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X. Zhou [a] , N. Carter [b] & W. Powell [a]

[a] Department of Entomology and Nematology, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts, AL52JQ, UK

[b] The British Trust for Ornithology, The National Centre for Ornithology, The Nunnery, IP242PU, UK

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Seasonal Distribution and Aerial Movement of Adult Coccinellids on Farmland

X. ZHOU,[1] N. CARTER[2] AND W. POWELL[1]

[1]*Department of Entomology and Nematology, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts AL5 2JQ, UK;* [2]*The British Trust for Ornithology, The National Centre for Ornithology, The Nunnery, Thetford IP24 2PU, UK*

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Seasonal and spatial aspects of coccinellid populations were studied on Rothamsted farm using a network of sticky traps in 1991 and 1992. Seasonal aerial population dynamics of Coccinella septempunctata *and* Propylea quatuordecimpunctata *were similar in both years, but the population size of the former was smaller in 1992. The seasonal population dynamics of* Adalia bipunctata *differed between the two years with a much larger population in 1992. All the species showed aggregated distributions on the farm, but* A. bipunctata *was the most strongly aggregated in both years. The study indicated that* C. septempunctata *was less discriminating in its use of habitats for feeding and breeding than were* A. bipunctata *and* P. quatuordecimpunctata *which mainly exploited non-crop habitats along hedgerows and grass banks.*

Keywords: Coccinella septempunctata, Adalia bipunctata, Propylea quatuordecimpunctata, *sticky trap, mapping*

INTRODUCTION

Coccinellids are important predators and can prevent aphid pests reaching outbreak levels in some years (Frazer, 1988), particularly when they aggregate in areas with large aphid densities (Kareiva & Odell, 1987). The farmland ecosystem in southern England is a mosaic of transitory crop habitats and more stable semi-natural habitats, such as hedgerows and woodlands. These semi-natural habitats are important overwintering sites for many groups of aphid natural enemies including coccinellids (Banks, 1954; Sotherton, 1984, 1985; Thomas *et al.*, 1991; Zhou & Carter, 1992). Coccinellids also utilize these diverse habitats as feeding and breeding sites during the summer (Banks, 1954; Zhou & Carter, 1992). Understanding local movements of adult coccinellids in farmland ecosystems during the year will provide important information to aid the development of strategies for their conservation and to enhance their contribution to the control of aphid pests.

