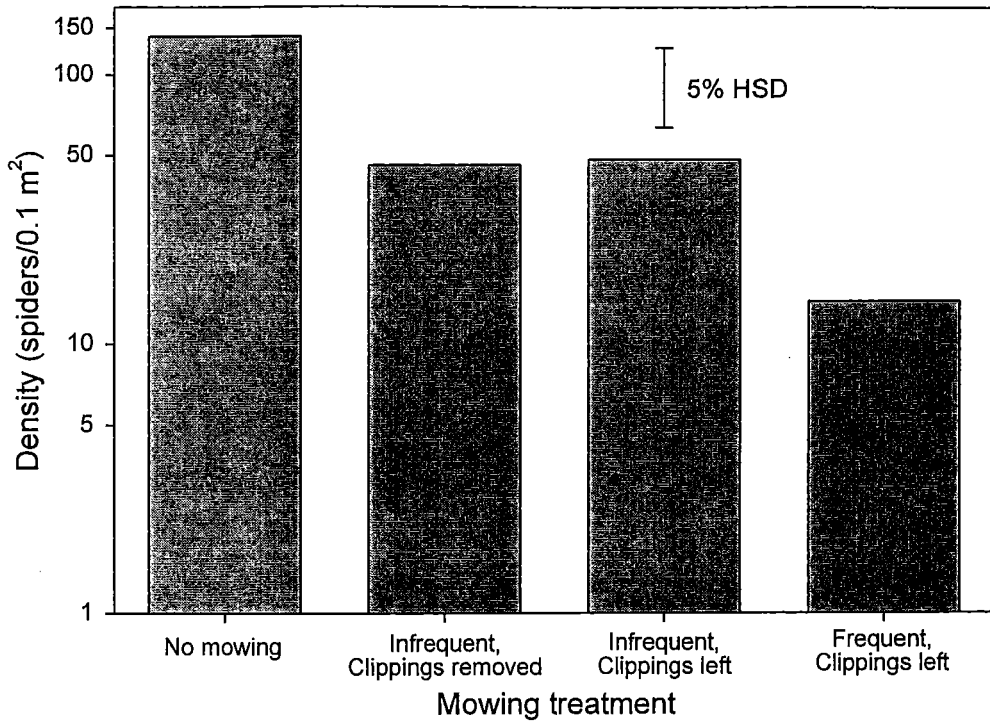


Figure 6-2. Mean density of spiders in four different mowing treatments, with 5% Tukey's HSD for comparison of means.

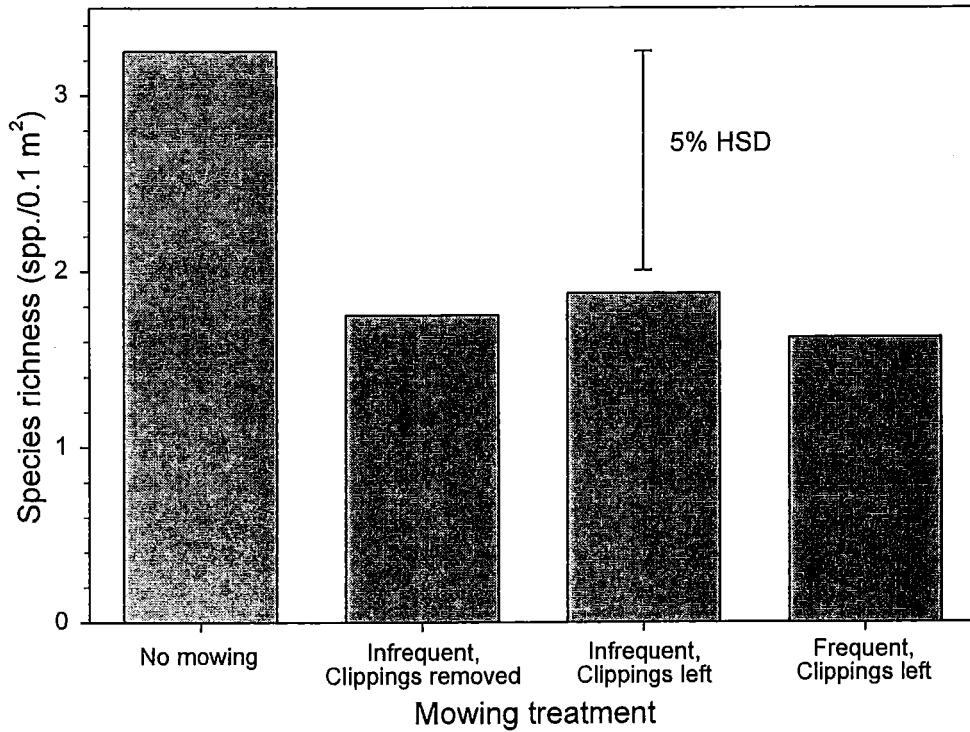


Figure 6-3. Mean species richness in four different mowing treatments, with 5% Tukey's HSD for comparison of means.

Table 6-1. Species of spider in standard Vortis samples from pasture plots treated with four mowing treatments ($n = 8$ for each treatment). See Methods for details of treatments, and Appendix A for authorities of species names.

Species	Mowing Treatment			
	None	Infreq-R	Infreq-L	Freq-L
<i>Lepthyphantes tenuis</i>	34	24	29	7
<i>L. tenuis</i> immatures	436	172	195	57
<i>Erigone wiltoni</i>	0	0	1	5
<i>E. prominens</i>	0	1	0	0
<i>Microctenonyx subitaneus</i>	0	0	0	1
Theridiidae sp. 'a'	33	4	3	0
Theridiidae sp. 'b'	19	0	0	0
Unidentified Mynogleninae immatures	3	0	0	0
Unidentified Araneoidea immatures	589	165	164	44
Unidentified Lycosidae immatures	1	2	3	1
Oxyopidae: <i>Oxyopes gracilipes</i>	0	2	0	0
Psecridae: <i>Poaka graminicola</i>	1	0	0	0
unidentified immature	1	0	0	0
Total	1117	370	395	115
mean density/0.1 m ²	139.6	46.3	49.4	14.4
s.d.	56.06	21.19	14.90	7.98

Table 6-2. Spider species richness in standard Vortis samples from pasture plots treated with four mowing treatments ($n = 8$ for each treatment). See Methods for details of treatments.

	Mowing Treatment			
	None	Infreq-R	Infreq-L	Freq-L
Total number of species	6	5	4	4
mean no. of spp./0.1 m ²	3.25	1.8	1.75	1.63
s.d.	0.707	1.165	1.126	0.744

Discussion

The effect of the repeated mowing treatments on spider numbers supports results from other studies that show detrimental effects of some farm practices (e.g., Haskins and Shaddy, 1986; Stinner *et al.*, 1986; Everts *et al.*, 1989), and of increasing levels of disturbance and intensity of management (Fan *et al.*, 1993; Downie *et al.*, 1999) on spider numbers. The increased frequency of mowing decreased the density of spiders considerably (Figure 6-2), and the species richness to a lesser extent (Figure 6-3).

The species composition and densities indicated in the results (Table 6-1) generally agreed with those found in other pasture and shelterbelt samples in the present work (Chapters 3 and 4). The species collected in the 'No mowing' treatment were more likely to be found in shelterbelts than in pasture, whereas the other mowing treatments contained species and densities that resembled those found in

pasture. *L. tenuis* was found in both mown and unmown plots in relatively high numbers, and Lycosidae immatures in relatively low numbers, as they are found in both pasture and shelterbelts. The *Erigone* spp. were not found in the unmown plots as they are generally a pasture species (Chapter 3: Table 3–2), and were also not found in shelterbelts (Chapter 4: Table 4–1). In contrast, the two theridiid species are generally found in shelterbelts (Tables 3–2, 4–1), and were found mainly in the ‘No mowing’ treatment (Table 6-1). A single *Microctenonyx subitaneus* was found in the frequently mown plots; this species is generally found in undisturbed shelterbelts rather than pasture (Chapter 4), but the presence of only one individual is of no real significance.

The effect of the mowing on the vegetation in the plots was mainly to reduce the height, and to some extent, change the plant species composition (R. Duncan, *pers. comm.*). Spiders generally do not respond to differences in plant species *per se*, but rather to changes in habitat structure, or to structural complexity of the habitat (Hatley and Macmahon, 1980; Greenstone, 1984). For example, Duffey (1974) found that both spider density and species richness increased with vegetation height in chalk grassland, and De Keer *et al.* (1989) found that variation in plant height in cattle pasture affected activity and species composition.

It is difficult in this case, as indeed it is for all farm practices, to separate effects of disturbance from effects of changes to habitat structure, as the two are invariably linked. For example, Rushton *et al.* (1987) found that habitat management affected spider species composition and was inversely related to vegetation biomass. In this experiment, there is both a vegetation height component and a disturbance component to the mowing treatments, and the combined effects only can be examined here. Further experiments to separate the effects of these components could be done. For example, by leaving plots unmown, but adding a disturbance treatment to the plots, by using a rake or roller, could allow comparison of different levels of disturbance independent of vegetation height.

However, a key result was that pasture that is mown frequently had a spider fauna that resembled that of grazed pasture, and the taller unmown vegetation had a fauna that was similar to that in shelterbelts. This result suggests that the principal difference between pasture and shelterbelt habitats for spiders is the cessation of disturbance in shelterbelts that allows the herbaceous vegetation to increase in height.

In this study, no effort was made to investigate possible short-term effects of mowing. For example, a comparison of the spider fauna immediately prior to and following mowing would enable the short-term effects and recovery, if any, from the mowing disturbance to be investigated.

Conclusions

Spider density and species richness decreased with increasing disturbance, and decreasing vegetation height. Unmown plots had a fauna and density similar to that in shelterbelts, while the mown plots were similar to pasture. In summary, this study shows that a simple management procedure, such as mowing, can change spider density and species composition in grass plots.

