

## **The field scale distribution of insects in winter wheat**

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### **ABSTRACT**

The work described in this paper characterises the spatial and temporal distributions of aphids and their natural enemies in winter wheat. Three uses of these data are presented, which investigate; firstly, the possible effectiveness of precision-based spatially varied pesticide application; secondly, crop-scouting strategies; and thirdly, predator-prey interactions. Results from field studies describing the development of populations of *Sitobion avenae* and *Metopolophium dirhodum* are presented and the implications for the development of Integrated Pest Management strategies discussed.

### **INTRODUCTION**

The development of reliable aphid-control strategies is an important component of Integrated Pest Management. Information regarding the field-scale distribution of aphid populations, both in time and space, could improve our ability to apply pesticides optimally and also increase our understanding of natural pest control. Until recently, there have been few spatially-explicit studies that describe or investigate field-scale insect distributions. Recent studies have demonstrated pattern both spatially and temporally, both for aphids and their natural enemies (Winder *et al.*, 1999; Holland *et al.*, 1999) whilst Murchie *et al.* (1999) showed that the quantification of insect spatial distribution might be used to develop precision targeting of insecticides. These studies used the new methodology of Spatial Analysis by Distance Indices (SADIE), developed to describe two-dimensional spatially-referenced count data (Perry *et al.*, 1996, 1999).

In this paper we present three examples of how information regarding the spatial and temporal distribution of insects can be of value for the development of Integrated Pest Management. The first example investigates the spatial distribution of aphids; the conclusions are relevant to precision insecticide applications. The second example illustrates how such spatial information may be used to improve crop-scouting and optimise spray applications. The third example demonstrates how spatial data may be used to investigate the relationships between prey populations and their natural enemies. We discuss these findings in the context of Integrated Pest Management.

## METHODS AND MATERIALS

Intensive sampling of a 5.7 ha field of winter wheat (Coffinswell, Newton Abbot, Devon, UK) was conducted on five occasions during 1999: 27 May, 7, 21 June, 5 and 19 July. A two-dimensional 16 x 16 grid comprising 256 sampling locations was positioned within the crop with a spacing of 12m. At each location aphid numbers and species were recorded by inspecting 25 tillers. Barrier-connected pitfall traps (Winder *et al.*, in press) were used to record ground-active beneficial insects.

Data were analysed by calculating the SADIE index of aggregation,  $I_a$ , and its associated probability level,  $P_a$ ; values of  $I_a$  around unity indicate a random arrangement of the observed counts, values larger than unity indicate spatial aggregation. SADIE cluster indices for each sample unit were contoured into red-blue plots; areas where the estimated degree of clustering was half as great again as that expected by chance were defined as clusters. Clusters are either patches where neighbouring units all had greater than average counts, or gaps where neighbouring counts were all smaller than average.

Additionally, regressions were done of aphid rate of increase ( $r_t$ ) against predator activity-density, recorded as the numbers of beetles caught in pitfall traps. Aphid rate of increase was calculated from:

$$r_t = \frac{\ln(n_t + 1) - \ln(n_0 + 1)}{t}$$

where,  $n_t$  and  $n_0$  represent the aphid counts at the end and the beginning of time interval  $t$ , respectively.

## RESULTS

Two aphid species, the grain aphid *Sitobion avenae* and the rose-grain aphid *Metopolophium dirhodum* predominated; for both species peak population was recorded on 21 June (Figure 1).