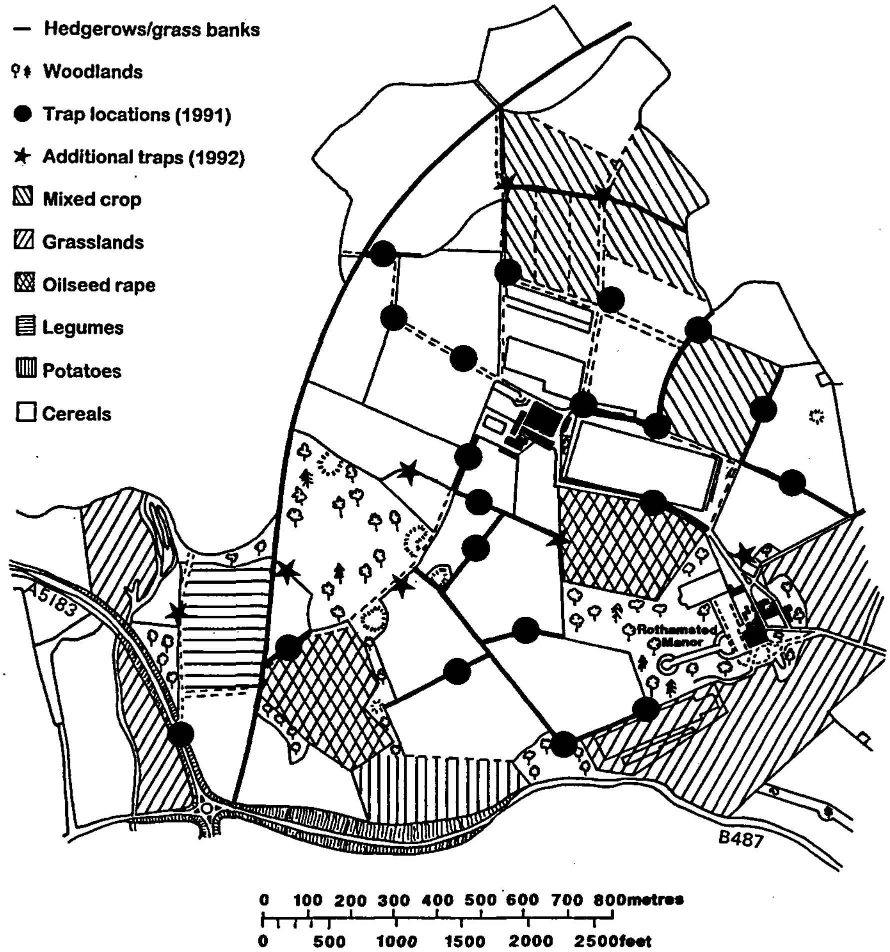

FIGURE 1. Map of the study site showing the distribution of crops and semi-natural habitats.

MATERIALS AND METHODS

The Study Site

The work was done on the farm of Rothamsted Experimental Station, Hertfordshire, southern England (51°4′N, 0°21′W). The farm has a total area of 330 ha and consists predominantly of arable and grass fields, usually surrounded with hedges or grass banks, two woods and a few small woodland patches (Figure 1). The woodland consists mainly of 50-year-old oak (*Quercus robur* L.) and beech (*Fagus sylvatica* L.), and some conifers. The main crops on the farm during 1991 and 1992 were winter wheat, barley, oilseed rape, beans and potatoes, although crops such as linseed, lupins and sunflowers were also grown in small areas.

The Coccinellids

There are about 42 coccinellid species in Britain (Majerus & Kearns, 1989), some of which are aphid-specific predators. Most of these have only one generation a year, but in warm years, some species may have a partial second generation (Zhou & Carter, 1992). Both larvae and adults of aphid-specific coccinellids prey on aphids. The adults are able to disperse long distances (Honek, 1989) and a maximum dispersal distance of 1.5 km was recorded during a mark–recapture study at Rothamsted (X. Zhou, unpublished). On the study site, *Coccinella septempunctata* adults hibernate mainly in the woodlands, and then move to feeding and breeding habitats in spring (Zhou & Carter, 1992). This paper reports studies on the seasonal movements and spatial distribution of adults of the three most common species: *C. septempunctata* L., *Adalia bipunctata* (L.) and *Propylea quatuordecimpunctata* (L.) on the farm during 1991 and 1992, using a network of sticky traps.

The Sticky Trap

In this study, each sticky trap consisted of two plywood boards (40 × 30 cm) coated with water-resistant paint. These boards were screwed on to a wooden post at right angles to each other. The trap was erected so that the middle of the upper and lower boards were 1.3 and 0.9 m above the ground respectively, with the upper one facing south and north and the lower one facing west and east. A yellow plastic sheet (30 cm wide) coated with sticky material (OECO-TAK, OECOS, Kimpton, Herts, UK) was attached to each side of the boards to provide an effective trapping area of 40 × 25 cm in each direction. The traps were checked for coccinellids once every week and the plastic sheets on each trap were changed every other week. The adult coccinellids were identified and the numbers of each species were recorded for each direction separately, and the specimens were removed from the traps. Twenty-one traps in 1991 and 29 in 1992 were used. To determine the position of each trap, a 100 × 100 m grid was superimposed on the farm map to divide the area into square quadrats. Each trap was located on a field boundary as near as possible to the centre of each of these quadrats, allowing for ease of operator access (Figure 1).

Data Analysis

There were no significant differences between numbers of adults caught on the traps facing different directions, and between the top and bottom boards, so only total numbers caught per trap were analyzed. Catches were separated into two time periods, based on the phenologies of each species and seasonal patterns of aerial activity observed during this study (Zhou & Carter 1992; X. Zhou, unpublished observations) (Figure 2). Adults caught on the sticky traps during the first period and second period were separated in the week ending on 4 June for all three species in 1991, and on 1 July for *C. septempunctata*, 13 May for *A. bipunctata* and 2 June for *P. quatuordecimpunctata* in 1992 (Figure 2). It was convenient to divide the season by these weeks when intense flight activity of the overwintered generation ceased. Increases in adult populations as a result of summer breeding were estimated by dividing the total number of newly bred adults trapped by the number of adults from the previous winter. Decrease of adult density after overwintering was estimated by dividing the total number of newly bred adults in the previous year by the number of surviving adults caught in the following spring.