Chapter 7: The feasibility of the use of field cages to investigate the effects of spider predation on aphid populations

Introduction

A number of methods have been used to investigate predation by spiders in the field, including visual observation (Kiritani *et al.*, 1972; Dean *et al.*, 1987), collection of prey remains (Nyffeler *et al.*, 1986), detection of labelled prey (Moulder and Reichle, 1972), dissection (Putman, 1967), serological techniques (Greenstone, 1978; Sunderland *et al.*, 1987a; Sopp *et al.*, 1992), and field cages (either excluding or adding spiders) (Hurd and Eisenberg, 1990; Clark *et al.*, 1994; Riechert and Lawrence, 1997; Lang *et al.*, 1999). These methods are used principally to measure the rates of predation, or to demonstrate the effects of spiders on prey populations (Powell *et al.*, 1996).

Field enclosures have also been used to investigate predation by spiders. They offer the advantage over laboratory studies of the experiments being done under conditions nearer to that of field conditions. In some experiments, predators are removed either by hand or by pitfall trapping (e.g., Clark *et al.*, 1994) or both methods (e.g., Lang *et al.*, 1999). Alternatively, predators can be added to enclosures. For example, Hurd and Eisenberg (1990) added lycosid spiders and mantids (Dictyoptera) alone and in combination into 1 m² enclosures in pasture and found that mantids reduced grasshopper numbers, and that lycosids reduced numbers of small spiders.

It is not known what effects New Zealand pasture spiders have on prey populations. To investigate methods to assess the effects of such spiders on a prey species, the pea aphid *Acyrtosiphon pisum* (Harris) (Hemiptera: Aphididae) was chosen as a prey. This aphid is present in a number of crops in New Zealand, including lucerne, where it is a vector of plant viruses (Butcher, 1984). This insect is readily cultured in the laboratory, and preliminary feeding experiments showed that adult *Lepthyphantes tenuis* were able to capture and eat adult pea aphids. Further, pea aphids drop from the plant when disturbed (Chau and Mackauer, 1997) which may make them available as prey for non-climbing spiders. The aim of this research was to investigate the feasibility of using field cages to investigate the effect of spiders on

pea aphids to answer the question: do spiders decrease the number of pea aphids in a field cage?

Methods

Expt 1 (Lucerne)

Fifteen field cages were placed in a lucerne crop (*Medicago sativa* L.) (sowing date and cultivar not recorded) near Lincoln University, Shands Road, (property of Mr John Morrish). The cage frames were made of galvanised iron of dimensions 92 cm L × 62 cm W × 73 cm H. (The frames were normally used in the Lincoln University glasshouses to support plant trays.) The cage covers were made of white, curtain netting material with a mesh size fine enough to hold both small instar spiders and aphids. The covers were sewn so that they were open only at the bottom. The cage area was 0.57 m².

In preparing the cages in the field, the frame was placed on the ground, and vegetation cleared from an area around the frame margin. Then the plants inside the frame were suction-sampled using a Vortis (Arnold, 1994) for one or two minutes to remove spiders from the lucerne. Immediately after suction-sampling, the cover was placed over the frame and sealed onto the ground using metal pegs and heaped soil around the base of the cage.

Pea aphids that were reared in the laboratory at room temperature on broad bean plants (*Vicia faba* L.) were released into the cages on 27 February 1995. Fifty third and fourth-instar aphids were released into each cage in small netting draw-string bags. Five aphids were placed in each bag and the bag was placed over a plant shoot then drawn tight. The bags were to provide some protection from heat and dehydration for the first few days until the aphids had established on the host plants. The bags were removed five days after the release. During the aphid release and removal of the netting bags, the cage cover was lifted from the ground along one side of the cage, then sealed again when the operations were complete. The period that the cage was unsealed was kept to a minimum.

Spiders were collected from undisturbed long grass using a D-Vac (Dietrick, 1961) in the Lincoln University Horticulture Research Area. Although unwieldy to use compared with the Vortis, the D-Vac was used because the larger aperture enabled collection from a wide area more quickly. In the field, D-Vac samples were emptied onto a white tray and any linyphiid or theridiid spiders were placed in

groups into medium-sized (29 × 42 cm) polythene bags for transport to the laboratory, where they were shaken from the bags onto another white tray. The spiders were then placed, five per container, into small plastic containers (40 mm diameter, 55 mm height) together with a piece of wet paper towel. The paper towel provided humidity which was very important for spider survival as the D-Vac seemed to dehydrate them. Some spiders placed their mouthparts on the paper, presumably to drink, which spiders will do if they are extremely thirsty (Foelix, 1996). The spiders in the plastic containers were kept in a refrigerator (*c.* 4°C) during the 3-5 days that it took to collect the required number of spiders. There was some mortality, presumably from the collection process, but also a small amount of cannibalism.

Spiders were released into cages on 12 March 1995 (13 days after the aphid release) in two treatments: low density (30 spiders per cage), and high density (60 spiders per cage). Control cages had no spiders added. The two treatment and control cages were arranged in a line of five blocks of three cages in a randomised block design. This design was used to give good interspersion of treatments (Hurlbert, 1984). One block was “sacrificed” to provide an estimate of pre-treatment aphid establishment. These cages were thoroughly suction-sampled using a Vortis and the samples stored in 70% ethanol for later counting.

The experiment ended on 28 March 1995 (16 days after spiders were added). Each cage cover was removed and the area inside the cage thoroughly suction-sampled using a Vortis. The samples were labelled, and 70% ethanol added to kill and preserve the contents for later counting and identification. In the laboratory, the samples were sieved through a 2 mm mesh to remove the plant material, and all spiders and aphids were counted under a dissecting microscope (× 40) using a Bogorov tray (a plastic tray with a channel cut in it, see Appendix B for details of the design). Samples were labelled only by cage number, not the treatment. The samples can be considered to have been sorted ‘blind’ because the sorter did not remember the random allocations of treatments done weeks earlier, and only after the counting had been completed were the samples matched with their corresponding treatment.

Expt 2 (Broad beans)

To provide a plant host that had a lower density of stems, and therefore, would be easier to suction using the Vortis, broad beans *Vicia faba* cv. ‘Coles Early Dwarf’ were planted on 12 December 1995, in four 20 m rows, 30 cm apart. Cages

were placed over the rows of broad bean plants on 19-21 January 1996. Soil was piled against the base of the frame to seal the cage at ground level. New cage covers were used which had a zippered top to make access to the inside of the cage easy without compromising the cage ground seal. A Vortis was used to suction the inside of the cages. In most cases, the plants were too tall to press the Vortis down to the ground. The tops of the plants were suction-sampled, then the Vortis brushed up the sides of the taller plants. The ground between the plants was suction-sampled where possible. Some stem damage to the plants was unavoidable, but was relatively minor. Other predators, if seen, were removed by hand. These included ladybirds (Coleoptera: Coccinellidae), lacewings (Neuroptera), and occasional *Badumna longinqua* (Koch) (Araneae: Desidae) that had built webs on the cage frames while they were in storage.

Fifty aphids were released into each of the cages on 22 January 1996. They were not in small cloth draw-string bags as for Expt 1. Instead, the aphids were just sprinkled over the plants. The release method was modified in this way because the aphids settled without the protection of the bags. Near the spider release date, there did not appear to be significant aphid establishment, so a further 50 third and fourth-instar aphids were released into each cage on 3 February 1996.

Spiders were collected using a D-Vac, as for Expt 1. However, fewer spiders were collected compared with Expt 1, so the treatment densities had to be halved. The cages were arranged in a line of four blocks of four treatments. The four treatments were: Pre-treatment (before spiders were added); control (no spiders added); low density (15 spiders per cage); and high density (30 spiders per cage). Spiders were released into cages on 5 February 1996 (14 days after aphids were added).

The experiment ended on 17 February 1996 (14 days after spiders were added). Each cage was opened and the plants inside suction-sampled with a Vortis. Then, the plants were cut off near ground level, briskly shaken inside the cage, removed from the cage, and the area inside the cage thoroughly suction-sampled again using the Vortis. The samples were processed as for Expt 1. Inadvertently, the samples from the 'Pre-treatment' cages were discarded before they had been sorted.

Expt 3 (Broad beans)

Broad beans cv. 'Coles Early Dwarf' were planted on 14 January 1996 in four 20 m rows, 30 cm apart as for Expt 2. The cages were set up on 21 February

1996, and sprayed with a pyrethrum-based household fly-spray (Black Flag® Natural Fly & Insect Killer, Reckitt & Colman (New Zealand) Ltd, Auckland. Active ingredients: 2.29g/ℓ pyrethrum; 10.78g/ℓ piperonyl butoxide) to clear cages of aphids remaining from Expt 2. Pyrethrum has low persistence, and breaks down within days in sunlight. After three days, 50 third and fourth-instar pea aphids were added to each cage on 24 February 1996.

Spiders were collected as for Expts 1 & 2. The treatments were assigned to the 16 cages in a randomised block design as in Expt 2. Spiders were added to cages on 9 March 1996, 11 days after the release of the aphids, at two densities: low (20 spiders per cage); and high (40 spiders per cage).

Blocks 1 and 2 were completed on 22 March 1996 (11 days after spider release), and blocks 3 and 4 were completed on 24 March 1996 (13 days after spider release).

Statistical analysis

Data were analysed using randomised block ANOVA. If the variances were not equal, the counts were transformed using \log_{10} before analysis. One-tailed Dunnett's tests were used to compare aphid densities in the two treatments with the control (alternative hypothesis: Treatment means < Control mean), and Fisher's LSD was used to compare spider densities among all treatments. The sample size required to statistically detect the observed treatment differences using ANOVA, was calculated for each experiment (Zar, 1984).

Results

Expt 1

The mean number of aphids did not differ significantly between treatments (blocked ANOVA: treatment $F_{2,6} = 0.75$, $P = 0.51$; block $F_{3,6} = 0.55$, $P = 0.67$; Figure 7-1), and mean aphid densities in the two spider treatments were not less than that in the control (one-tailed 5% Dunnett's value = 2597), but spider numbers also did not differ significantly between treatments (blocked ANOVA: treatment $F_{2,6} = 0.82$, $P = 0.49$; block $F_{3,6} = 1.19$, $P = 0.39$; Figure 7-2). Aphid density tended to be negatively correlated with spider density (Figure 7-3, Pearson's correlation coefficient, $r = -0.485$, $P = 0.11$), although not significantly so. Removing the lower, right point (65, 432) made little difference to the correlation ($r = -0.459$, $P = 0.16$).