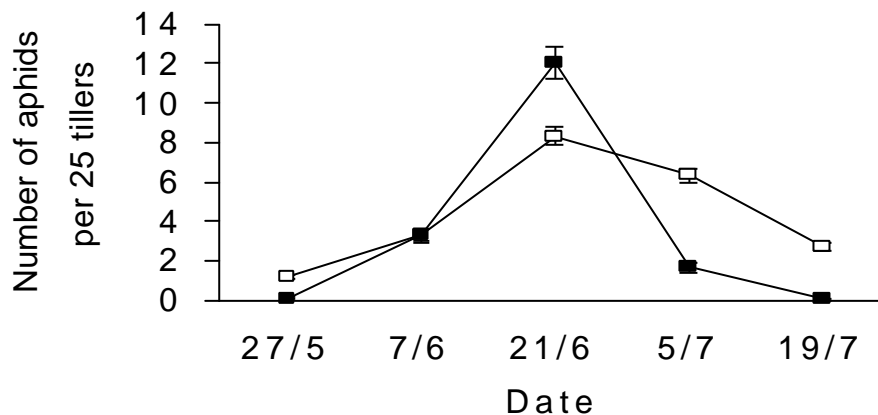


Figure 1. Arithmetic mean aphid counts ( $\pm 1$  standard error) for entire field on each of the five sample dates. Counts from 25 tillers recorded at 256 locations. Filled and open squares represent *Metopolophium dirhodum* and *Sitobion avenae*, respectively.

Analysis of spatial pattern showed considerable spatial aggregation on most dates (Table 1). For *S. avenae*, gap clusters were considerably larger than patch clusters in the red-blue plots (Figure 2). Individual patches covered areas up to approximately 1000m<sup>2</sup>, although most were considerably smaller. Similar patterns were evident for *M. dirhodum*. For both species, the location of patches was ephemeral.

Table 1. Degree of spatial pattern for two aphid species and two ground-active predatory beetles, over five sample dates.

	<i>Sitobion avenae</i>		<i>Metopolophium dirhodum</i>		<i>Pterostichus melanarius</i>		<i>Pterostichus madidus</i>	
	$I_a$	$P_a$	$I_a$	$P_a$	$I_a$	$P_a$	$I_a$	$P_a$
27 May	1.28	0.0548	1.15	0.1668	1.50	0.0070	0.99	0.4615
7 June	2.21	0.0002	1.33	0.0334	4.27	0.0002	1.19	0.1171
21 June	1.17	0.1222	1.82	0.0002	1.78	0.0002	2.12	0.0002
5 July	1.24	0.0736	0.88	0.7836	1.84	0.0002	1.77	0.0002
19 July	1.11	0.1967	1.29	0.0639	2.66	0.0002	1.71	0.0003

