

The impact of dimethoate on the spatial distribution of beneficial arthropods in winter wheat

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Summary

The within-field spatial distribution of beneficial arthropods was assessed using two-dimensional grids of pitfall traps and suction sampling across two winter wheat fields of 4 and 16 ha, before and after an application of dimethoate. An unsprayed 6 m wide buffer zone was left around half the edge of the larger field. Arthropod numbers fluctuated to varying extents prior to spraying. Two species of Carabidae (*Pterostichus madidus* and *P. melanarius*), Linyphiidae, Lycosidae and *Aphidius* spp. (Braconidae) all showed their greatest reduction after spraying. For five carabid taxa, *Tachyporus* spp. (Staphylinidae) and Collembola the decline in numbers following spraying was no greater than any reduction found during the pre-spraying period. Within field spatial distributions of three arthropod groups were analysed using SADIE. *P. madidus*, present in patches across the centre of both fields prior to spraying, was removed by dimethoate and by 34 days after spraying had recovered most at the field edges. Linyphiidae were evenly distributed across both fields prior to spraying. Their numbers were reduced considerably by dimethoate and they did not recover to pre-spray levels. However, where recovery occurred this was across the centre of both fields indicating their

potential to reinvade whole fields. *Aphidius* species were also evenly distributed across both fields prior to spraying, but did not recover after spraying. Some, but not all arthropods survived within the unsprayed buffer zone and there was some indication that reinvansion of the mid-field was more extensive where this was present. The importance of field margins with respect to insecticide treatments is discussed.

Key words: Carabidae, parasitic wasps, spiders, Collembola, SADIE, predatory insects, insecticides

Introduction

Winter wheat crops are inhabited by a diverse range of beneficial invertebrate species, many of which are susceptible to insecticides; this has been the subject of numerous laboratory, semi-field and field scale trials. The subject has been periodically reviewed (Croft & Whalon, 1982; Smith & Straton, 1986; Croft, 1990) and a database of insecticide toxicity to non-target invertebrates was compiled (Theiling & Croft, 1988). The impact of each insecticide treatment is mediated by a combination of chemical, toxicological, ecological and operational factors (Jepson, 1989). Applications made when a large proportion of beneficial species are active will be the most damaging, such as insecticides applied to control summer cereal aphid outbreaks. Broad-spectrum organophosphate products are still commonly used in the UK because of their lower cost (Oakley, 1994), despite their known hazard to beneficial species. Dimthoate, especially is known to be toxic to a wide range of beneficial arthropods (Vickerman & Sunderland, 1977; Duffield & Aebischer, 1994; Mead-Briggs, 1998; Walters *et al.*, 1998) and is frequently used as a toxic standard (Floate *et al.*, 1989; Çilgi *et al.*, 1996). For field applications another important factor influencing the outcome is the size of the treated area and the potential for reinvansion by individuals from untreated areas (Duffield & Aebischer, 1994). Reproduction by surviving individuals or emergence from other life stages protected at the time of application may also contribute to repopulation. The duration of

effect increases with the scale of the treated area and the rate of reinvasion by each species is determined by behavioural, ecological and toxicological factors (Jepson, 1989). Within farmland the untreated areas may be neighbouring untreated fields and non-crop areas such as field boundaries. The latter have been shown to act as important overwintering sites from which reinvasion occurs in the spring (Wallin, 1985, 1986; Coombes & Sotherton, 1986; Jensen *et al.*, 1989; Thomas *et al.*, 1991; Dennis & Fry, 1992). Other species may be found in both crop and field margins during their peak activity periods (Lyngby & Nielsen, 1980; Wallin, 1988) or may prefer the field margins for breeding if the crop is unsuitable (Desender & Alderweireldt, 1988). If field margins are an important resource from which reinvasion may occur then the rate and extent of reinvasion will be influenced by field size and margin quality.

Several studies have demonstrated that beneficial species including Carabidae (Hengeveld, 1979; Thomas, Parkinson & Marshall, 1998; Holland *et al.* in press), parasitic wasps (Ruggle & Holst, 1995; Longley *et al.*, 1997b) and Linyphiidae (Wratten & Thomas, 1990; Thomas, Hol & Everts, 1990) as well as pest species such as cereal aphids (Winder, Holland & Perry, 1999) were unevenly distributed within fields or even within the landscape. Some species may exist as a series of local semi-autonomous populations (den Boer, 1990), termed a metapopulation (Levins, 1961). These populations interact through dispersal, thus the size of each metapopulation and the distance between each will be governed by their dispersal ability. The factors which govern the location of these populations are uncertain although, for ground-active species, environmental factors, distribution of prey or predation are all likely to be influential. For aphid-specific and parasitic species, prey distribution is likely to be the most important factor. Insecticide applications may disrupt these distributions, depending on the size of the metapopulation with respect to the area treated and whether any barriers exist that could prevent reinvasion (Sherratt & Jepson, 1993). However, field scale evaluations of insecticide effects are rare because of the sampling effort required. Such heterogeneous distributions within fields may confound the interpretation of

insecticide trials, especially when samples are taken only from a small area, the effects found depending on the initial distribution within the field and the subsequent pattern of reinvasion.

Conservation Headlands, in which the outer 6m of the crop is only selectively sprayed with herbicides and no insecticides are used in summer, have been shown to be effective in preserving invertebrates important in the diet of game bird chicks that feed predominantly along the crop edge (Sotherton, 1991) and also beneficial predatory arthropods resident within them (de Snoo, van der Poll & de Leeuw, 1995). These areas also reduce drift into the field boundary (Cuthbertson & Jepson, 1988; Longley *et al.*, 1997a) where many beneficial species are active. In the UK, buffer zones were recently introduced as a means of protecting water courses from pesticide contamination (Croxford, 1998), but they will also reduce spray deposition within the vegetation surrounding the watercourse and the adjacent unsprayed area of crop (de Snoo & de Wit, 1998). Reinvasion by Carabidae and Linyphiidae was predominantly from the field margins inwards (Jepson & Thacker 1990; Thomas, Hol & Everts 1990), thus reinvasion of treated fields from these unsprayed crop areas and field boundaries may be quicker and more extensive than in fully sprayed fields.

In practice whole cereal fields are treated with insecticides but their impact at such a scale is rarely monitored. The aims of this study were to examine the impact of a field scale application of the organophosphate insecticide, dimethoate and the extent to which this disrupted the distribution of beneficial invertebrates within fields. To determine the importance of field boundaries as a resource from which reinvasion may occur and in conjunction to what extent this was influenced by field size. Finally whether unsprayed crop areas influenced reinvasion.