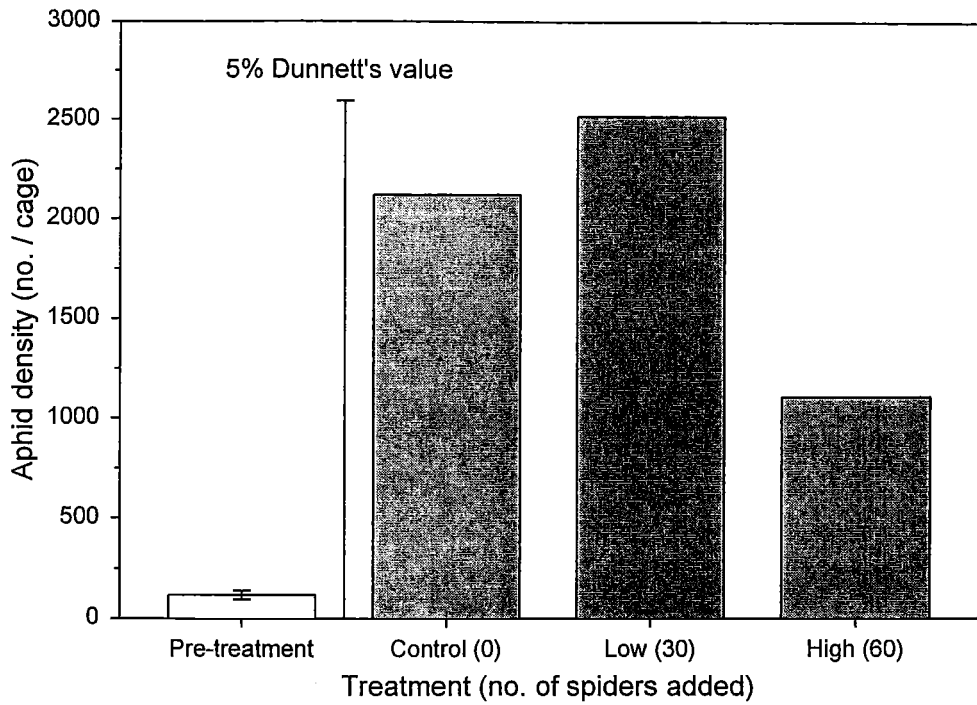


Figure 7-1. Expt 1: Mean density of aphids in lucerne cages, with one-tailed Dunnett's value for comparison of treatment means with the control. Pre-treatment density (mean±S.E., $n = 3$) shows density immediately before addition of the spiders.

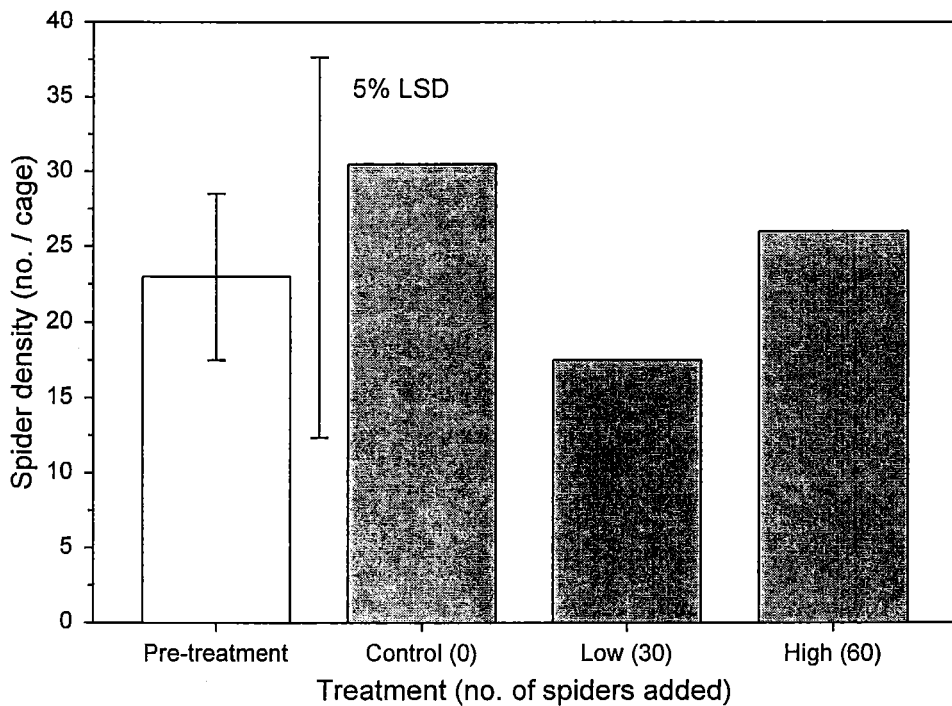


Figure 7-2. Expt 1: Mean density of spiders in lucerne cages, with 5% LSD for comparison of treatment means. Pre-treatment density (mean±S.E., $n = 3$) shows density immediately before addition of the spiders.

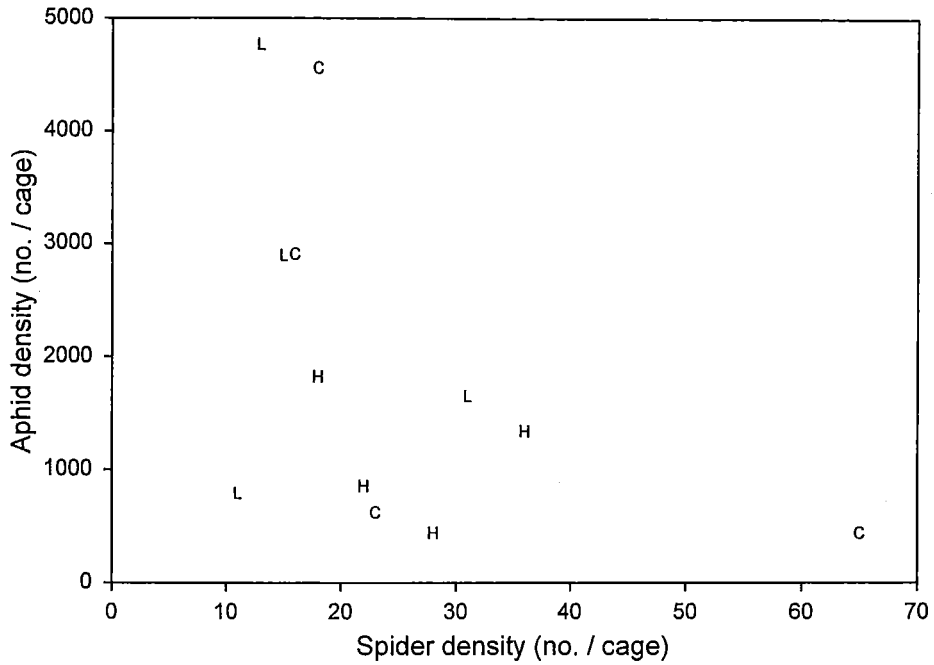


Figure 7-3. Expt 1: The relationship between aphid density and spider density in all treatments in lucerne cages. (C = control, L = low spider density, H = high spider density). Pearson's correlation coefficient, $r = -0.485$, $P = 0.11$).

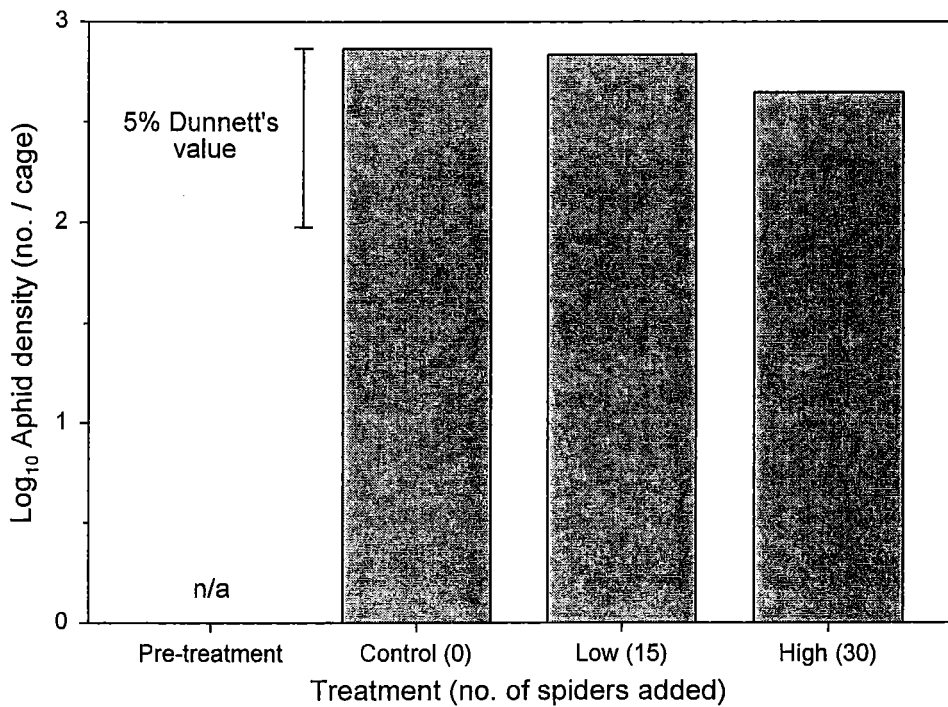


Figure 7-4. Expt 2: Mean density of aphids in broad bean cages, with one-tailed Dunnett's value for comparison of treatment means with the control. "n/a" = not available (see Methods).