The spatial distribution of aerial populations of the three dominant species, *C. septempunctata*, *A. bipunctata* and *P. quatuordecimpunctata*, was studied by fitting Taylor's power law to spatial variances and means calculated from weekly catches for each species in each year: $\log_{10}(s^2) = a + b \log_{10}(m)$ (Taylor, 1961), where s^2 is the spatial variance and m is the spatial mean. Both parameters a and b are measures of aggregation: for $a = 1, b < 1$ the population is regularly distributed in space; if $b = 1$, it is randomly distributed; and if $b > 1$, it is aggregated. Differences between the regression slopes and intercepts were compared among species in each year, and between 1991 and 1992 for each species.

Detailed distributions of the three species were mapped using UNIMAP (Uniras, Unimap 200).

RESULTS

Species Composition

A total of nine and eight coccinellid species were caught in 1991 and 1992 respectively, and in both years, *C. septempunctata*, *A. bipunctata* and *P. quatuordecimpunctata* were the most abundant (Table 1). In 1991, these three species were caught in similar numbers, but in 1992, *A.*

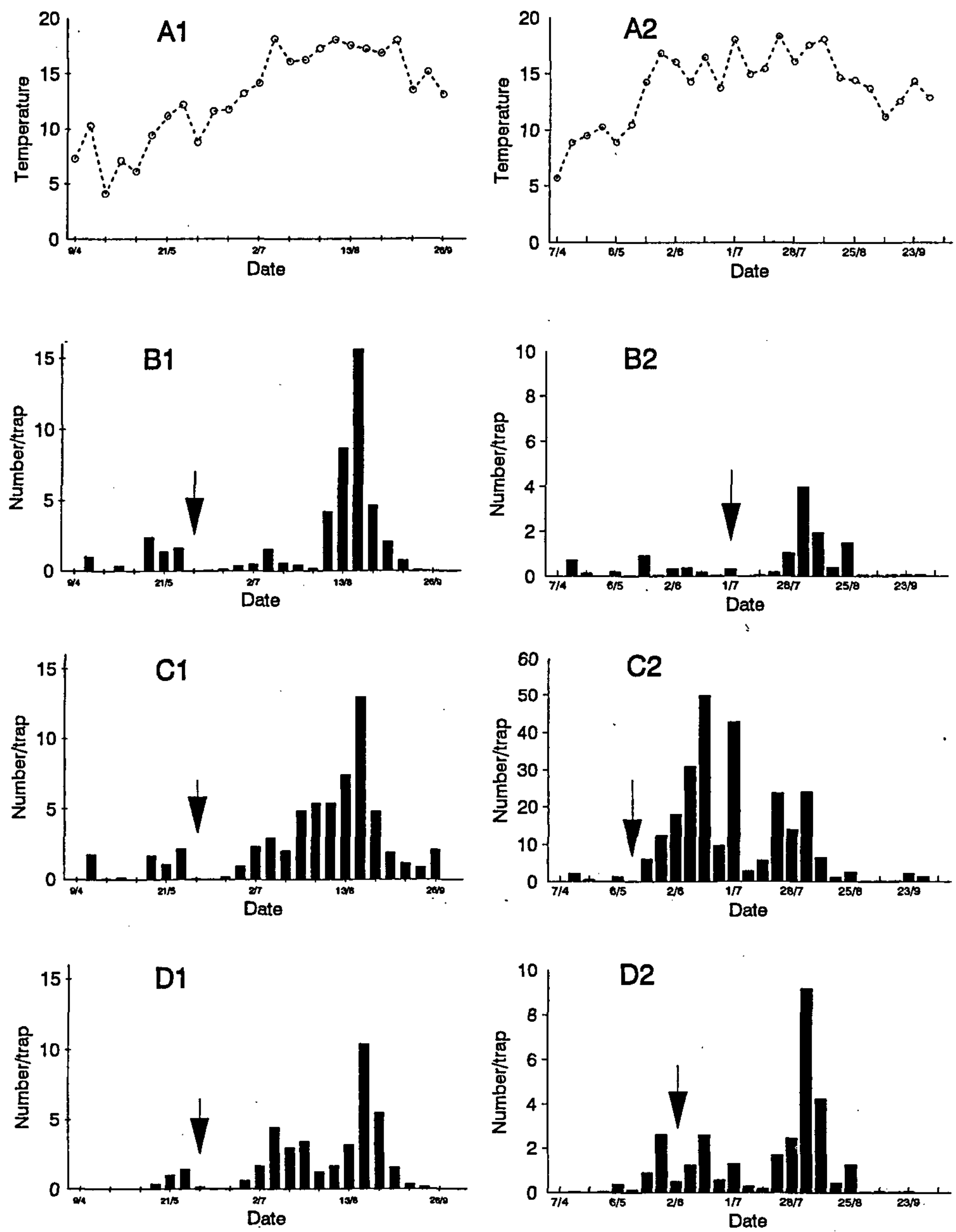

FIGURE 2. The average number of coccinellid adults caught in the sticky trap network per trap per week over the season in 1991 (1) and 1992 (2) with the average weekly temperature in 1991 (A1) and 1992 (A2); (B) *C. septempunctata*; (C) *A. bipunctata*; and (D) *P. quatuordecimpunctata*. (Adults caught before the week indicated by arrows were considered to be overwintered adults and those caught after that week were considered to be mainly individuals which had developed that year.)

bipunctata adults were caught on the traps in much greater numbers than the other two species (Table 1). The population level of *P. quatuordecimpunctata* was similar in both years, but *C. septempunctata* was much less abundant in 1992 than in 1991.

TABLE 1. Relative abundance of coccinellid species caught on sticky traps in 1991 and 1992 (percentage of each species in the total sample)

Year	Species								
	Cs	Pq	Ab	Ad	Pv	Eq	Ms	Cq	Sv
1991	33.73	24.72	36.76	2.30	1.56	0.66	0.20	0.1	0.05
	(2.78)	(2.62)	(3.64)	(0.55)	(0.33)	(0.13)	(0.09)	(0.05)	(0.05)
1992	4.36	12.55	77.82	1.69	1.88	1.18	0.46	0.04	0