Materials and Methods

Arthropods were sampled simultaneously in two winter wheat fields (*cv.* Riband), of 4 ha and 16 ha, in Dorset, UK using pitfalls traps and a Dvac suction sampler during 1997. Both fields were surrounded by 3 m wide field boundaries consisting of a mature hedge and a herbaceous hedge bank.

Along the eastern edge of the large field, a 2 m wide herbaceous strip and a dirt road separated the crop edge and the hedgerow.

A grid of pitfall traps with approximately 30 m spacing was used within each field with a single trap at each sampling point. In the larger field, the grid was 8 units wide and between 8 to 11 units long, with 75 traps in all. In the smaller field it was 6×4 units with 5 extra traps, making 29 in all. The outer sampling position was approximately 3 m from the field edge. Each sample location was surveyed and located using the national grid reference. The pitfall traps (6 cm diam.), partly filled with water and detergent, were operated for two days then all arthropods were removed and stored in 70% alcohol. Samples were taken on five occasions (15/5, 29/5, 12/6, 26/6, 9/7) between May and July 1997. Two days (11 July) after this last sample the fields were sprayed with dimethoate (0.86 l ha^{-1}), leaving a 6 m unsprayed buffer zone around the northern half of the larger field. The crop was at GS73 at time of spraying which is towards the end of the period when cereal aphids cause economic damage. Both fields were then sampled as above on three occasions, 6, 20 and 34 days after spraying.

A suction sample consisting of ten 5s sucks (total area sampled = 0.92 m^2) was taken approximately 2 m from each of the sampling points in the two fields. Samples were taken on the 15/5, 29/5, 13/6 and 6 and 20 days after the dimethoate treatment. The majority of the pitfall samples were comprised of Carabidae, which were identified to species or genus, and Araneae, which were identified to family. In the suction samples the predominant groups were the parasitic wasps which were identified to genus, Araneae which were identified to family and Collembola.

Data analysis

Arthropod numbers captured for any one species may differ through time according to phenology and activity. Consequently, capture rate in pitfall traps may vary with breeding cycle, food supply and environmental conditions. The results presented for pitfall traps therefore represent a combination of activity and density. These natural fluctuations can confound the interpretation of pesticide trials. To overcome this and allow an assessment of the insecticidal impact compared to

natural fluctuations, for each field the number of each taxon captured (transformed to $\log_{10}(n+1)$) on the previous sampling occasion was subtracted from next to create a 'log-difference' (Duffield & Aebischer, 1994) and these values were plotted over time. These are presented for most taxa found in the pitfall traps, but only data for *Aphidius* spp. are presented from the Dvac suction sampling. No error is available because there was only a single replicate of each field size, however, because of the spatial sampling arrangement the mean value for each field provide a comprehensive measure of invertebrate numbers.

To examine how the insecticide affected the spatial distribution of invertebrates, data were analysed from two days prior to the insecticide application and for all dates afterwards. A more detailed analysis of their distribution prior to spraying is given in Holland, Perry & Winder (in press). Analysis was done for pitfall captures from two different taxonomic groups for which the counts were sufficiently high and which have different dispersal methods: *Pterostichus madidus* F. (Coleoptera: Carabidae), a large ground-active beetle which disperses primarily by walking and the Linyphiidae, small spiders which disperse by ballooning on air currents (Millidge & Locket, 1953) but also over short distances by walking (Thornhill, 1983). Numbers of *Aphidius* spp. (Braconidae) from the suction samples were also analysed. These parasitic wasps are capable of limited active flight (Vorley & Wratten, 1987), although wind dispersal may occur. The distribution of these arthropods was first mapped using the programme Surfer (Golden Software Inc., 1997).

Spatial pattern was then quantified using the improved SADIE method described in Perry *et al.* (1999). This technique measures clustering of arthropods, either in patches of greater than average density (indicated by positive-valued indices v_i with their average value \bar{v}_i and associated probability P_i) or gaps of less than average density (indicated by negative-valued indices v_j with their average value \bar{v}_j and associated probability P_j). Unlike previous methods, clustering is measured at each location sampled, for each of which there is an index. Each individual index is constructed from a comparison between the observed clustering for that unit and randomizations of the observed counts amongst the sample units; mean index values are assessed using tests based on the variability of

those randomly arranged samples. If the absolute values of both the mean patch and gap index are around unity, the data conform to the null hypothesis of spatial randomness; a significantly large absolute value of either index indicates clustering. The method seeks to distinguish an isolated large count surrounded by smaller values from one that is part of a patch of nearby units also with relatively large values that forms a patch. The clustering index for the isolated count is negligible. Similarly, a solitary small count may be differentiated from a group of similar values that form a distinct 'gap'. A patch cluster is a set of neighbouring units for which the clustering index, v_i , is greater than 1.5 for all units in the set; a gap cluster is defined similarly except that the clustering index, v_j is less than -1.5 (Perry *et al.*, 1999).

Results

When the change in abundance was examined for both fields the carabid beetles, *Pterostichus melanarius* Ill., *P madidus*, the spiders (Linyphiidae and Lycosidae), parasitic wasps (*Aphidius* spp.) and total predatory arthropods all showed their largest decline immediately following the dimethoate treatment. Five of the carabid taxa: *Amara* spp., *Bembidion lampros* (Herbst), *Harpalus rufipes* (Degeer), *Nebria brevicollis* (F.), *Trechus quadristriatus* (Schrank), *Tachyporus* spp. (Staphylinidae) and Collembola exhibited a moderate decline after spraying, the extent of which was no greater than that found during the pre-spraying period (Fig. 1). Aleocharinae (Coleoptera: Staphylinidae) showed no decline after spraying. Some taxa exhibited an increase between the first and second sample periods after spraying. Except for *H. rufipes* and *T. quadristriatus*, changes through time were similar in both fields and the response after spraying was the same.