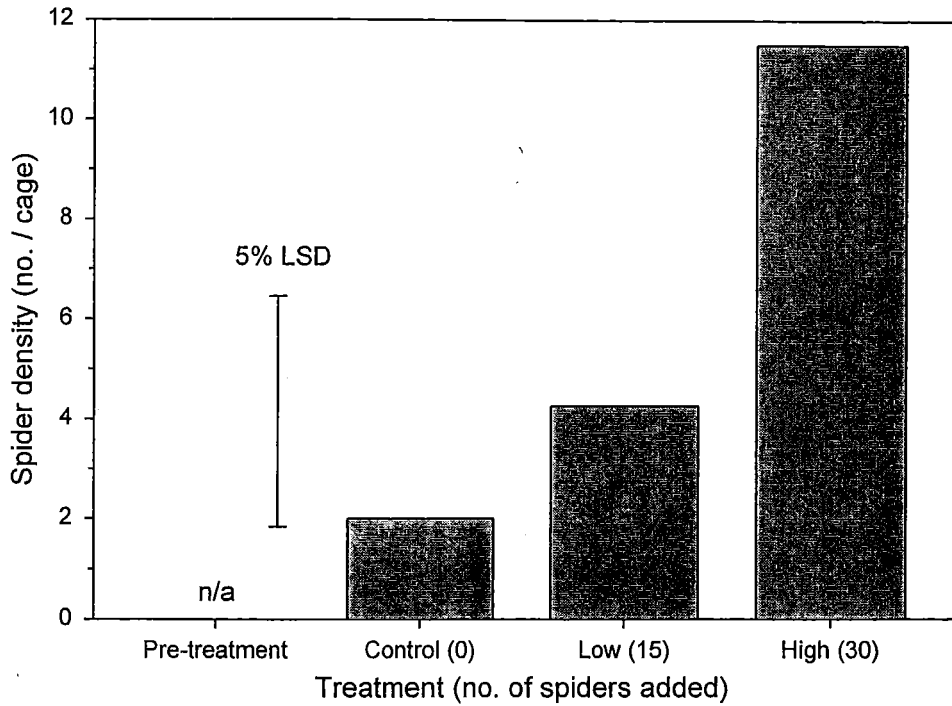


Figure 7-5. Expt 2: Mean density of spiders in broad bean cages, with 5% LSD for comparison of treatment means. "n/a" = not available (see Methods).

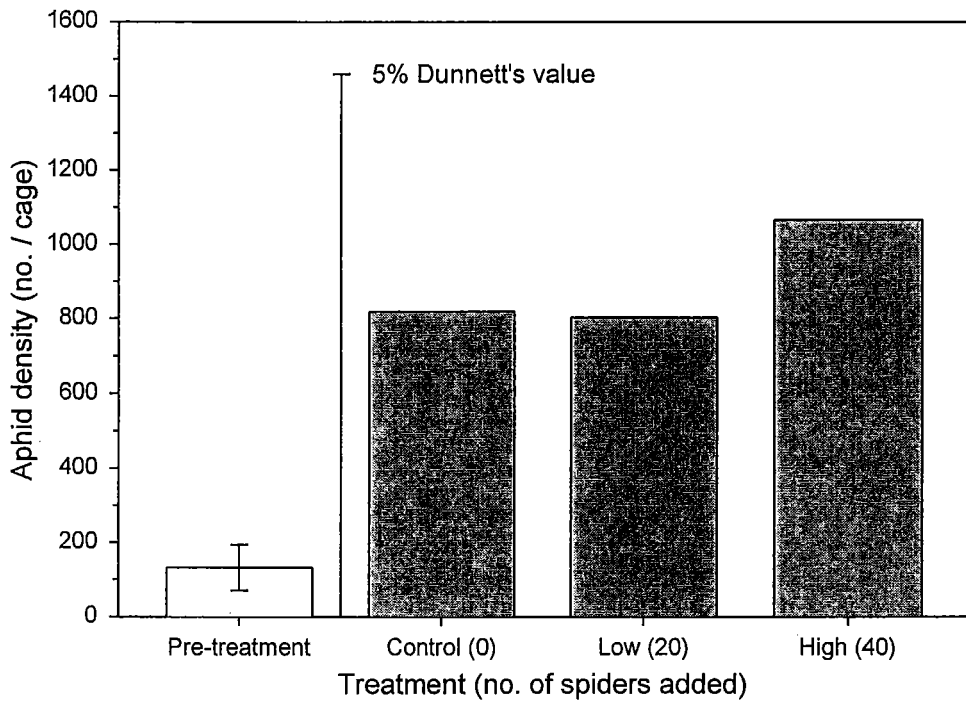


Figure 7-6. Expt 3: Mean density of aphids in broad bean cages, with one-tailed Dunnett's value for comparison of treatment means with the Control. Pre-treatment density (mean±S.E., $n = 4$) shows density immediately before addition of the spiders.

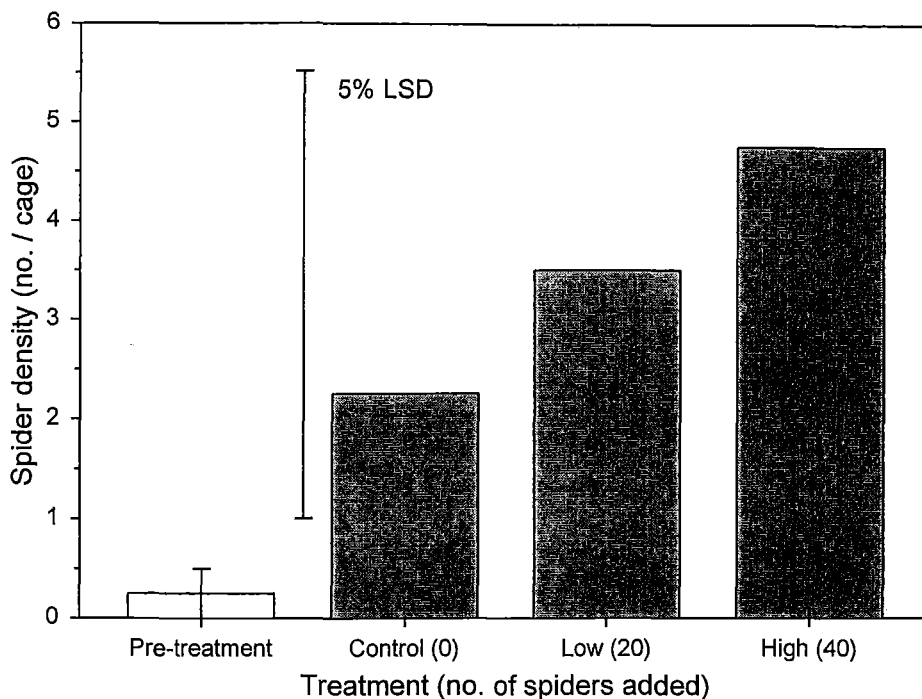


Figure 7-7. Expt 3: Density of spiders in broad bean cages with, 5% LSD for comparison of treatment means. Pre-treatment density (mean±S.E., $n = 4$) shows density immediately before addition of the spiders.

Expt 2

The mean number of aphids did not differ significantly between treatments (blocked ANOVA: treatment $F_{2,6} = 0.19$, $P = 0.83$; block $F_{3,6} = 3.0$, $P = 0.12$, Figure 7-4), and mean aphid numbers in the two spider treatments were not less than that in the control (one-tailed 5% Dunnett's value = 0.8876). Spider numbers differed significantly between treatments (blocked ANOVA: treatment $F_{2,6} = 13.81$, $P = 0.006$; block $F_{3,6} = 0.79$, $P = 0.54$) with greater numbers of spiders in the high density treatment (mean 11.5, pooled S.E. 1.34), than the low density and control treatments (means 2.0 and 4.25, respectively) (Figure 7-5). Aphid density and spider density were not correlated (Pearson's correlation coefficient, $r = -0.275$, $P = 0.39$).

Expt 3

The mean number of aphids did not differ significantly between treatments (blocked ANOVA: treatment $F_{2,6} = 0.12$, $P = 0.89$; block $F_{3,6} = 0.38$, $P = 0.77$, Figure 7-6), and mean aphid numbers in the two spider treatments were not less than that in the control (one-tailed 5% Dunnett's value = 1395), but spider numbers also

did not differ significantly between treatments (blocked ANOVA: treatment $F_{2,6} = 0.92$, $P = 0.45$; block $F_{3,6} = 1.84$, $P = 0.24$; Figure 7-7). Aphid density and spider density were not correlated (Pearson's correlation coefficient, $r = 0.049$, $P = 0.88$).

Sample sizes

For Expt 1, a sample size of $n \approx 51$ or more would be needed to detect a difference of 1018.5 aphids/cage between $k = 3$ treatments with $\alpha = 0.05$ and $\beta = 0.20$ (where $k =$ number of treatments, $\alpha =$ probability of a Type I error, and $\beta =$ probability of a Type II error) (Zar, 1984). This sample size reduces to $n \approx 46$ for $k = 2$ treatments (one spider density treatment and a control). For Expt 2, to find a significant difference of 0.2175 aphids/cage between \log_{10} transformed treatment means would require a sample size of $n \approx 120$ ($k = 3$) and $n \approx 96$ ($k = 2$). For Expt 3, a sample size was not calculated because the high spider density treatment had more aphids per cage than the control treatment, and there is little point in detecting a difference in that direction when only a decrease in aphid numbers (relative to the control) is important here.

Discussion

Expt 1 showed a problem in that the spider densities (Figure 7-2) were not consistent with the intended treatments. In particular, the control cages had a higher number of spiders than the spider treatment cages. Possible reasons for the high number of spiders in the control cages were (1) spiders moved into the cage through gaps in the cage material or in the ground seal, (2) spiders emerged from eggsacs after the cage had been initially vacuumed, and (3) the spiders were not adequately removed during the initial vacuuming. Of these three reasons, the third is more likely. The first reason is unlikely because the cages were sealed at the base with soil and Linyphiidae and Theridiidae do not burrow through soil. Though the cages were temporarily unsealed for the release of the aphids and for the retrieval of the aphid bags, this was only for one or two minutes and involved only one side of the cage. While the cage was unsealed, periodic observation was made of the unsealed area to see if any spiders or other arthropods were moving into or out of the cage. No spiders were seen during that time. The second reason is also unlikely because examination of the samples at the end of the experiment didn't show excessive numbers of small spiderlings. Probably then, the reason for the high numbers of spiders was the Vortis was

impaired at removing spiders by the tall dense lucerne. However, if this is the case for the control cages, then it should also be true for the other treatments and for the final collection as well. Unfortunately, the initial collections taken from the cages were not kept, so it is not possible to know how many spiders, if any, were removed during the initial vacuuming and how that compared with the final collection. A fourth possibility remains that the high numbers were simply natural spatial variation that could only be overcome by having a much larger sample (more cages) or larger cage sizes.