	(0.54)	(2.18)	(3.29)	(0.32)	(0.47)	(0.56)	(0.18)	(0.03)	

Cs, *Coccinella septempunctata*; Pq, *Propylea quatuordecimpunctata*; Ab, *Adalia bipunctata*; Ad, *Adalia decempunctata*; Pv, *Psyllobora vigintidnopunctata*; Eq, *Exochomus quadripunctata*; Ms, *Micraspis sedecimguttata*; Cq, *Calvia quatuordecimguttata*; Sv, *Subcoccinella vigintiguatuorpunctata*; data in brackets are SED.

Seasonality

In both years, the first capture of *P. quatuordecimpunctata* occurred 1 month later than the first captures of *C. septempunctata* and *A. bipunctata*. Also, *A. bipunctata* was caught 2 weeks later in 1991 and 4 weeks later in 1992 than *P. quatuordecimpunctata* and *C. septempunctata* (Figure 2). There were only a few *C. septempunctata, A. bipunctata* and *P. quatuordecimpunctata* adults caught before catches reached a maximum in both years (Figure 2). The largest number of flying adults occurred in the same week during mid-August in 1991 for all three species and their numbers were similar (Figure 2). In 1992, the main capture period for *A. bipunctata* occurred 7 weeks earlier and that for *C. septempunctata* and *P. quatuordecimpunctata* occurred 2 weeks earlier than in 1991. Many more *A. bipunctata* but fewer *C. septempunctata* and about the same number of *P. quatuordecimpunctata* were caught in 1992 compared with 1991 (Figure 2). The number of adults caught on the traps was larger when the average temperature over the week was higher during the spring flight period for all the species and in both years (Figure 2). The effects of temperature on the catch number were not apparent during the summer/autumn flight period (Figure 2).

The pattern of seasonal flight activity was similar for *C. septempunctata* and *P. quatuordecimpunctata* in both years. However, *A. bipunctata* had a much longer main flight period in 1992 than it did in 1991 (Figure 2).

The reductions in adult numbers after overwintering, estimated from the sticky trap catches between 1991 and 1992, were 91.7% for *C. septempunctata*, 92.7% for *A. bipunctata* and 87.5% for *P. quatuordecimpunctata*. There were 5.6 and 2.9 times more *C. septempunctata* adults after summer breeding, 7.9 and 62.9 times more *A. bipunctata* adults, and 12.2 and 6.0 times more *P. quatuordecimpunctata* adults in 1991 and 1992 respectively.