There were considerable differences in the impact of insecticide on total numbers per field and their spatial distribution for the three taxa with different dispersal abilities. For *P. madidus* total numbers within the field and at 3 m from the field edge were similar prior to spraying and decreased to similar levels immediately following the insecticide treatment, even within the untreated buffer zone (Fig. 2a). Numbers recovered more quickly and to a greater extent within the field edge

compared to the mid-field and more so for the unsprayed buffer zone and the mid-field area which it enclosed. The total number of *P. madidus* captured were similar prior to and 34 days after the insecticide treatment, however their distribution changed. Prior to spraying there was significant clustering into patches ($P_i < 0.05$) along the western edge and south-east corner of the large field (Fig. 3a) and in the centre of the small field (Fig. 3b). Following spraying *P. madidus* started to reinvade each field from the margins. Even 34 days after spraying this species were found mostly in the traps located around the margins of both fields. In the large field there was significant clustering into a patch located within the unsprayed buffer zone, but there was no significant clustering into patches or gaps in the small field.

Prior to spraying the Linyphiidae were significantly clustered into patches ($P_i < 0.01$) and gaps ($P_i < 0.01$) within the large field (Fig. 4a), but not the small field (Fig. 4b). Following spraying the Linyphiidae exhibited the same proportion of decline in the edge and mid-field areas even within the buffer zone (Fig. 2b). They showed a small recovery following spraying, although not in all areas. By 19 days after spraying linyphiids were present across most areas of both large and small fields, although in lower numbers than prior to spraying. They then declined across both fields. The distributions changed after spraying and although patches were found within the large field, these differed in their location on each sampling occasion. In the large field these patches were, however, predominantly located within the half surrounded by the unsprayed buffer zone.

Aphidius spp. were relatively evenly distributed within both fields prior to spraying (Fig. 5) and decreased in all areas after spraying, even in the buffer zone (Fig. 2c). Numbers were considerably reduced in all areas of both fields for 20 days after spraying. Cereal aphids on individual tillers were also counted prior to and following spraying, but only very low numbers were present after spraying.

Discussion

The study revealed the extent to which numbers of beneficial arthropods naturally fluctuate within wheat fields and the difficulty this causes when trying to detect the true impact of an insecticide application. This causes especial difficulty when appraising insecticide effects on beneficial arthropod species which are declining naturally. Some phytophagous groups and their specific predators will decline as the crop matures. This could be overcome by appraising only those species not expected to decline during the post-treatment monitoring period.

Insecticide effects may also be difficult to interpret or fail to detect the true effect if only small areas within a field are monitored or if a species exhibits either low numbers or spatial heterogeneity (Mead-Briggs, 1998). Such a distribution has been shown for most groups of beneficial arthropods including Carabidae, Staphylinidae, Araneae and parasitic wasps (Hengeveld, 1979; Holopainen, 1995; Ruggle & Holst, 1995; Longley *et al.*, 1997b ; Thomas *et al.*, 1998; Holland, Perry & Winder, 1999). These reasons may explain why large-scale farming system studies (Holland *et al.*, 1994) sometimes fail to detect the expected reduction following the application of an insecticide with a high toxicity to beneficial species (Büchs *et al.*, 1997; Frampton, 1998; Holland, 1998). The taxonomic level at which results are analysed is also important; no effect may be detected at the family level but individual species may vary considerably in their response (Büchs *et al.*, 1997).

To some extent the above problems can be overcome by using a replicated plot approach as is recommended for insecticide trials (Brown *et al.*, 1990; Anon, 1991; Perry & Anon, 1999), but if a species is absent or present only in low numbers within some of these areas the replication is reduced. This was clearly demonstrated in a series of four UK field trials, where, of 28 statistical comparisons, only five carabid species indicated a significant treatment effect for dimethoate (Mead-Briggs, 1998), despite its known toxicity to this family (Floate *et al.*, 1989; Çilgi *et al.*, 1996). Unsprayed control areas are also usually present within the field and reinvasion from these can be greater than from the field margins (Duffield & Aebischer, 1994). Moreover, the plot size in field trials rarely exceed 1 ha and reinvasion is more rapid than would occur in larger fields, thus the

duration of impact is dependant upon the size of the treated area (Duffield & Aebischer, 1994).

Movement by survivors from treated areas may also confound results. Spatial studies can help in the design of replicated plot trials to ensure spatial heterogeneity is accounted for and that the plot size is sufficiently large to ensure treatment effects are not confounded by reinvasion.

Many of the taxa found in this study were in natural decline at the time the insecticide was applied and the effects were not always apparent. The taxa for which spatial analysis was conducted all showed extensive reductions following the insecticide application, but two of the groups exhibited the capacity to repopulate. *P. madidus*, although a relatively large, mainly nocturnal ground active beetle, was highly susceptible. This is in agreement with the predictive modelling approach used for a ground beetle, *P. melanarius* which has a similar size and habitat. Wiles & Jepson (1994) found this species to be one of the most vulnerable to summer applications of deltamethrin, later confirmed by Alford *et al.* (1998) using a model incorporating spray distribution. No significant effect of dimethoate was detected in replicated plot trials for this species despite numbers being high enough for analysis (Mead-Briggs, 1998; Walters *et al.*, 1998), confirming Mead-Briggs's criticism of the replicated plot approach for Carabidae.

Some arthropods may have emerged from pupae within the fields after the dimethoate was applied, contributing to the repopulation. However, of the species which pupate within fields (*P. melanarius*, *P. madidus*, *H. rufipes*, and *T. quadristriatus*) most would have already emerged by the time the dimethoate was applied (Thiele, 1977; den Boer & den Daanje, 1990; Fadl & Purvis, 1998). Moreover, if substantial numbers were emerging within the field then they would have appeared as patches within the field. This was not apparent for *P. madidus* or the other species.

The more homogeneously distributed Linyphiidae were affected substantially by dimethoate in this study, in replicated plot trials (Mead-Briggs, 1998; Walters *et al.*, 1998) and in a field scale application (Vickerman & Sunderland, 1977). Linyphiidae are therefore considered good indicators of insecticide impact (Everts *et al.*, 1989). Linyphiidae have the dispersal ability to invade quickly after spraying and although found within the centre of each field six days after spraying, numbers

did not recover to pre-spray levels and no particular reinvasion pattern was detected. A similar recovery time was found when a 2 ha field was partially sprayed with insecticide with recovery to pre-spray levels taking up to 3 weeks or over 8 weeks depending on the species (Thomas, Hol & Everts, 1990). Reinvasion rate was related to distance from the unsprayed area.

