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Distribution and abundance of ladybirds (Coleoptera: Coccinellidae) in non-crop habitats

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Abstract. The abundance and distribution of coccinellids in non-crop habitats was studied using removal sampling and visual observation. Coccinellids were most frequently found on grassland habitats. Coccinellid abundance appeared to be most strongly correlated with the percentage ground cover of thistle, grasses and nettles. The most commonly collected coccinellids were *Coccinella septempunctata* and *Adalia bipunctata* comprising 60% and 35% of the catches respectively. Most coccinellids were found on *Rubus* spp. with nettles (*Urtica dioica*) and grasses being the next most favoured plant species. *Adalia bipunctata* was the most commonly found coccinellid species on nettles and birch (*Betula* spp.) whereas *C. septempunctata* was the most commonly found species on grasses, *Rubus* spp. and oak (*Quercus* spp.). These results are discussed in light of current thinking on the importance of "island" habitats as part of an integrated pest management programme.

INTRODUCTION

Coccinellids are found in many habitats, including those as diverse as cities, fields, gardens, sea coasts and mountains (Majerus & Kearns, 1989; Hodek & Honěk, 1996). Individual species within the Coccinellidae frequently display fairly specific habitat requirements (Majerus & Kearns, 1989), therefore there can be considerable variation in coccinellid numbers and species composition between habitats (Hodek, 1973; Elliott & Kieckhefer, 1990; Elliot et al., 1991). There is also evidence to suggest that populations of some coccinellids appear to track populations of their prey, although with a degree of lag (Leather & Lehti, 1982; Leather & Owour, 1996). Many coccinellids are aphidophagous as both larvae and adults, although not all aphid species are equally suitable as food for these predators (Mills, 1981). Prey location by coccinellid adults is influenced by a number of factors, such as the honeydew produced by aphids acting as an arrestant stimulus (Carter & Dixon, 1984), or plant density affecting micro-climate and searching ability (Honěk, 1982a).

While much is known concerning the physiology, predatory behaviour and biology of the more common species of coccinellids (Hagen, 1962; Honěk, 1982b; Majerus & Kearns, 1989; Hodek & Honěk, 1996), there is little understanding of the factors influencing coccinellid distribution and population size in non-crop habitats. Recently, there have been a number of studies suggesting that the use of "island" habitats within crops which mimic natural habitats can be used to successfully encourage the influx of natural enemies into fields (Thomas et al., 1992; Lys & Nentwig, 1994). It is difficult to predict what the plant composition of these habitats should be to most effectively encourage and conserve populations of natural enemies. It is therefore important that the factors determining coccinellid distributions in non-crop habitats are fully understood. This study examines the effect that habitat type and prey availability have on the distribution and abundance of coccinellids in non-crop habitats.

MATERIAL AND METHODS

Study sites

All study sites were based at the Silwood Park field station (Berkshire, south-east England). Three habitats were chosen: woodland; woodland margins and grassland. Sites were chosen for each of these habitats. They were comparable in terms of exposure, plant diversity and vegetation type, while covering a large range of plant densities and aphid abundances. The habitats most comprehensibly meeting these requirements tended to be open woodlands and their margins (i.e. within a metre of the woodland edge), with the predominant plant species being sycamore (*Acer pseudoplatanus*), birch (*Betula pubescens*), oak (*Quercus* spp.), bramble (*Rubus fruticosa* agg.) and nettles (*Urtica dioica*). The most frequently found grass species were *Poa trivialis*, *Trisetum flavescens*, *Festuca rubra*, *Holcus lanatus* and *Dactylis glomerata*. Thistles (*Cirsium* spp.) and docks (*Rumex* spp.) were also common.

Data collection

Studies on the abundance and distribution of coccinellid species were carried out during May, June and July, when numbers of adult coccinellid numbers peak in southern England. At each monthly sample, 6 sites were chosen in each of three different habitats (woodland interiors, woodland margins and grassland). Ten quadrats were placed at each site. On grassland and woodland margins quadrats of at least 9 m^2 (3 × 3 m) were marked out. The quadrats were placed to maximise equitability of plant species, based on the plant composition and diversity at each

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site. The quadrats were found to be consistent in terms of plant species numbers within each habitat type. Within woodlands, the presence of mature trees necessitated the quadrat area being increased to 25 m^2. Quadrat size was always noted and all were situated at least 5 m from the edge of the study site. Plant community within a habitat in this context is defined as the area circumscribed for the study (Crawley, 1986). To obtain a measure of frequency of plant occurrence, each quadrat was sub-divided into 100 smaller sub-quadrats and species recorded as present or absent within each sub-quadrat. Recording was carried out between 1,800 and 2,000 h GMT on each occasion.