The second experiment, using broad beans instead of lucerne, gave different spider densities between the treatments as intended, but no difference between aphid densities. Given the high number of aphids at the end of the experiment, it was obviously not necessary to make a second release of aphids into the cages. In this experiment the spider density in the control cages was lower than the spider addition treatments as intended. This probably reflects the effectiveness of the Vortis at collecting spiders from the largely bare soil inside the cages, and possibly the low initial densities of spiders present which, however, cannot be determined because again the initial collection samples were not kept for analysis.

The third experiment was a repeat of Expt 2 except that there was no second addition of aphids. However, in this case, though spider densities among the treatments reflected the trend expected (Figure 7-7), the densities were not significantly different and were very low. The 'high spider density' cages had 40 spiders released per cage and a mean of only 4.75 spiders/cage were retrieved at the end of the experiment. This low recapture rate probably reflects a low survivorship of spiders inside the cages. Because the soil was mostly bare between the broad bean plants (a few small weeds were present) and the bean plants were cut and removed during the final collection, the Vortis would be expected to have a high collection efficiency and so the densities almost certainly reflected the actual densities of spiders remaining at the end of the experiment.

The aphid populations did very well in cages, increasing to densities high enough to severely damage some plants. The environment in the cages (although not measured) was probably more humid and certainly had less wind, than outside the cages. Observations in an initial experiment in a clover crop (in which aphids failed to establish because of drought conditions) showed that clover plants inside the cages were taller, greener and had more abundant flower heads compared with those plants

outside the cages. This indicated that the cages were somehow alleviating the drought conditions for the clover plants. Observations of broad bean plants outside the cages showed that they are blown about in the commonly windy conditions, whereas plants inside the cages were not moved, as the cover deflected and reduced air movement into the cages.

When disturbed, pea aphids drop from the plant (Chau and Mackauer, 1997). In windy conditions (common in Canterbury summers), the plants would be moved about and knocked together which would probably disturb the aphids. Because the cage covers reduced the effects of wind, the aphid populations inside the cages would probably be much less disturbed than those outside, and thereby survive and reproduce at a faster rate than would field populations. Frazer *et al.* (1981) found caged populations of pea aphids could reach five times the usual field densities. When the aphids reach such high densities relative to the spiders as they did in these experiments, there is little hope of detecting an effect of spider predation. Any predation effects are likely to be much smaller than the large variation in aphid numbers between replicates. This is demonstrated by the very large sample sizes that would be needed ($n \approx 51$ for Expt 1, and $n \approx 120$ for Expt 2) to statistically detect the observed differences between the treatments. Clearly, this field cage technique in its current form is not feasible for investigating spider predation on pea aphids.

Further work

1. Measure the environment both inside and outside the cages (e.g., humidity, temperature, light, wind speed) to quantify the effects of the cage on the habitat inside, in order to design cages that contain more field-like conditions.
2. Release spiders and aphids into the cages at the same time and run the experiment for two weeks only. This would enable investigation of the effects of the spiders on low aphid populations, and not have the experiment go so long that the aphids can develop unnaturally high densities.
3. Use clover as a crop instead of broad beans or lucerne. Clover also supports aphid populations, but is not so tall a plant as to exclude those spiders that live near the ground from possibly affecting the aphid abundance.
4. Investigate better methods of removing spiders and aphids from cages at the start of the experiment.

Chapter 8: General discussion

Though the spider fauna has been relatively well studied in agroecosystems in many other countries, particularly in Europe (see Chapter 1), there are currently only two such published studies in New Zealand agroecosystems. Martin (1983) used a variety of collection methods to investigate the fauna (including spiders) in a Nelson, South Island, pasture and Topping and Lövei (1997) used pitfall trapping and a D-Vac followed by hand searching in several different North Island pastures and a roadside verge. An objective of this thesis was to describe the spider fauna from Canterbury, South Island, pasture and, for the first time, list the fauna from New Zealand shelterbelts. This objective was achieved in Chapters 3, 4 and 5.

A key result was that pasture had both a lower species richness and a lower density of spiders compared with shelterbelts (Chapters 3, 4). The pasture fauna was dominated by the introduced European linyphiid species *Lepthyphantes tenuis*, which is also common in North Island pasture (Topping and Lövei, 1997) and in arable land in Europe (Sunderland, 1996). A native linyphiid, *Erigone wiltoni*, was also prevalent in pasture here (Chapter 3) and in a Nelson pasture (Martin, 1983).

Most pasture species belonged to the families Linyphiidae, Theridiidae, and Lycosidae (Tables 3–1, 3–2, 5–5). In contrast, shelterbelts had species from those three families and the additional ones of Agelenidae, Araneidae, Clubionidae, Ctenidae, Gnaphosidae, Hahniidae, Idiopidae, Micropholcommatidae, Oxyopidae, Psechridae, Salticidae, Synotaxidae, and Thomisidae (Tables 3–2, 4–1). Although a few immatures of the families Salticidae and Psechridae were found in pasture (Table 3–2), individuals from these families were predominantly found in shelterbelts. Members of family Linyphiidae dominated the pasture spider fauna (Tables 3–1, 3–2, 5–5), but were less dominant in shelterbelts although they contributed more endemic species there than in pasture.

When 11 shelterbelts or woodlots were sampled (Chapter 4), there was a six-fold difference in mean density of spiders between these habitats. Densities ranged from 62/m² to 369/m² (Table 4–1). The three lowest-density shelterbelt sites had densities similar to that in a North Island abandoned pasture (98/m²) (Topping and Lövei, 1997), whereas the intermediate shelterbelt sites had similar densities to those of a North Island roadside verge (120/m²) and a herb pasture (130/m²) (Topping and Lövei, 1997). The spider densities in shelterbelts in this study were often much

greater than those in pasture, which ranged from 6.8/m² (Table 3–1) to 77/m² (Table 3–2). Similar densities have been recorded in North Island grazed pasture, 5–35/m² (Topping and Lövei, 1997), and in pasture overseas: Poland, 2–73/m² (Delchev and Kajak, 1974; Kajak, 1978); Bulgaria, 12–17/m² (Delchev and Kajak, 1974); the U.K., 29–77/m² (Cherrett, 1964); Canada, 17–83/m² (Turnbull, 1966); and in U.S.A., 33/m² (Wolcott, 1937)

In a Belgian study, a border of a grazed pasture had twice as many species (70 cf. 37) and families (12 cf. 6) of spiders than did the pasture (Maelfait and De Keer, 1990), and in Canada, the grassy border of a wheat field had more species (53 cf. 28) and families (14 cf. 10) than did the adjacent wheat field (Doane and Dondale, 1979). The current work found a similar difference between the shelterbelts and pasture in the numbers of species (25 cf. 13) and families (14 cf. 5) (Table 3–2), although the large number of undetermined Araneoidea immatures in both habitats may disguise the possibility that more linyphiid and theridiid species were in common between the two habitats than this study showed. If the Araneoidea immatures are assumed to belong to only species that were already recognised in each respective habitat, then the shelterbelts were populated by a large number of species that did not contribute to the pasture fauna. Of the shelterbelt fauna, only three species (*L. tenuis*, theridiid sp. 'a', and *Lycosa hilaris*) were found in New Zealand pasture in any numbers (Tables 3–1, 3–2, 5–5) (Martin, 1983; Topping and Lövei, 1997). Two *Erigone* species (*E. wiltoni*, and *E. prominens*), which were commonly found in pasture (Table 3–2) (Martin, 1983), were absent from the shelterbelts.

Exploiting shelterbelts to increase the numbers of spiders in pasture seems of little use in New Zealand when shelterbelts provide habitat mainly for species that do not live in pasture. Also, some pasture species were not found in the adjacent shelterbelts, so shelterbelts are unlikely to provide refugia from disturbance for those pasture species. Further, the density of spiders declined rapidly with distance away from the shelterbelt into the pasture (Figure 3–1). This indicates that adding fenced shelterbelts to field margins would not substantially increase the numbers of spiders in an established pasture. However, the role that shelterbelt spiders play in the colonisation of a newly cultivated pasture (from which the resident spiders have been eliminated either by cultivation, or have migrated away because of habitat destruction or diminished prey populations), is not known. Also, the effect of

distance from the shelterbelt was studied in only one pasture-shelterbelt pair in this study (although repeated samples in several seasons showed the same pattern of distribution) so the possibility exists that other pastures could have a different distribution. In particular, the distribution of spiders may be influenced by the direction of the prevailing winds relative to the shelterbelt because of the ballooning habit of many pasture spiders. Because this thesis has concentrated on the influence of shelterbelts as refugia for spiders, what remains unknown in New Zealand is the use of shelterbelts as refugia by pest species, and the effects of shelterbelt spiders on these pest populations.

There are a number of possible reasons why the pasture had fewer species and individuals of spiders than did the shelterbelt. One reason is that the pastures are disturbed, largely by grazing, which can damage webs and reduce the numbers of web-building spiders (Delchev and Kajak, 1974), compared with the ungrazed shelterbelts that were studied. Another reason may be that prey abundances are lower, or that different prey types are present in pasture compared with the shelterbelt. In this work, the numbers and types of prey were not studied, although it would not be surprising to find that, along with differences in spider fauna and abundances, there are also similar differences in the insect and mite fauna and abundances between the pasture and shelterbelt habitats. For example, Merfield *et al.* (in press) used time-lapse video and recorded higher predatory activity of mites in Canterbury shelterbelts compared with post-and-wire fence habitat. Because of the need for suitable structures to which to attach webs, the distribution of web-building spiders can be influenced by the habitat structure (Robinson, 1981; Greenstone, 1984; Ward and Lubin, 1993; Samu *et al.*, 1996). The tall, dense grass often found in shelterbelts may provide more suitable web-building sites for some species than are available in the short, grazed pasture, whereas short vegetation may be preferred by some other species. However, the shelterbelts were inhabited by spiders from a number of families that do not build webs, although members of these families can also be influenced by habitat structure (Greenquist and Rovner, 1976; Robinson, 1981). Lastly, the microclimate, particularly humidity and light intensity, is likely to differ between the shelterbelt and pasture, and have an influence on species distribution. Especially likely to be affected are species that live in litter and which require high humidity, e.g., *Parapua punctata* (Micropholcommatidae) (Forster and Forster, 1999).

Because of the sometimes tall, dense vegetation, the densities from the Vortis samples are likely to be an underestimate of actual density (Chapter 2). In that case, the differences in density from Vortis samples between shelterbelts and pastures (where short vegetation would allow spiders to be sampled more efficiently) is likely to be even more marked than shown.