Aphidius spp. also exhibited a relatively even distribution prior to spraying, and along with their hosts, did not recover within the post-treatment monitoring period. A previous study also found *Aphidius* spp. to be evenly distributed prior to an insecticide application, but although their aphid hosts returned, *Aphidius* spp. did not recover (Longley *et al.* 1997b). Similarly, numbers of *Aphidius* *avaenae* (Braconidae) were reduced by 74% in a field trial using dimethoate (Vickerman & Sunderland, 1977).

The field margins were shown to be important refuges for reinvasion by *P. madidus*. Other beneficial species, including the Linyphiidae and parasitic wasps, also reside in these areas throughout the year and consequently should be protected from spray drift if they are to act as a resource. Deposition studies have revealed that a 6m buffer zone can substantially reduce spray drift into field margins (Cuthbertson & Jepson, 1988; Longley *et al.*, 1997a) thereby protecting non-target species, although this has only been demonstrated at present for butterflies (Dover *et al.*, 1990). Predatory and other beneficial invertebrates such as those important for farmland birds are also protected within the unsprayed crop (Rands, 1985; de Snoo *et al.*, 1995; de Snoo & de Leeuw, 1996), although in this study some arthropods within the untreated buffer zone also showed substantial declines following spraying. This may have occurred if drift into the unsprayed was exceptionally high, this depending on wind speed at time of spraying, droplet size distribution and crop structure. Movement by arthropods between the unsprayed areas and the treated crop may have also occurred, resulting in residual exposure. Whether wider (>6 m) buffer zones are more reliable needs examination. When 3- and 6-m wide buffer zones were compared there was no extra enhancement of the number of insect groups or their density with the wider strip (de Snoo, 1996),

although the author states this must be treated with caution because insect distributions vary considerably between fields.

Numbers of individual species collected at each position were sometimes insufficient for analysis. Capture rates could have been improved by using more traps at each sampling point, using barriers or by leaving them open for longer. The sampling effort required in assessing spatial distributions is high and in this study was mediated by the resources available. Monitoring an unsprayed field would have provided information on the temporal fluctuations which occurred in the absence of the insecticide, however, this information is available in the literature (Thiele, 1977; den Boer & den Daanje, 1990; Fadl & Purvis, 1998). How arthropod spatial distributions differ within fields in the absence of insecticides has been reported for some species of carabids (Hengeveld, 1979; Helenius, 1995; Thomas *et al.*, 1998; Holland *et al.*, 1999), Linyphiidae (Thomas & Jepson, 1997) and parasitic wasps (Longley *et al.*, 1997). Significant aggregations were detected within the large field for *P. madidus* and Linyphiidae. By contrast, within the small field the sampling grid was usually too small to detect more than one cluster. Ideally grid size should be chosen according to the species under investigation, although some compromise is usually needed in multi-species evaluations. The SADIE indices provided a suitable means of assessing the size and significance of clusters, provided that sufficient sampling points were used, that was not always apparent from visual observation of the pattern. Such an approach is more rigorous and quantitative, placing the emphasis on the results rather than what the human brain and eye conspire to see. Even when contour lines are plotted using GIS software, this places more emphasis on the higher counts although these may only be few in number and do not represent a cluster (examples in Holland *et al.*, 1999). These and other data (Holland *et al.*, 1999) have indicated that a minimum of 25 sampling points is needed and preferably at least 36. Thus, sampling scale may have to be adjusted to ensure sufficient sampling points can be accommodated within the area under investigation.

Overall, the study indicated that dimethoate disrupted the spatial distribution of beneficial invertebrates within a cereal field and that the pattern of recovery was related to dispersal ability.

Carabidae were also found to recover more slowly than Linyphiidae in previous field assessments (Vickerman & Sunderland, 1977; Jepson & Thacker, 1990; Duffield & Aebischer, 1994). The failure of parasitic wasps to recover was attributed to the insecticide, but may have been because their hosts also failed to reinfest the crop. Unsprayed buffer zones may help protect beneficial invertebrates in field margins and thereby the reinvasion of fields by some species, but requires further evaluation. Spatial studies provide detailed information which can be treated with a high degree of confidence, however, because of the sampling effort required restrict replication when resources are limited.

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Figures 2a-c. Temporal variation in the capture of *Pterostichus madidus* and Linyphiidae in the pitfall traps and *Aphidius* spp. collected by suction sampling in the large winter wheat field. Values presented are total counts per date (\pm SE) from sampling locations within the unsprayed buffer zone (\square), the sprayed mid-field area enclosed by the buffer zone (\circ), the sprayed edge (\blacksquare), the sprayed mid-field area enclosed by the sprayed edge (\bullet).

Figure 3. *Pterostichus madidus* counts sampled on an approximately rectangular 30m grid in the large and small winter wheat fields. Above-average clustering at each sample unit into patches of greater than average neighbouring counts is measured by the clustering index, v_i . Below-average clustering creating gaps of less than average neighbouring counts is measured by the clustering index, v_j . Strong clustering into patches is indicated by units surrounded by circles with $v_i > 1.5$. Strong evidence of gaps is indicated by units surrounded by squares with $v_j < -1.5$. In each case, the average value of the patch clustering for the entire sample, \bar{v}_i and presence of gaps, \bar{v}_j is shown above the map, together with its statistical significance on the null hypothesis that the observed counts were arranged randomly amongst the sample units. Dashed line indicates location of unsprayed buffer zone. (*= P_i or $j < 0.05$; **= P_i or $j < 0.01$; ***= P_i or $j < 0.001$).

Figure 4. Linyphiidae counts sampled on an approximately rectangular 30m grid in the large and small winter wheat fields. Notation, methodology and symbols are the same as in figure 3a.

Figure 5. *Aphidius* species counts sampled on an approximately rectangular 30m grid in the small and large winter wheat fields. Notation, methodology and symbols are the same as in figure 3.