Spatial Aspects of the Three Species

The linear regression of $\log_{10}$ (variance) on $\log_{10}$ (mean) accounted for more than 95% of the variance for all three species in 1991 and more than 85% in 1992. The regression slope for *A. bipunctata* was significantly greater than those for *C. septempunctata* and *P. quatuordecimpunctata* in 1992 ($F_{2,64} = 17.8$; $P = 0.001$), but not in 1991 ($F_{2,56} = 1.914$). However, the intercept of *C. septempunctata* was significantly smaller than those for *A. bipunctata* and *P. quatuordecimpunctata* in 1991 ($F_{2,60} = 10.12$; $P = 0.01$). There were no significant differences in the regression slopes and intercepts between the 2 years for *C. septempunctata* ($F_{1,39} = 3.316$, $F_{1,41} = 0.0$), for *A. bipunctata* ($F_{1,43} = 2.52$, $F_{1,45} = 0.048$) and for *P. quatuordecimpunctata* ($F_{1,38} = 0.782$, $F_{1,40} = 3.195$) respectively. Therefore, the data of each species from both years were combined, and the regression slope of *A. bipunctata* was the greatest and that of *C. septempunctata* was the smallest ($F_{2,128} = 81.78$, $P < 0.001$) (Figure 3).

Weekly distribution maps based on the data from the sticky traps indicated that the three

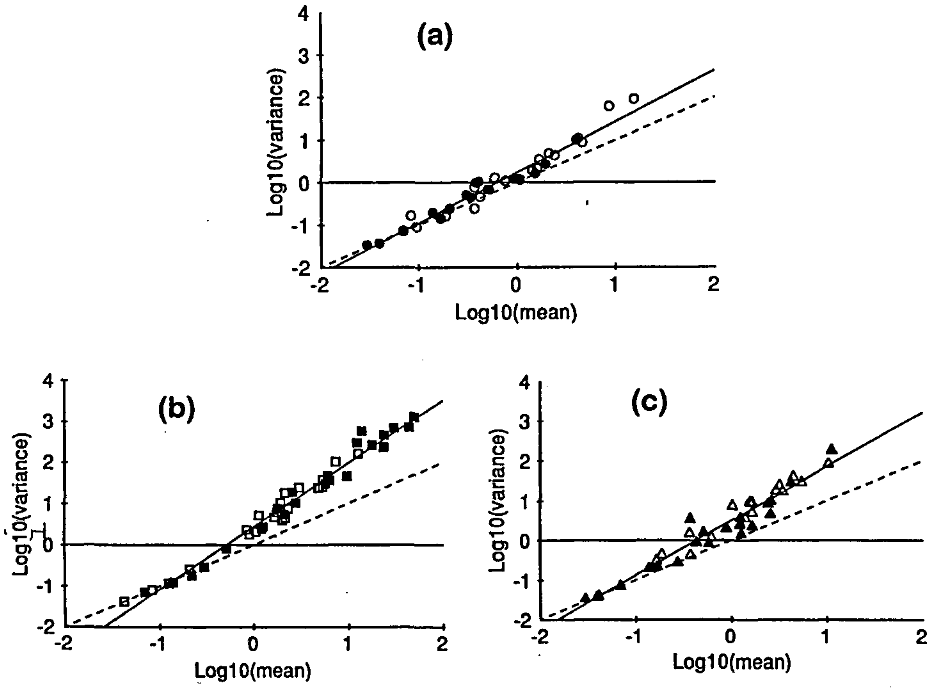

FIGURE 3. Relationship between spatial variance and spatial mean (unfilled symbols are data in 1991 and the filled ones are data in 1992). (a) *C. septempunctata*, $Y = 0.235\ (0.028) + 1.193\ (0.035)X$, $F_{1,41} = 1149.93$, $P < 0.001$; (b) *A. bipunctata*, $Y = 0.441(0.030) + 1.531(0.036)X$, $F_{1,46} = 1793.12$, $P < 0.001$; (C) *P. quatuordecimpunctata*, $Y = 0.487(0.036) + 1.367(0.047)X$, $F_{1,40} = 833.49$, $P < 0.001$, where Y is $\log_{10}$ (variance) and X $\log_{10}$ (mean) and the numbers in brackets are standard errors. (The dashed line represents the relationship of $Y = X$.)

species had seasonal variations in distribution. As there were more than 54 distribution maps, four were selected, one for each species at the movement peak and one for *A. bipunctata* when it moved to overwintering sites (Figure 4). In both years, *P. quatuordecimpunctata* appeared first on traps placed near to grass banks or hedgerows. *A. bipunctata* also appeared first and disappeared last on traps near hedgerows, especially where urban areas bordered the farm. These two species had a patchy distribution throughout the year (Figure 4). In contrast, *C. septempunctata* was distributed more evenly throughout the season, although only a few individuals were trapped early. Most adults of *C. septempunctata* were trapped near to summer breeding sites, which were mostly cereal, bean and sunflower crops (Figure 4).