Another objective of this thesis was to investigate the effects of two management practices, pasture type (Chapter 5), and mowing (Chapter 6) on spider pasture communities. Three pasture types were compared both in agroforestry (pasture with widely-spaced trees) and open pasture (Chapter 5). No difference in spider density was found between the pasture types (Table 5–1), although the low replication meant that only a difference in density of 36/m² or more between agroforestry and open pasture would have been statistically significant compared with the observed difference in mean density of 6/m². Further sampling of more pasture types, with higher sample sizes, may help confirm whether or not there are differences between pasture types in their spider density.

Mowing pasture plots had an effect of reducing mean spider density and species richness (Chapter 6). A combination of factors (disturbance, prey availability, habitat structure, and microclimate) were probably responsible for those differences. The unmown plots had a fauna and density similar to those in shelterbelts, whereas the mown plots were similar to grazed pasture. It was not possible to separate the effects of disturbance and vegetation height in this study, but both were probably important. The results (Chapter 6) demonstrate that a simple manipulation, like mowing, could be used to alter the spider density and species composition in pasture.

A further thesis objective of investigating the relationship between spider density and vegetation height and cover was carried out in Chapter 5. The total spider density was correlated with vegetation height in open pasture, but not in agroforestry pasture (Table 5–2), but this result should be treated with caution because only 4.8% of correlations were significant at $P < 0.05$. However, correlations of the density of *L. tenuis*, the most common species, revealed that the abundance of this species is positively correlated with vegetation height in open pasture (Table 5–4). Further work investigating this relationship could be done by experimentally manipulating vegetation height and measuring the abundance of *L. tenuis*.

The last objective of this thesis was the investigation of the feasibility of evaluating spider predation on aphids by using field cages. This was found to be not

practical because of low spider survival, and very high aphid populations (Chapter 7). The large variance in aphid numbers meant that unacceptably high numbers of replicates (at least 46 per treatment) would be needed to obtain statistical significance for the differences in treatment means obtained in this study. Further research, as suggested in Chapter 7, should be done before the field cage method is discarded.

Further research

The information in this thesis provides a starting point for further research. Some suggestions for this in New Zealand agroecosystems, include more intensive sampling in the same pastures, more extensive sampling over a wider region, investigation of dispersal and movement of spiders, and of diet and trophic relationships of spiders.

More intensive sampling

There needs to be further sampling of shelterbelts and pastures, but using a more diverse range of sampling techniques. A wider range of collection methods (e.g., pitfall traps, turf removal followed by heat extraction, and sweep-netting) could be used to determine whether or not there are species that were not collected using Vortis sampling. The Vortis efficiency needs to be further tested, especially for effects of vegetation height, time of day, and sampling duration on spider collection efficiency. If necessary, intensive suction sampling (within a barrier, followed by removal of vegetation and re-suction-sampling or hand searching) could be used to obtain better estimates of spider density (Sunderland *et al.*, 1995).

More extensive sampling of habitats

The further sampling of pastures and field margins of different types, and sampling at various distances from field margins, could be done on a wider scale. Sampling from more farms could answer the question: Are the results from near Lincoln representative of the wider district? Further sampling of farms at a provincial or national scale could help answer questions about possible regional differences in spider fauna and patterns of abundance. Also, whether or not there are differences with altitude or latitude could be investigated.

Dispersal and movement of spiders

To determine what role shelterbelt spider populations play in the colonisation of paddocks, knowledge of spider movement is needed. How far spiders move from a

shelterbelt is not known. This could be investigated by labelling spiders in the shelterbelt and detecting their presence elsewhere. Possible labelling methods include: radio-labelling, paint or dust marking, and rare element (e.g., rubidium) marking (Powell *et al.*, 1996). Such labelling methods could help determine the origin of spiders that colonise a newly cultivated paddock. The method of spider dispersal into a newly cultivated paddock is also not known. Sticky traps and directional pitfall traps could be used to determine what proportion of spiders, and what species, colonise by ballooning and by walking, and how quickly spiders colonise a newly cultivated paddock.

Diet and trophic relationships of spiders

Before any inferences can be made about the possible usefulness of spiders in the biological control of pests, the diet of spiders needs to be known. Field observations of spiders capturing and eating prey (e.g., Dean *et al.*, 1987), or laboratory serological methods (e.g., Sunderland *et al.*, 1987a), could be used to determine what spiders in pasture eat. Of great importance is the question: What pest species, if any, are eaten by spiders? To answer this question, monoclonal antibodies for specific pest species could be created and then used to screen spiders for the presence of the target pest (Kidd and Jervis, 1996). Questions that could arise from that work are: Do spiders reduce prey populations, and, if so, by how much?

Also of interest from an ecological point of view are such questions as: i) What part do spiders play in the food web of a pasture? ii) How much intra-guild predation (predation of spiders on other spiders and predators) exists? and iii) What quantity of prey (in biomass, or annual productivity) is eaten by spiders in pasture?

Conclusions

While the results from this research show that it is possible to manipulate the spider fauna and increase spider density by providing shelterbelts, the benefits to spider density beyond the field margin seem minimal because few species that lived in shelterbelts also inhabited pasture. Also, some pasture species were not found in the shelterbelts, and spider density decreased rapidly away from the shelterbelt. With the large number of shelterbelt spider species not present in pasture, the shelterbelt may act more as a 'habitat island' for endemic spider species that are unsuited to living in disturbed, short-vegetation pastures. Until the diet of pasture species is

known, any benefits from the presence of spiders for New Zealand pasture pest control will remain questionable.

The current work contributes to the understanding of the distribution and abundance of spiders in a major New Zealand crop, namely pasture. This kind of knowledge in other countries has led to investigations of the usefulness of spiders in pest control (e.g., Wyss *et al.*, 1995)). Whether habitat manipulation for conservation biological control of pests using spiders will apply in New Zealand agriculture will not be known until further studies are done, particularly on the diet of spiders in pasture, but also in other types of agroecosystems in New Zealand.

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Appendix A: Spider species list

Table 8-1. Table of species names and authorities of all New Zealand spider species listed in this thesis, with endemism status (Endemic to New Zealand, Native, Introduced), and a guide to how common the species was encountered in both pasture and shelterbelts (– = not encountered, R = rare, O = occasional, C = common) and in what numbers (L = low numbers, M = medium numbers, H = high numbers). Spider species names follow Forster (1959), Forster (1970), Forster and Wilton (1973), Forster and Platnick (1977), Forster and Blest (1979), Millidge (1984), Forster *et al.* (1988), Vink and Sirvid (1998), and Forster and Forster (1999).

Species	Status	Habitat type	
		Pasture	S/belt
LINYPHIIDAE			
<i>Araeoncus humilis</i> (Blackwall 1841)	Introduced	OL	OL
<i>Diplocephalus cristatus</i> (Blackwall 1833)	Introduced	–	RL
<i>Diploplecta</i> sp.	Endemic	RL	OL
<i>Erigone prominens</i> Bösenberg & Strand 1906	Introduced	CL	RL
<i>Erigone wiltoni</i> Locket 1973	Native ¹	CL	RL
<i>Laetesia minor</i> Millidge 1988	Endemic	–	RL
<i>Laetesia trispathulata</i> (Urquhart 1885)	Endemic	–	RL
<i>Lepthyphantes tenuis</i> (Blackwall 1852)	Introduced	CH	CH
<i>Maorineta tumida</i> Millidge 1988	Endemic	–	RL
<i>Maorineta</i> sp.	Endemic	–	RL
<i>Microctenonyx subitaneus</i> (O.P.-Cambridge 1875)	Introduced	RL	CL
Mynogleninae			
<i>Haplinis fucatina</i> (Urquhart 1894)	Endemic	–	RL
<i>Haplinis mundenia</i> (Urquhart 1894)	Endemic	–	RL
<i>Haplinis titan</i> Blest 1979	Endemic	RL	–
<i>Pseudafroneta incerta</i> (Bryant 1935)	Endemic	–	RL
THERIDIIDAE			
<i>Rhomphaea</i> sp. ²	Endemic		
Unidentified sp. 'a'	Endemic	OL	CH
Unidentified sp. 'b'	Endemic	RL	OL
ARANEIDAE			
Unidentified immatures	Endemic	–	RL
ARANEOIDEA³			
Unidentified immatures	–	CH	CH
LYCOSIDAE			
<i>Lycosa hilaris</i> Koch 1877 ⁴	Endemic	OL	OL
Unidentified immatures	Endemic	OL	OL
OXYOPIDAE			
<i>Oxyopes gracilipes</i> (White 1894)	Native	–	RM
AGELENIDAE			
Unidentified immatures	?		OL
SYNOTAXIDAE			
<i>Pahora</i> sp.	Endemic	–	OL
<i>Runga akaroa</i> Forster 1990	Endemic	–	R
PSECHRIDAE			
<i>Poaka graminicola</i> Forster & Wilton 1973	Endemic	RL	CL
CLUBIONIDAE			
<i>Clubiona clima</i> Forster 1979	Endemic	–	RL

Appendix A: Spider species names and authorities

Species	Status	Habitat type	
		Pasture	S/belt
<i>Clubiona contrita</i> Forster 1979	Endemic	–	RL
<i>Clubiona huttoni</i> Forster 1979	Endemic	–	RL
Unidentified immatures		–	OL
GNAPHOSIDAE			
<i>Nauheia tapa</i> Forster 1979	Endemic ⁵	–	RL
Unidentified immatures		–	RL
SALTICIDAE			
Unidentified sp. 'a'	Endemic	–	OL
Unidentified sp. 'b'	Endemic	–	OL
Unidentified immatures	Endemic	RL	CL
MICROPHOLCOMMATIDAE			
<i>Parapua punctata</i> Forster 1959	Endemic	–	RL
CTENIDAE			
Unidentified immature	Endemic	–	RL
IDIOPIDAE			
<i>Misgolas</i> sp. immature	Endemic	–	RL
THOMISIDAE			
Unidentified immatures	Endemic	–	RL
HAHNIIDAE			
<i>Rinawa otagoensis</i> Forster 1970	Endemic	–	RL
DESIDAE			
<i>Badumna longinqua</i> (Koch 1867) ⁶	Endemic	–	–
UNKNOWN FAMILY			
Unidentified immatures	–	RL	CL

¹ Millidge (in Forster *et al.*, 1988) considers that *Erigone wiltoni* is an introduced species because although *E. wiltoni* has not been found elsewhere, this worldwide genus of spiders has no known endemic species in New Zealand.