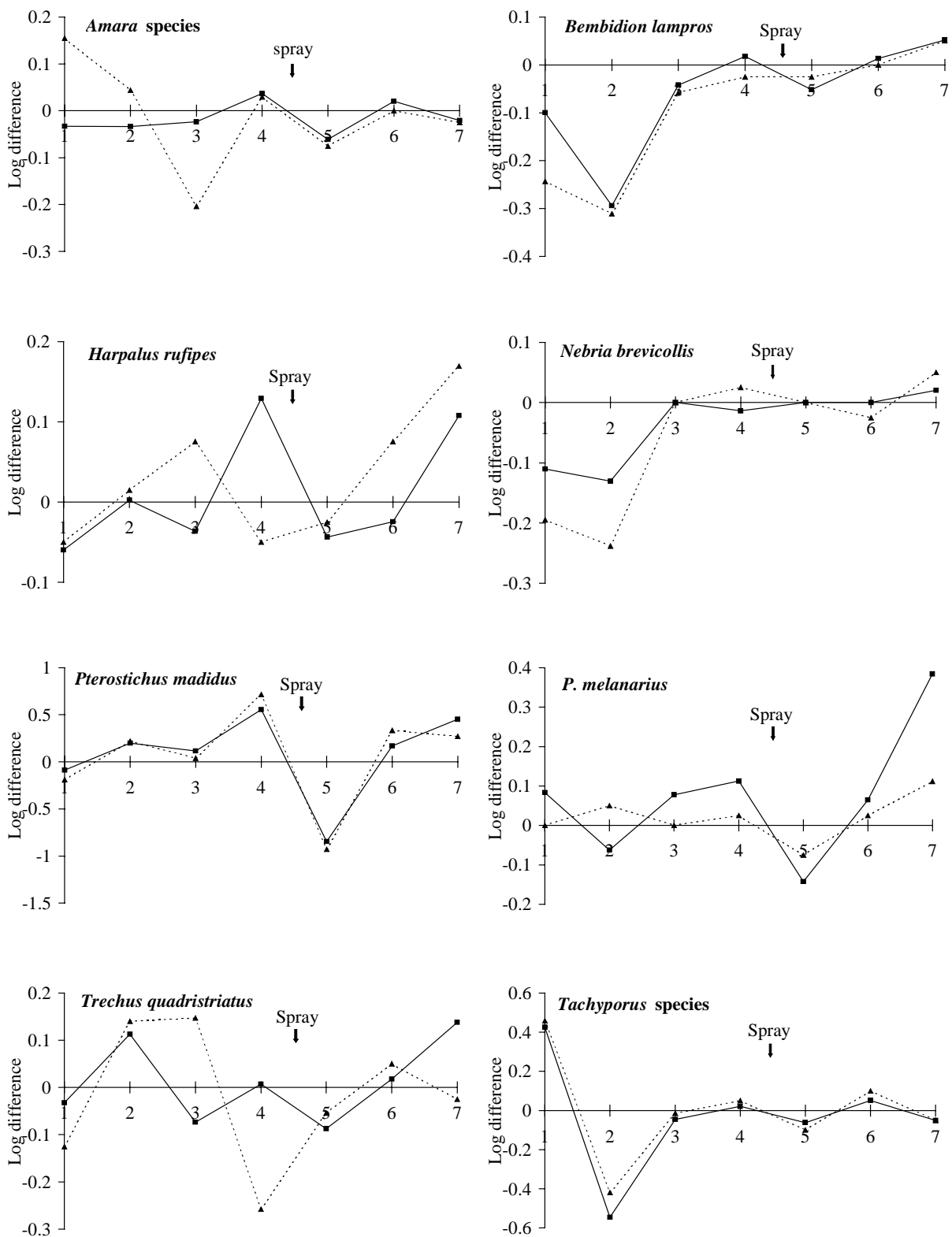


Figure 1. The mean difference in transformed counts, $\log_{10}(c+1)$, between successive sample dates for arthropods in the small (dashed line) and large (solid line) winter wheat fields, excluding those in the outer 3m of the crop. (This figure is continued on the next page)