DISCUSSION

There are three seasonal dispersal phases of coccinellid adults on farmland as reported by Banks (1955): overwintering adults dispersing from nettles (*Urtica dioica* L.) and other non-crop habitats, adults which had developed on nettles and adults which had developed on crops. As the main overwintering habitats of *C. septempunctata* are woodlands (Zhou & Carter, 1992), there is an additional dispersal phase, which is the dispersal of adults from these habitats to nettles and non-crop habitats early in the spring. These dispersal phases were reflected in the trap catches over the season. Differences in seasonal dynamics between the species may reflect their different phenologies. *C. septempunctata* mainly breeds on crops (Hodek, 1973) and starts to oviposit in late May and early June (Zhou & Carter, 1992). *A. bipunctata* prefers breeding on shrubs and

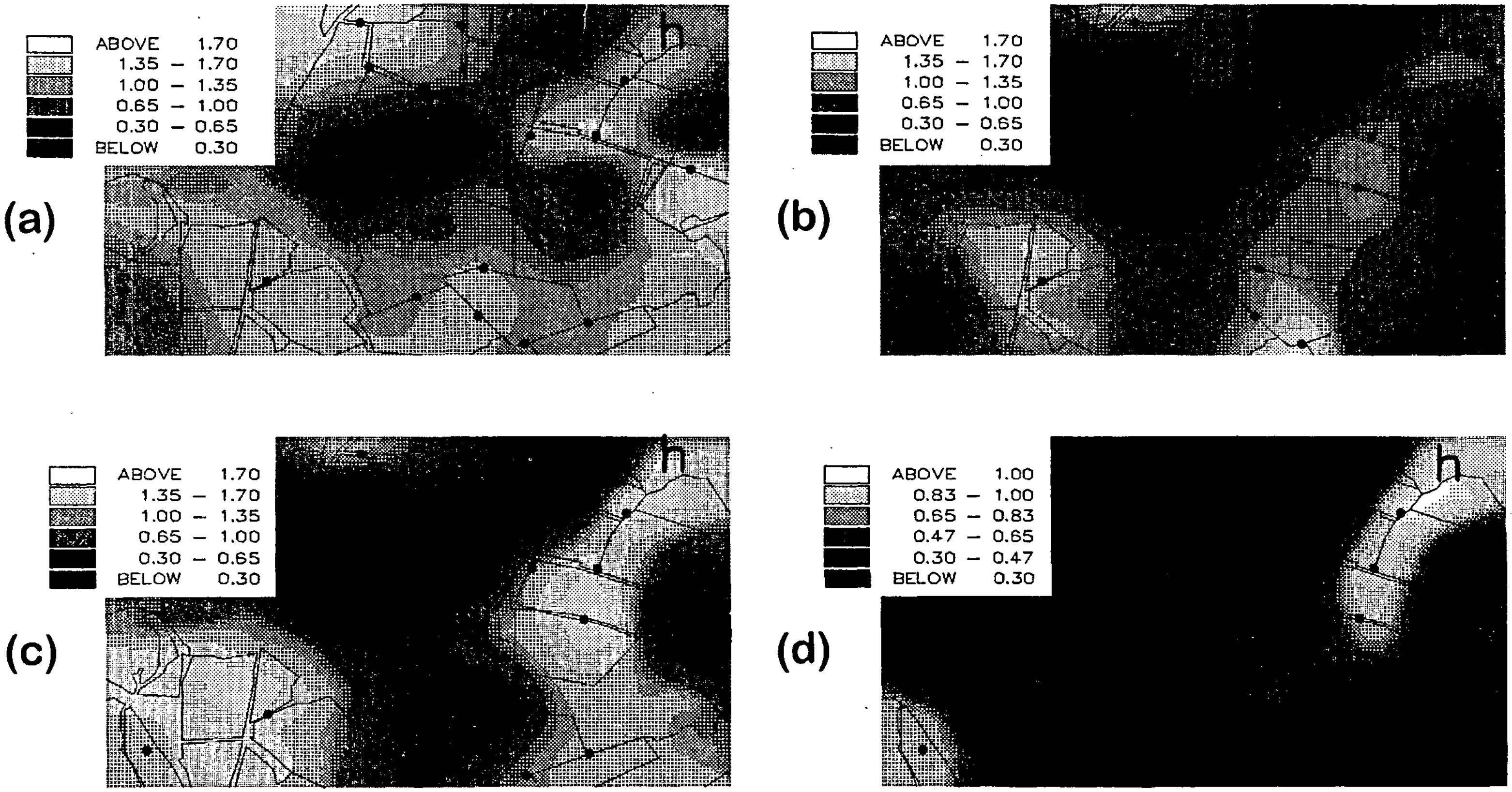

FIGURE 4. The spatial distribution of coccinellids at the study site in 1991 (dots on the maps are trap positions, h is the housing estate). The numbers in the legend are on a $\log_{10}$ (number/trap + 1) scale. (a), (b) and (c) are the distributions when trap catches reached the maximum in the week of 14–20 August. (Note that *C. septempunctata* (a) had a more even distribution, while *P. quatuordecimpunctata* (b) and *A. bipunctata* (c) had more patchy distributions.) (d) is the distribution of *A. bipunctata* in the week of 27 August–3 September.

trees and starts to breed earlier in the season, and *P. quatuordecimpunctata* prefers shrubs for breeding (Hodek, 1973; Honek, 1985). *C. septempunctata* also has a longer development time than the other species at the same temperature (Hodek, 1973). The main flight peaks in the summer occur when newly emerged adults disperse in search of food to increase their reserves for overwintering at a time when aphid populations in their summer breeding sites are declining to (Hodek, 1973; Honek, 1990; Zhou & Carter, 1992).

Adult survival rate after overwintering as estimated from the numbers caught on sticky traps in spring was very low for all three species (less than 15%). However, as flight activity is affected by temperature, this can only be regarded as a rough indication of overwintering survival. Nevertheless, more detailed studies of *C. septempunctata* mortality in overwintering sites (Zhou *et al.