Each individual plant of each species present within the quadrats were assigned index numbers, and from these random individual plants were chosen. Removal sampling was used to study the coccinellid abundance on these randomly chosen plants. To compare the relationship between plant species and coccinellid distribution, ten sub-quadrats within each main quadrat were randomly chosen and the plants were scanned for the presence of ladybirds. This allowed us to determine the distribution of coccinellids relative to plant type. Aphid abundance was measured at every coccinellid collecting site. Direct estimates of aphid abundance were made using leaf counts from plants selected at random within each quadrat. On trees, 200 leaves were examined whereas on herbs and shrubs 100 leaves were searched. To provide a uniform measure of abundance, and to allow direct comparisons between sites, all sub-quadrat data were converted to counts per m^2. These data were then used in the subsequent analyses.

Statistical analyses

Since the data from each of the 10 quadrats within each of the habitats were not independent of each other, mean values for each of the variables were calculated to avoid pseudoreplication. Data relating to percentage cover were arc sine transformed (Sokal & Rohlf, 1995). The data collected on each of the three monthly counts was collected from different sites each month, and therefore these data are considered to be independent.

Aphid distribution was analysed using a 2-way ANCOVA, with the proportion of plant ground cover as the covariate. Factors used were habitat and month. Coccinellid distribution was analysed in a similar way, again with habitat and month as factors and percentage ground cover was used as the covariate. Post-hoc Scheffé tests were used to identify significant differences between habitat types.

To investigate the relationships between coccinellid numbers and plant species a series of multiple regression analysis was performed. As percentage cover of a particular plant species and the abundance of aphids found on that plant are likely to be positively correlated, both variables were used in the multiple regression against coccinellid number found on that plant species. Partial correlations were then examined to investigate the influence of these explanatory variables on the response variable. This was performed for coccinellids found on sycamore, birch, oak, bramble, nettle, thistle and grass.

RESULTS

Removal sampling, during which 371 ladybird beetles were collected, revealed that *Coccinella septempunctata* L. was the most common species trapped; comprising 59.5% of the catches (Table 1). Some 243 coccinellids were counted during the examination of ladybird distribution. Most were found on *Rubus* spp. with nettles and grasses being the next most favoured. *Adalia bipunctata* L. was the most commonly found coccinellid species on nettles, thistles and birch, whereas *C. septempunctata* was the most commonly found species on grasses, *Rubus* spp. and oak (Table 2). The most commonly found aphid species were: *Sitobion avenae* on grasses; *Microlophium carnosum* on nettles; *Myzus* spp. on thistles; *Amphorophora rubi* and *Sitobion fragariae* on bramble; *Euceraphis punctipennis* on birch; *Drepanosiphum platanoidis* on sycamore and *Tuberculoides annulatus* on oak.

TABLE 1. Proportion and numbers of different coccinellid species sampled.

Species	n	%
Coccinella septempunctata	217	59.5
Adalia bipunctata	129	34.8
Calvia quatuordecimguttata	11	2.9
Propylea quatuordecimpunctata	7	1.9
Adalia decempunctata	7	1.9
Total	371	

Coccinellid distribution

There were significant differences between habitats in coccinellid numbers ($F_{2, 43} = 4.11$, $p < 0.05$), with most coccinellids being found in grassland areas (Fig. 1). There was no effect of month ($F_{2, 43} = 1.16$, N.S.), and the interaction term was non-significant ($F_{4, 43} = 0.33$, N.S.). There was no effect of percentage ground cover ($F_{1, 43} = 0.35$, N.S.). Overall, post-hoc tests showed that while grassland had significantly more coccinellids than woodland ($p < 0.01$) and woodland margins ($p < 0.005$), there was no difference between the latter two ($p = 0.98$).