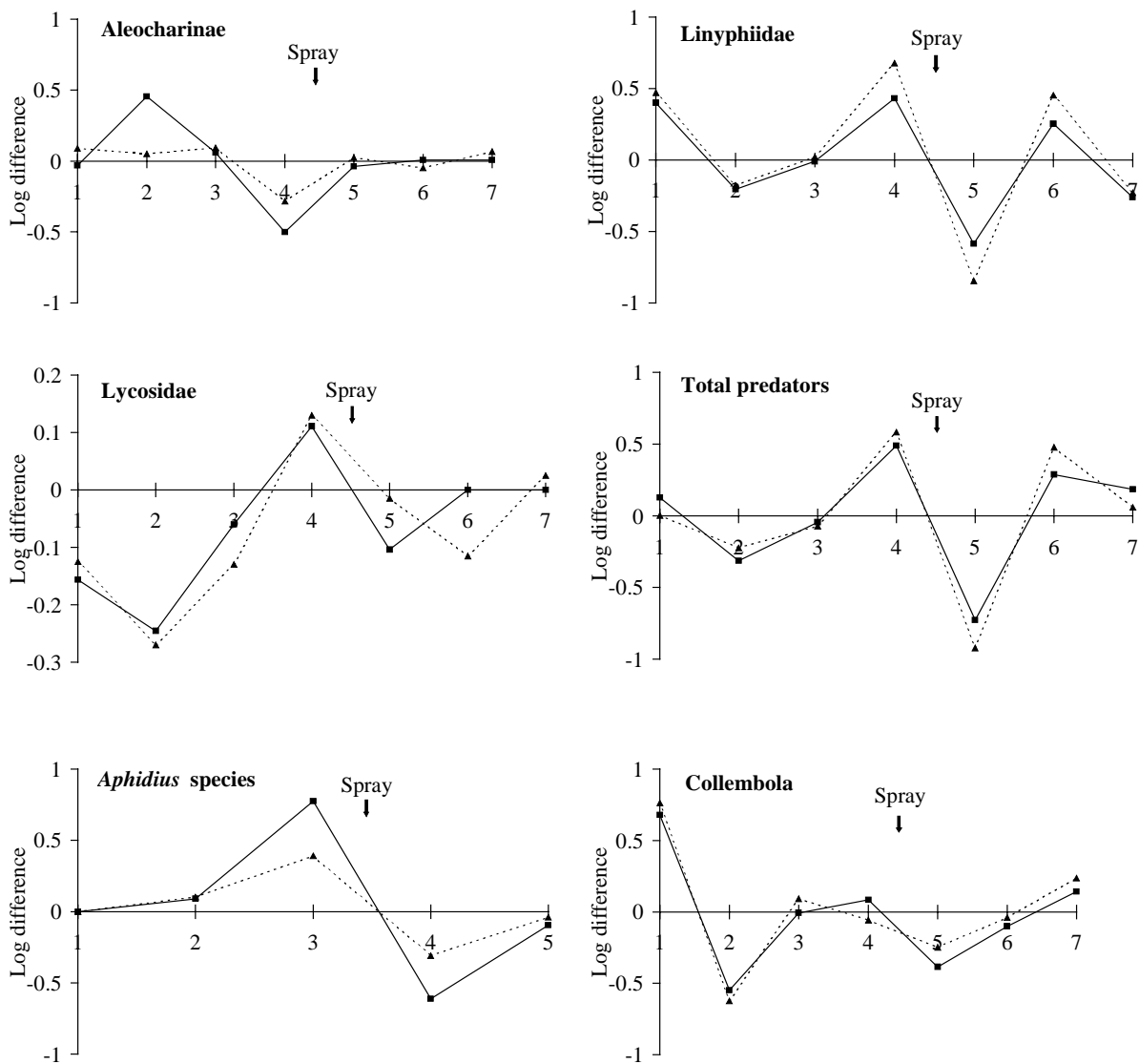
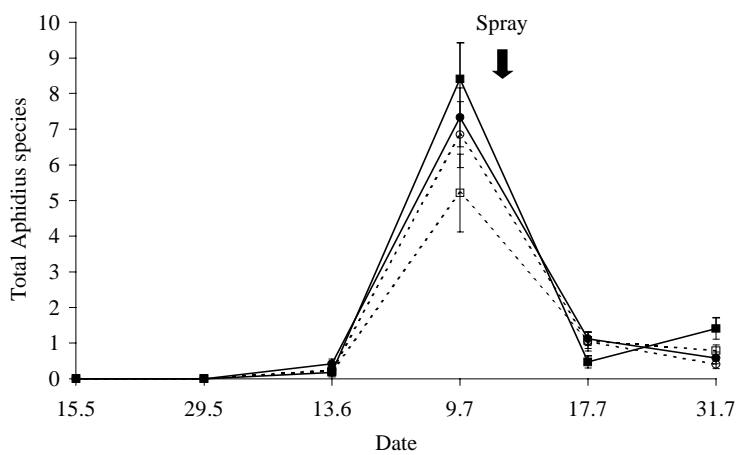
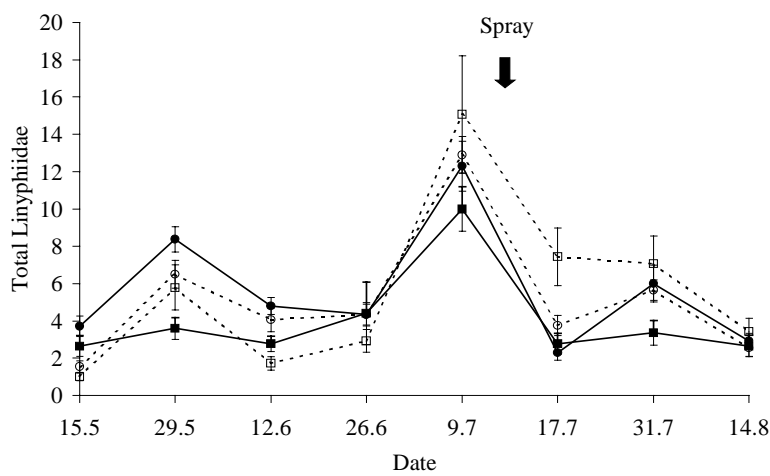
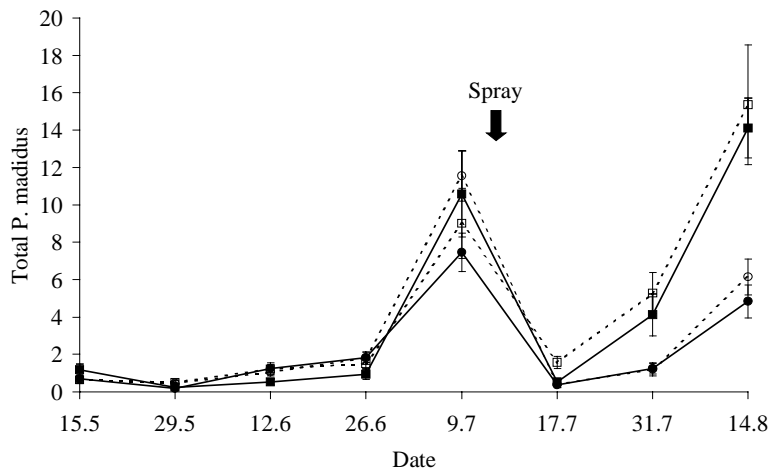
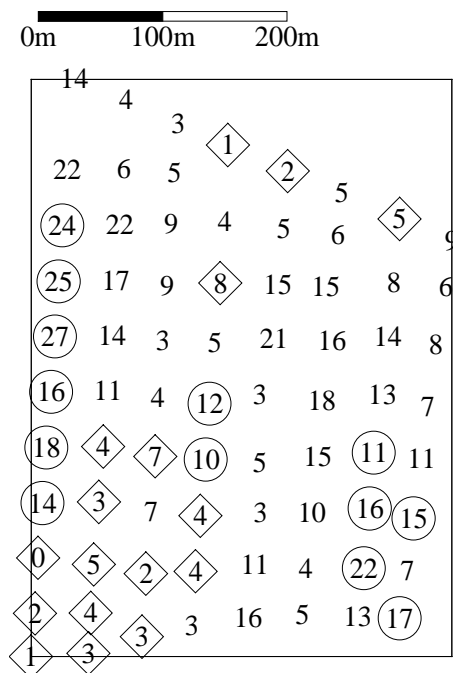


Figure 1. The mean difference in transformed counts, $\log_{10}(c+1)$, between successive sample dates for arthropods in the small (dashed line) and large (solid line) winter wheat fields, excluding those in the outer 3m of the crop.

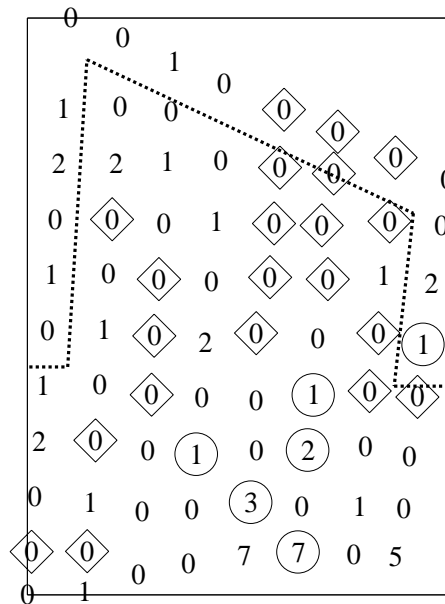


Figures 2a-c. Temporal variation in the capture of *Pterostichus madidus* and Linyphiidae in the pitfall traps and *Aphidius* spp. collected by suction sampling in the large winter wheat field. Values presented are total counts per date (\pm SE) from sampling locations within the unsprayed buffer zone (\square), the sprayed mid-field area enclosed by the buffer zone (\circ), the sprayed edge (\blacksquare), the sprayed mid-field area enclosed by the sprayed edge (\bullet).