*, in preparation) provided a very similar estimate. Summer breeding success estimated by the increased number of adults caught during the summer differed considerably between species and between years, especially for *A. bipunctata*. Breeding success may depend on the availability of aphid populations in crops and non-crop habitats (Hemptinne & Dixon, 1991). These data may only be used as a rough indication of population changes as they were estimated from trap catches only and assumed that immigration into the study area occurred at a similar rate to emigration out of the area. The level of migration in and out of the area is not known although adults can hibernate and breed within the study area (Zhou & Carter, 1992). More data on local population dynamics are needed to confirm these results.

The mean and variance relationship indices indicate that all three species had aggregated distributions. *C. septempunctata* was less host specific than other species, feeding on a range of aphid species in diverse habitats and it is able to fly long distances to find suitable habitats both for breeding and hibernation (Honek, 1989). In contrast, *A. bipunctata* and *P. quatuordecimpunctata* prefer habitats containing shrubs and trees, or grass banks (Hodek, 1973), which was confirmed from the mapping technique in this study when most individuals were caught on traps near these types of habitat. There are two factors causing these coccinellid species to have clumped distributions; first, adults display a positive prey taxis and show restricted search behaviour after initial prey contact (Carter & Dixon, 1982; Kareiva & Odell, 1987). As a result, the adults become aggregated in areas with high aphid densities. These areas differed at different times of the year, plants carrying early aphid populations (e.g. nettle) being utilized by coccinellids on emergence from overwintering sites, and plants carrying late aphid populations (e.g. umbellifers in hedgerows) being utilized later in the year (Zhou & Carter, 1992). Secondly, oviposition of coccinellids occurs near aphid colonies and larval survival is dependent on abundant aphid populations. In summer, large numbers of adults, especially *C. septempunctata*, were caught on traps near their breeding sites. Early and late in the season when the adults moved out of and into hibernation sites respectively, most adult flight activities occurred around the hibernation sites and adults were mostly caught on traps near these sites. For instance, adult *A. bipunctata* were mostly caught on the trap near the housing estate, which was their preferred hibernation site (Hodek, 1973) (Figure 4(d)).

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