² *sensu* Forster and Forster (1999).

³ *sensu* Coddington and Levi (1991), includes Linyphiidae, Theridiidae, and Araneidae in the current study.

⁴ *Lycosa hilaris* Koch almost certainly does not belong in genus *Lycosa* (C.J. Vink, *pers. comm.*).

⁵ Forster (in Forster and Blest, 1979) has doubts that the genus *Nauheia* Forster 1979 is endemic.

⁶ A contaminant of stored field cage frames only – not found in pastures or shelterbelts.

Appendix B: Bogorov tray design

Sorting Tray, Plan View 1:1

Material: Clear acrylic (Perspex) 12 mm thick

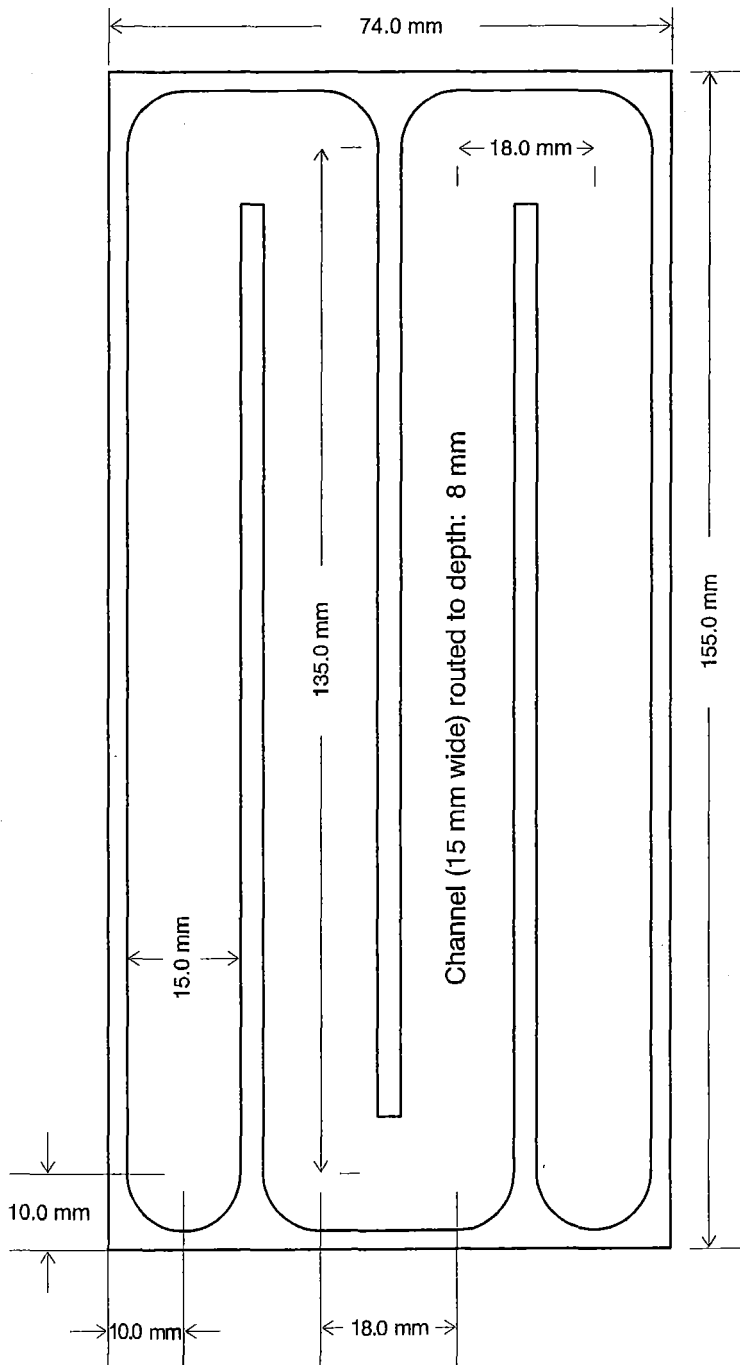
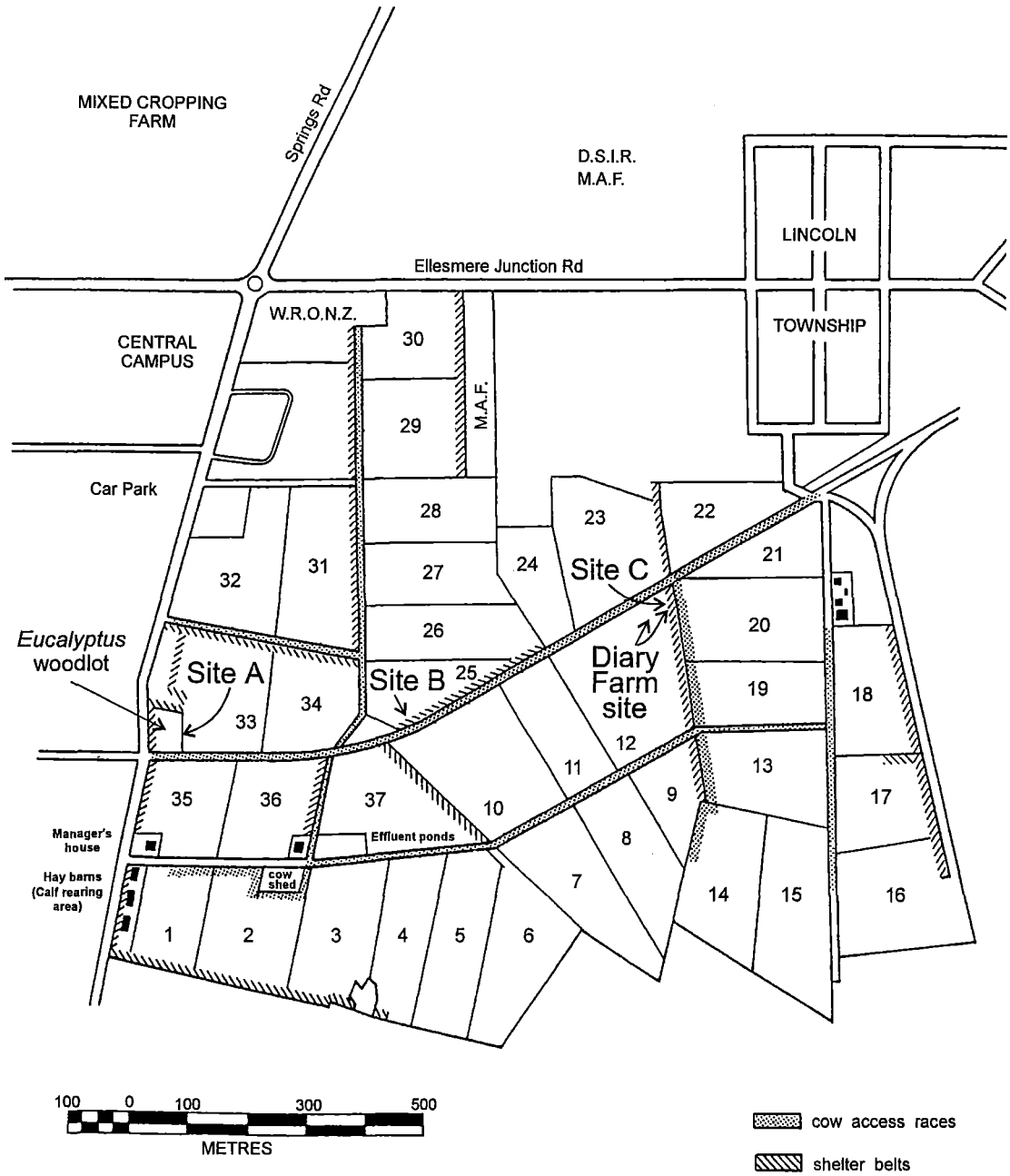


Figure B-1. Plan view of Bogorov tray used for counting large numbers of arthropods.

Appendix C: Farm maps and site locations



DAIRY FARM

Total Area (including shelterbelts) = 108.35 ha

Total area irrigated = 108.35 ha

Figure C-1. Lincoln University Dairy Farm. Shelterbelt sites A, B, and C, and Dairy Farm site (paddock 12). Paddock layout and numbering correct at January 2000.