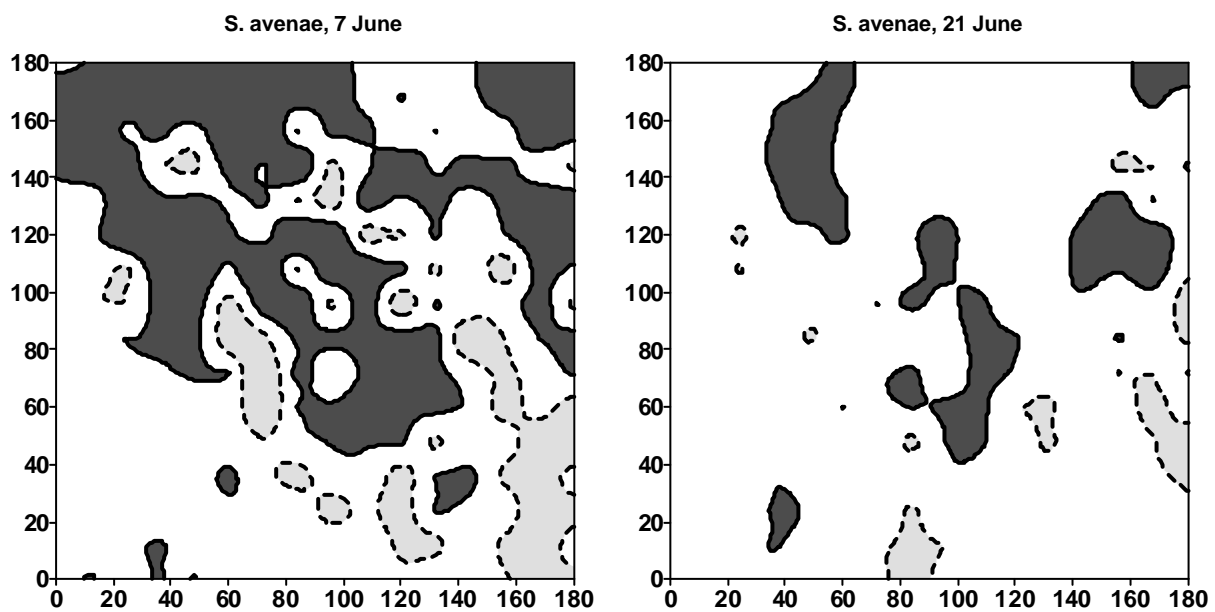


Figure 2. Red-blue plots for *S. avenae* on 7 and 21 June. Clustering indices for each of 256 units contoured into areas of strong clustering, patches bounded by dashed contours, gaps in hatched areas bounded by solid contours.

Simulation was used to study four possible crop-scouting strategies, using as an example the observed data for *M. dirhodum* on 21 June. Each of the strategies: a square, a line transect, a cross and a random sample, was compared for sample sizes ( $N$ ) of 9 and 16 units. For the square, line transect and cross, the sampled units were contiguous to each other. After the position of the centre of each such arrangement was found for each simulation by random placement, the other units to be sampled were determined unambiguously. By contrast, the random sample, by definition, required each sample unit to be chosen randomly and independently of all others in the sample. The geometric mean count per sample was calculated from each of 32 simulations of each strategy. This was compared to the true value of 6.58, derived from all 256 observed counts. All strategies, as expected, provided reasonable estimates of the true geometric mean when assessed over all 32 simulations. However, a more stringent criterion to measure the efficiency of each strategy was the percentage of simulations for which its estimate was within 5% of the true value. Not surprisingly, better estimates were derived for samples of  $N = 16$  units than from  $N = 9$  (Table 2). When  $N = 9$  units were sampled, the random sample and cross strategy proved to be the most reliable, whilst for  $N = 16$  units, the random, cross and line transect methods were comparable. Hence, with constant sampling effort the reliability of a population estimate was dependent upon the way in which the crop was traversed.

Theoretically, a random sample should always be the most accurate. The reason for the reduction in accuracy in non-random samples, in which units are contiguous, is that such arrangements must often coincide with a patch (or gap), yielding a misleadingly large (or small) estimate. For example, the very poor performance of the 4x4 square of  $N = 16$  units occurred because it was frequently located entirely within a patch or gap (see Figure 2). Since all line transects of  $N = 16$  units would straddle several patches and gaps there would be less reason for a biased estimate to result, as confirmed by Table 2.

Table 2. Comparison of four crop-scouting strategies on efficiency of simulated estimates of geometric mean, for *M. dirhodum* density on 21 June at two sample sizes. The true geometric mean over the entire field ( $N = 256$ ) was 6.58. The value shown is the average of the estimates over 32 simulations; the number in brackets is the percentage of the 32 simulations for which the sample estimate was within 5% of the true value.

Strategy	$N = 9$	$N = 16$
Square	5.77 (6.3)	6.60 (3.1)
Line transect	7.16 (3.1)	6.91 (18.8)
Cross	5.94 (9.4)	6.27 (18.8)
Random sample	7.39 (12.5)	6.75 (15.6)

A wide range of predatory ground and rove beetles, and lycosid and linyphiid spiders were caught during the study. Data from the predatory ground beetle genus *Pterostichus* are included here as an illustration. Both *P. melanarius* and *P. madidus* were considerably aggregated (Table 1). The effect of *P. melanarius* on the population dynamics of *S. avenae* and *M. dirhodum* was confirmed by significant regressions of intrinsic rate of aphid increase ( $r_m$ ) on predator activity-density (Table 3). This was particularly evident for *M. dirhodum* between 21 June and 5 July, where there were negative relationships between the variables, indicating that the predatory beetles had a measurable retardant effect on the rate of aphid population increase, and providing evidence of their value as biological control agents.

Table 3. Regressions of intrinsic rates of aphid increase between consecutive sample dates on *Pterostichus melanarius* pitfall trap catches. Subscripts indicate sample occasion.  $ME = \log_{10}(Pterostichus\ melanarius)$ .