Aphid distribution

In contrast, most aphids were found in woodland and woodland margins ($F_{2, 43} = 7.05$, $p < 0.005$; Fig. 2). Again, there was no significant effect of month on aphid abundance ($F_{2, 43} = 0.03$, N.S.), and the interaction term was also non-significant ($F_{4, 43} = 0.51$, N.S.). However, there was a significant relationship between percentage ground cover and aphid numbers ($F_{1, 43} = 6.48$, $p < 0.02$). Post hoc tests found that there were significant differences between woodland and grassland in aphid numbers ($p < 0.05$), but

TABLE 2. Observed distribution of coccinellids relative to plant type (rounded to nearest percentage, totals in parentheses).

Species	Grasses	Nettles	*Cirsium* spp.	*Rubus* spp.	Sycamore	Oak	Birch
Adalia bipunctata	20% (9)	72% (45)	60% (3)	18% (18)	43% (3)	17% (2)	50% (7)
Coccinella septempunctata	80% (36)	28% (17)	40% (2)	82% (80)	0	75% (9)	35% (5)
Thea vigintiduopunctata	0	0	0	0	57% (4)	8% (1)	8% (1)
Propylea quatuordecimpunctata	0	0	0	0	0	0	8% (1)

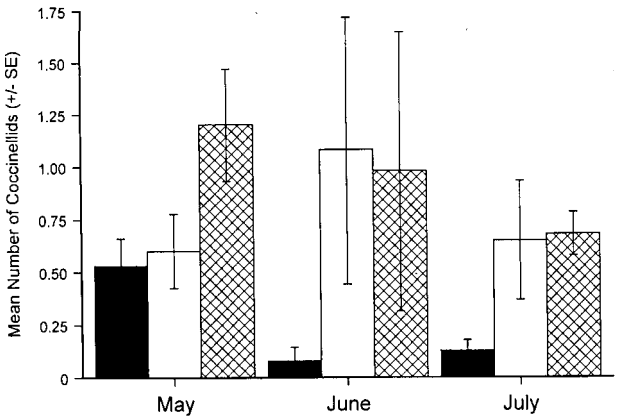

Fig. 1. Mean number of coccinellids per m^2 (± S.E.) sampled per quadrat in woodland (solid bars), woodland margins (open bars) and grassland (hatched bars) over three months.

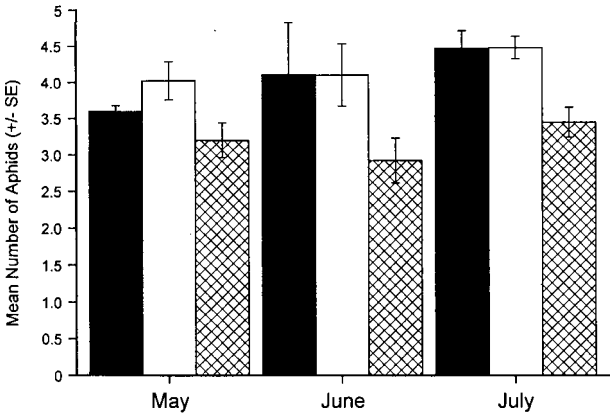

Fig. 2. Mean number of aphids on 200 randomly chosen leaves (trees) or 100 leaves (other plants) per m^2 (± S.E.) from quadrats placed in woodland (solid bars), woodland margins (open bars) and grassland (hatched bars) over three months.

there were no other differences found between the other sites.

Influence of plants and associated aphids on coccinellid numbers

These results are summarised in Table 3. Coccinellid numbers on oak and grass were strongly influenced by both proportion ground cover (oak: $\beta = -0.77$; grass: $\beta = 0.31$) and aphid numbers (oak: $\beta = 0.8$; grass: $\beta = 0.47$). Coccinellid numbers on thistle and nettle were only influenced by the proportion ground cover of those plants (thistle: $\beta = 0.63$; nettle: $\beta = 0.42$).

TABLE 3. Multiple regression of % plant cover and aphid numbers against coccinellid numbers.

Plant	F-value	$p <$	r^2
Sycamore	$F_{2,37} = 1.57$	N.S.	0.08
Birch	$F_{2,38} = 0.52$	N.S.	0.03
Oak	$F_{2,36} = 7.12$	0.005	0.28
Bramble	$F_{2,46} = 2.14$	N.S.	0.09
Nettle	$F_{2,46} = 3.36$	0.05	0.13
Thistle	$F_{2,28} = 9.71$	0.001	0.41
Grass	$F_{2,51} = 24.38$	0.0001	0.49