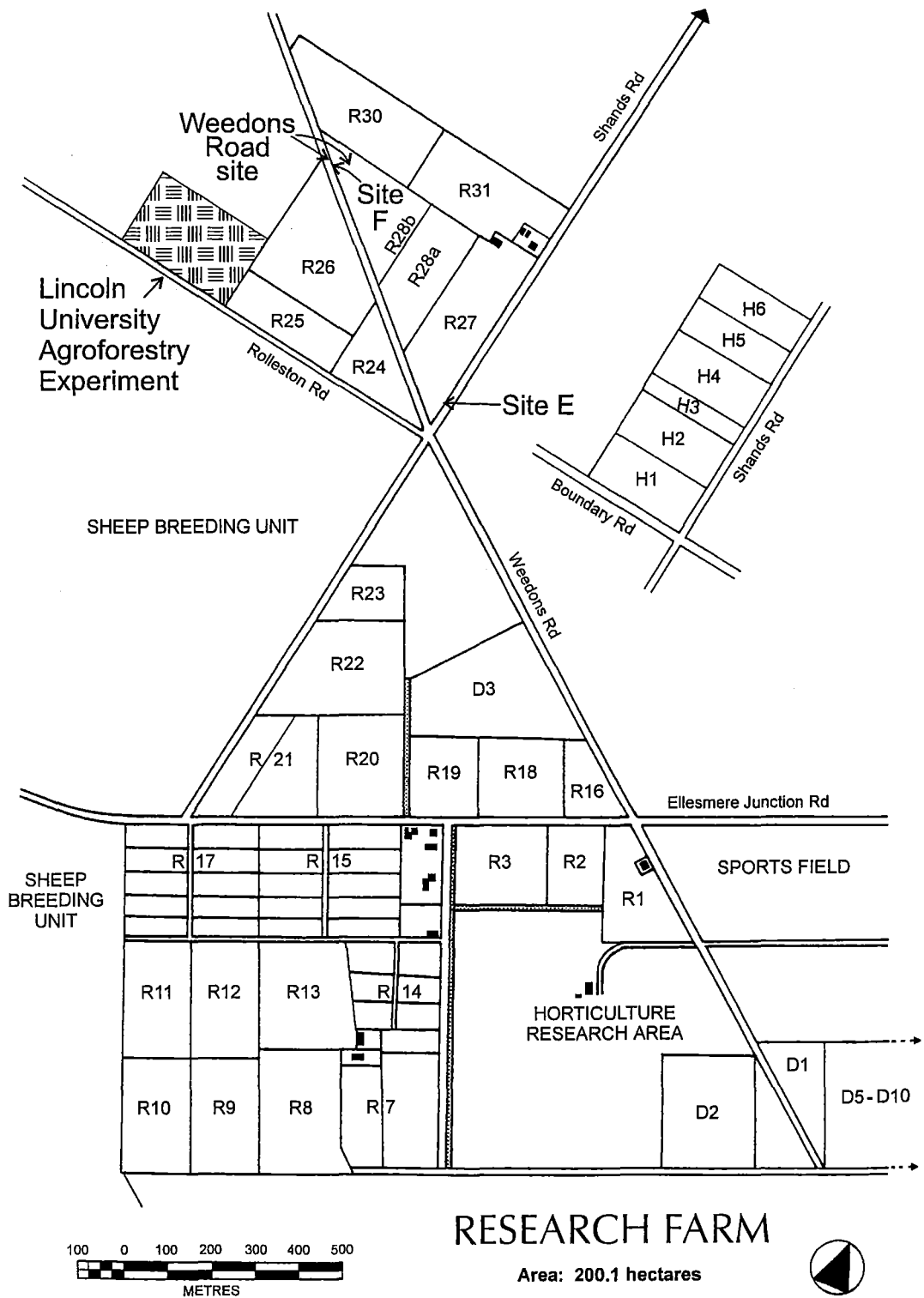


Figure C-2. Lincoln University Research Farm. Shelterbelt sites E and F, Weedons Road site (paddock R28), and location of the Lincoln University Agroforestry Experiment. Paddock layout and numbering correct at January 2000.

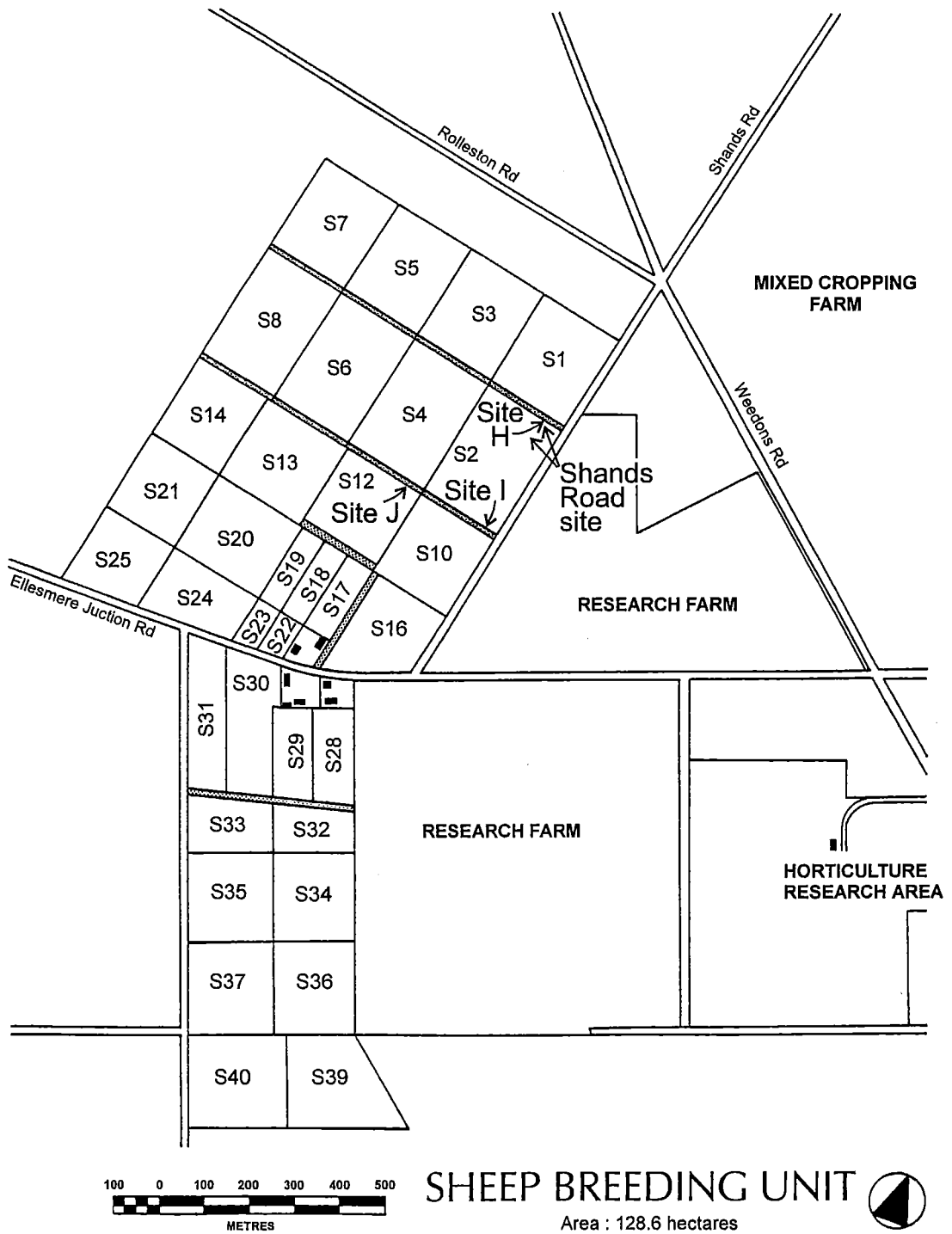


Figure C-3. Lincoln University Sheep Breeding Unit. Shelterbelt sites H, I, and J, and Shands Road site (paddock S2). Paddock layout and numbering correct at January 2000.

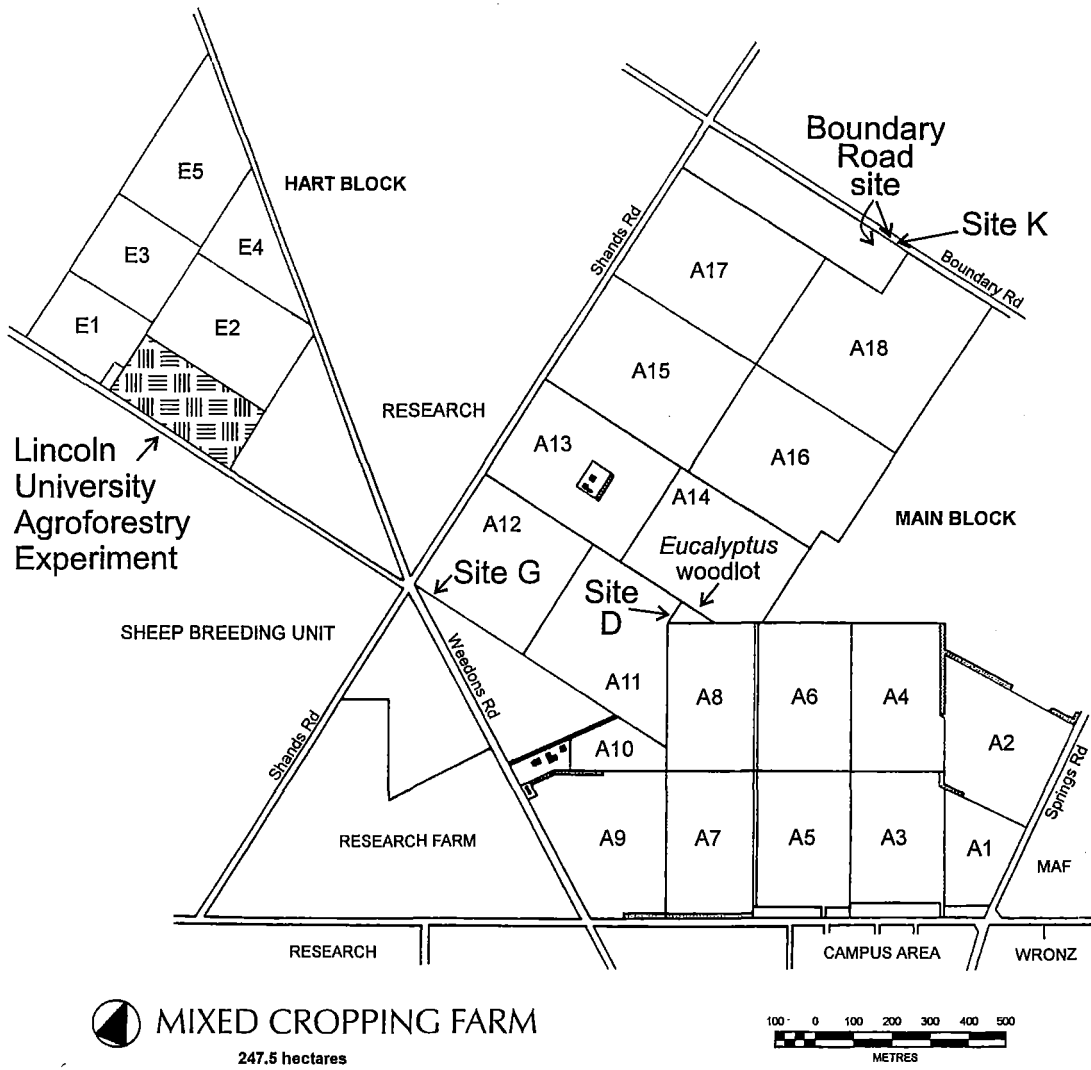


Figure C-4. Lincoln University Mixed Cropping Farm. Shelterbelt sites D, G and K, Boundary Road site, and location of the Lincoln University Agroforestry Experiment. Paddock layout and numbering correct at January 2000.