$r_m$	<i>Sitobion avenae</i>		<i>Metopolophium dirhodum</i>
27/5 to 7/6	$r_m = 0.055 - 0.049 ME_{27/5}$	$P=0.069$	$r_m = 0.129 - 0.010 ME_{27/5}$
	$r_m = 0.100 - 0.044 ME_{7/6}$	$P=0.039$	$r_m = 0.168 - 0.038 ME_{7/6}$
7/6 to 21/6	$r_m = 0.042 + 0.018 ME_{7/6}$	$P=0.281$	$r_m = 0.086 + 0.001 ME_{7/6}$
	$r_m = 0.063 + 0.003 ME_{21/6}$	$P=0.843$	$r_m = 0.082 + 0.010 ME_{21/6}$
21/6 to 5/7	$r_m = -0.012 + 0.008 ME_{21/6}$	$P=0.592$	$r_m = -0.098 - 0.048 ME_{21/6}$
	$r_m = -0.018 + 0.010 ME_{5/7}$	$P=0.374$	$r_m = -0.093 - 0.031 ME_{5/7}$
5/7 to 19/7	$r_m = -0.048 - 0.007 ME_{5/7}$	$P=0.492$	$r_m = -0.105 + 0.012 ME_{5/7}$
	$r_m = -0.042 - 0.019 ME_{19/7}$	$P=0.114$	$r_m = -0.081 - 0.020 ME_{19/7}$

## DISCUSSION

The analyses presented in this paper illustrate the use of spatially-referenced data. In this study, there is both spatial and temporal pattern evident that could influence the development and efficiency of Integrated Pest Management systems. Aphids were spatially aggregated within ephemeral patches; these patches shifted around the field markedly throughout the sampling period.

If the population dynamics of discrete within-field aphid populations was mediated primarily by initial aphid infestations, then spatial pattern would be largely dependent on the location of initial aphid foci, due to aphid immigration or over-wintering. Populations would then develop in those locations, statically throughout the season. However, this was not the case in this study. The processes that mediate the development of actual temporal and spatial patterns are poorly understood.

Local-scale (i.e. <1m) changes in pattern may be due to the mobility of aphids, perhaps due to disturbance caused by strong gusts of wind, large rain droplets (Mann *et al.*, 1995) or natural enemies. Field-scale changes in pattern may be due to a number of factors, possibly including natural enemies. In this study we show that aphid population increase is related to predator numbers, which are themselves patchy in distribution. The effect of many natural enemies, including

predatory beetles, spiders and parasitoids, may result in a spatially dynamic system. Whatever the cause, these results describe a system where the location of aphid patches was unpredictable.

Our studies show that the spatial arrangement of counts influences the reliability of population estimates. However, it must be remembered that although the random sample is theoretically the most accurate, the expected time taken to traverse the crop for this strategy exceeds the others, for which sampling takes place over a strictly limited extent. In the worst case, the distance traversed for the random sample would equal the perimeter of the field. There is a trade off between the reduction in efficiency for the competing strategies and their speed of execution. When spatial pattern is present, then strategies that ignore this information are never optimally efficient. In particular, strategies based solely on mean/variance statistics or incidence, without regard for location, cannot provide the most effective approach. Currently, crop scouting is often undertaken by basing assessments on counts during a 'W' or similar shaped traverse through the crop. This study suggests that such a strategy may be a sensible compromise between a random sample and a block sample; further investigation of sample size may be warranted for cereal crops and their aphid pests.

The generalist predator *P. melanarius* was shown to influence the intrinsic rate of increase of both *S. avenae* and *M. dirhodum* populations. It is likely that other species within this group may also influence aphid population dynamics. Other spatial studies imply that such predators may have an important effect on the spatial distribution and population dynamics of their prey (Bohan *et al.*, 2000). The examples given in this paper demonstrate the importance of investigating such systems using spatially-referenced data. More understanding of processes leading to spatial pattern could increase our understanding of ecosystem processes and allow the development of more reliable decision-making strategies, as part of Integrated Pest Management systems.

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