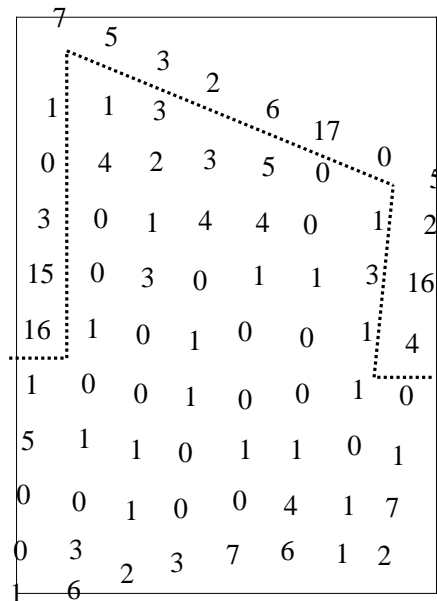
Large field - 2 days pre-treatment
 $\bar{x}=9.54$ $\bar{v}_i=1.41^*$ $\bar{v}_j=-1.44^*$



Large field - 6 days post-treatment
 $\bar{x}=0.64$ $\bar{v}_i=1.29^*$ $\bar{v}_j=-1.40^*$



Large field - 20 days post-treatment
 $\bar{x}=2.64$ $\bar{v}_i=1.00$ $\bar{v}_j=-1.03$



Large field - 34 days post-treatment
 $\bar{x}=9.25$ $\bar{v}_i=1.37^*$ $\bar{v}_j=-1.54^{**}$

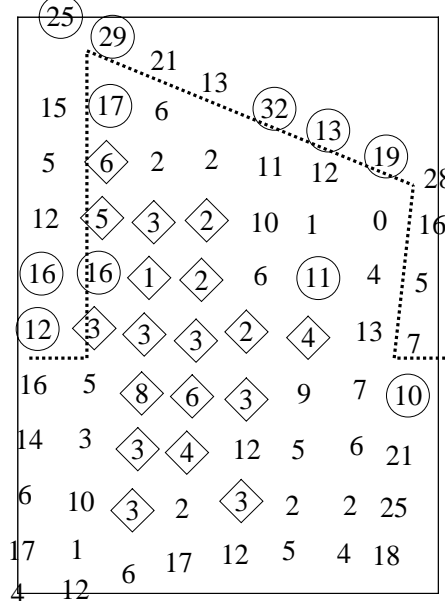
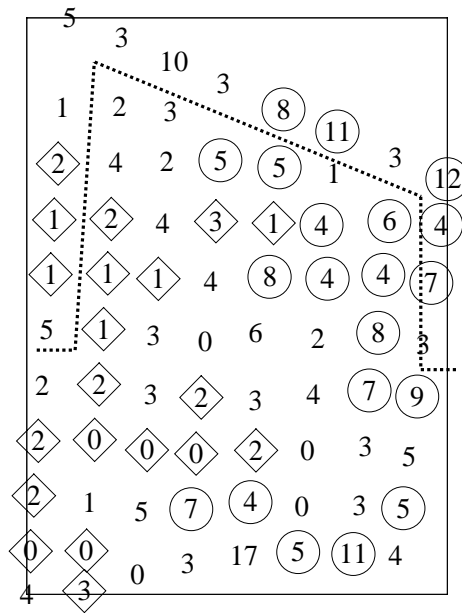
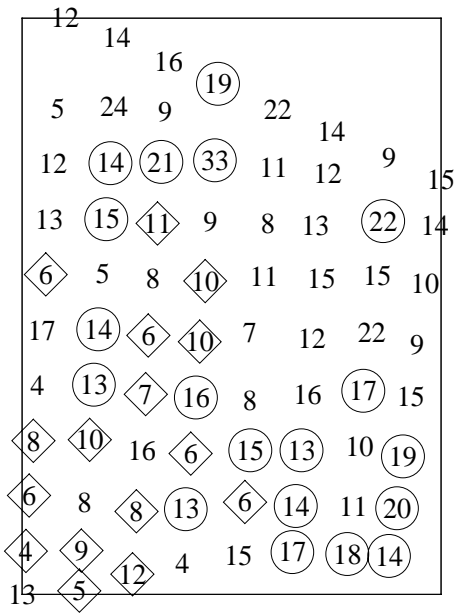
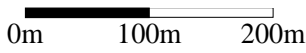


Figure 3. *Pterostichus madidus* counts sampled on an approximately rectangular 30m grid in the large and small winter wheat fields. Above-average clustering at each sample unit into patches of greater than average neighbouring counts is measured by the clustering index, v_i . Below-average clustering creating gaps of less than average neighbouring counts is measured by the clustering index, v_j . Strong clustering into patches is indicated by units surrounded by circles with $v_i > 1.5$. Strong evidence of gaps is indicated by units surrounded by squares with $v_j < -1.5$. In each case, the average value of the patch clustering for the entire sample, \bar{v}_i and presence of gaps, \bar{v}_j is shown above the map, together with its statistical significance on the null hypothesis that the observed counts were arranged amongst the sample units. Dashed line indicates location of unsprayed buffer zone. (*= P_i or $j < 0.05$; **= P_i or $j < 0.01$; ***= P_i or $j < 0.001$). (Figure continued on next page).