DISCUSSION

Coccinellid abundances were not affected by the month of sampling or the overall level of ground cover. However, they were significantly more common on grasslands than on either of the woodland habitats and oak. Coccinellid numbers were positively correlated to plant cover for nettle, thistle and grass. Coccinellid density remained fairly stable throughout the season when summed over all three habitats, which does not correspond to other published results (Clayhills & Markkula, 1974; Galecka, 1980; Ives, 1981). In a parallel study (Leather & Rombe, in prep.), temperature had a marked effect on the number of coccinellids caught on any one date. Habitat preference by coccinellids, which are more abundant on grasslands and margins, may be related to the fact that these habitats are more exposed to the sun than wooded habitats. Consequently temperatures in grasslands and margins are higher (Honěk, 1983; Shulka, 1990). In the present study average temperatures during sampling were 15, 13 and 11°C for grasslands, margins and woodlands respectively, in May. In June the temperatures had risen to 19, 18 and 15°C; and in July to 18, 17 and 15°C.

Coccinella septempunctata and *A. bipunctata* were the most common coccinellid species found in the study (Table 1). Coccinellid distribution was frequently correlated with the proportion of ground cover of a given plant species (Table 3). This phenomenon was also described by Shulka (1990) and Honěk (1982a) who found that the population density of coccinellids was related to aphid density, and other studies have found that ladybird population size also correlated with plant density, landscape and time of year (Evans & Youssef, 1992). There was a definite indication that some species had habitat preferences. In particular, *C. septempunctata* was not found in densely wooded areas and this reflects their preference for sparse stands (Honěk, 1985). Larvae and pupae of *C. septempunctata* and *A. bipunctata* were frequently found on *Rubus* spp. and *Urtica dioica* indicating that these plants are important for these coccinellid species, confirming earlier observations (Banks, 1955; Mills, 1981). This would suggest that these plants act as predator refuges and may be useful in field margins to augment natural enemy numbers in crops. The association of particular coccinellid species with particular plant species may be explained by the fact that plant structure affects coccinellid searching efficiency (Carter et al., 1984; Hacker & Bertness, 1995). By way of illustration, coccinellid larvae tend to fall off smooth leaved plants more often than from plants with more textured leaf surfaces. It is only those species whose larvae possess specialised features such as an enlarged anal disc, like *A. bipunctata*, that are commonly found associated with trees.

Studies on habitat manipulation within agricultural landscapes, such as "island" habitats in cereal crops, have concentrated on polyphagous predators including carabid beetles and spiders (Thomas et al. 1991, 1992; Lys &

Nentwig, 1992, 1994). The augmentation of specific natural enemies of aphid pests such as coccinellids are likely to have greater benefits for biological control than an increase in the general background level of predation. Studies of the relationship between prey and natural enemies (Begon et al., 1996) suggest that aphidophagous ladybirds possess two properties (searching ability and aggregation on host patches) that characterise good biological control agents. However, coccinellids have generally failed as biological control organisms against aphids in greenhouses (Greathead, 1989). The cause of failure in biological control is probably related to the weak reproductive response of *A. bipunctata* to aphid populations (Hemptinne et al., 1992). However, these results were obtained in studies of coccinellids as the sole control organism in glasshouses. In the field coccinellids comprise part of a complex of natural enemies, which includes obligate aphidophagous larvae and generalist predators. Generalist predators frequently exhibit severe intra-guild predation, which reduces their efficacy as biocontrol agents (e.g. Wittmann & Leather, 1997). Adult and larval coccinellids indulge in cannibalism of conspecific eggs and larvae; and, to lesser degree cannibalism of other coccinellid species (Agarwala & Dixon, 1992).

Coccinellids such as *A. bipunctata* and *C. septempunctata* are specialists on a limited number of aphid species (Blackman, 1967), and as such make potentially ideal biocontrol agents. Their preferences for grasses, thistles and brambles is also fortuitous. In north-west Europe, plants such as these quickly invade disturbed areas, and will also more slowly overrun fields where grazing is reduced. As such, it would require little (if any) management to create coccinellid havens in crop margins. This study goes some way to identifying the complex relationships between coccinellids and features of the surrounding landscape. Elliott & Kieckhefer (1990) felt that this would help agriculturalists to manipulate landscapes to increase coccinellid populations available to colonise agricultural crops. The habitat requirements of the coccinellid species revealed in this study indicate that only a slight modification of the various proposed "island" habitats would be required to elevate coccinellid levels in crop ecosystems.

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