Large field - 2 days pre-treatment
 $\bar{x}=12.4$ $\bar{v}_i=1.71^{**}$ $\bar{v}_j=-1.64^{**}$

Large field - 6 days post-treatment
 $\bar{x}=3.75$ $\bar{v}_i=1.70^{**}$ $\bar{v}_j=-1.49^{**}$



Large field - 20 days post-treatment
 $\bar{x}=5.51$ $\bar{v}_i=1.46^{**}$ $\bar{v}_j=-1.39^*$

Large field - 34 days post-treatment
 $\bar{x}=2.85$ $\bar{v}_i=1.75^{***}$ $\bar{v}_j=-1.76^{**}$

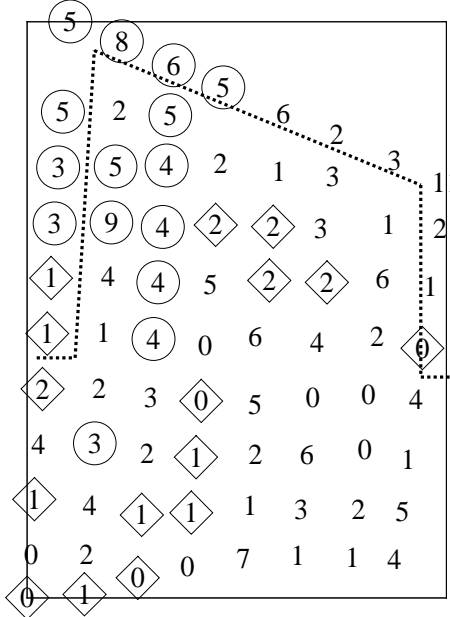
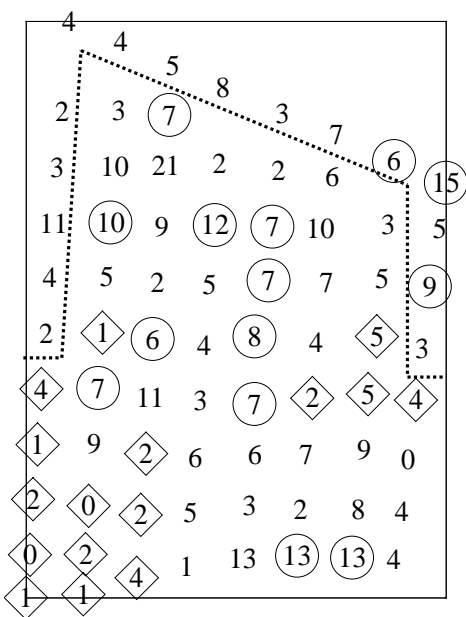
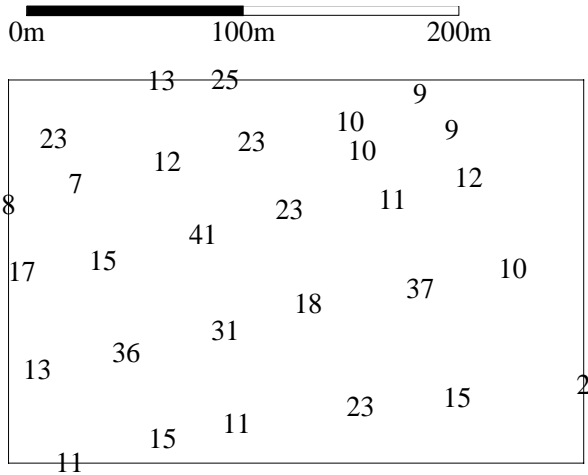
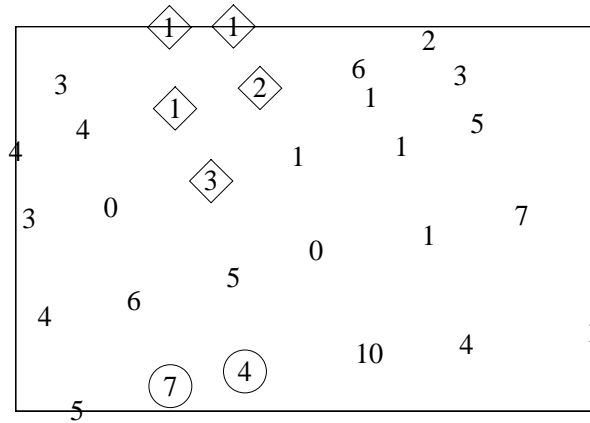


Figure 4. Linyphiidae counts sampled on an approximately rectangular 30m grid in the large and small winter wheat fields. Notation, methodology and symbols are the same as in Figure 3a. (Figure continues on next page).

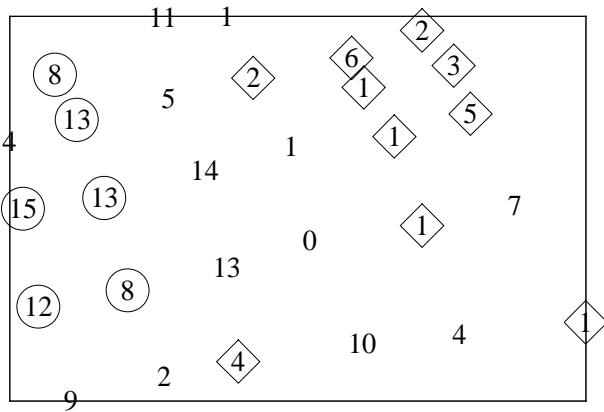
Small field - 2 days pre-treatment
 $\bar{x} = 16.9$ $\bar{v}_i = 1.08$ $\bar{v}_j = -1.05$



Small field - 6 days post-treatment
 $\bar{x} = 3.28$ $\bar{v}_i = 1.22$ $\bar{v}_j = -1.18$



Small field - 20 days post-treatment
 $\bar{x} = 6.07$ $\bar{v}_i = 1.69^{**}$ $\bar{v}_j = -1.86^{***}$



Small field - 34 days post-treatment
 $\bar{x} = 3.83$ $\bar{v}_i = 1.26$ $\bar{v}_j = -0.96$

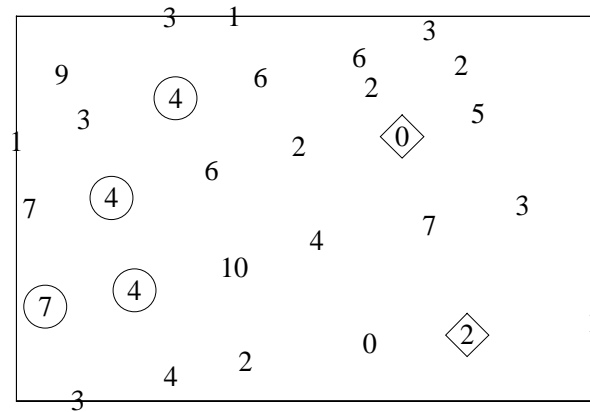


Figure 4. Linyphiidae counts sampled on an approximately rectangular 30m grid in the large and small winter wheat fields. Notation, methodology and symbols are the same as in Figure 3a.

